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Bibliometric Analysis of Eco-design Research and Socio-Scientific Issues in Environmental Learning: A Study with VOSviewer to Strengthen Eco-Literacy and Critical Thinking Skills

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Abstract: This study aims to map and analyze research trends on Eco-design and Socio-Scientific Issues (SSI) in environmental learning through bibliometric analysis. Data were collected from the Scopus database covering publications from 2013 to 2024 related to Eco-design, SSI, environmental education, eco-literacy, and critical thinking. Bibliometric data were analyzed using VOSviewer software to visualize research networks including co-authorship, co-occurrence (keywords), citations, co-citations, and overlay analysis. The findings revealed four main research clusters linking environmental education, SSI, Eco-design, eco-literacy, and critical thinking. The results also show that research has evolved from descriptive studies to a more integrative and application-oriented approach that combines design innovation with socio-scientific reflection. The overlay visualization shows a temporal shift from early themes such as environmental awareness to a more recent emphasis on sustainability, critical thinking, and ecological literacy. These results highlight that the integration of Eco-design with SSI promotes a transformative paradigm in environmental education by connecting ethical and scientific perspectives with real-world solutions. This study provides a conceptual foundation for developing an interdisciplinary learning model that strengthens students' ecological literacy and critical thinking skills in sustainability-oriented education.

Keywords: Bibliometric; Critical thinking; Eco-design; Eco-literacy; Socio-scientific issues

Introduction

Environmental degradation has become one of the most critical global challenges of the 21st century, threatening both natural ecosystems and human well-being. Issues such as global warming, sea-level rise, and the increasing frequency of extreme weather events pose real threats to the stability of the planet's ecosystems and societies (Chen & Mai, 2024; David Raj et al., 2024). Studies have shown that education plays a vital role in mitigating the impacts of environmental crises by shaping awareness, attitudes, and behaviors toward sustainability (Chen & Mai, 2024; Newsome et al., 2023; Wang et al., 2024). In Indonesia, problems such as deforestation, rapid urbanization, and plastic pollution continue to exert pressure on local ecosystems (Cahyaningsih et al., 2022; Fatimah et al., 2024; Kumar et al., 2023). Although environmental education has been incorporated into the national curriculum, its implementation often remains fragmented, focusing

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mainly on conceptual knowledge rather than fostering transformative learning and sustainable action (Marouli, 2021; Pérez-Martín & Esquivel-Martín, 2024).

In this context, environmental education becomes a key instrument for developing ecological awareness and responsible behavior. It provides learners with the capacity to understand the interdependence between humans and nature, and to act collectively for sustainability (Cebrián et al., 2021; Yadav et al., 2022). This aligns with the principles of Education for Sustainable Development (ESD), which emphasizes the cultivation of knowledge, attitudes, and skills necessary for sustainable living (Braßler & Sprenger, 2021; R Tiwary, 2023; Yang & Xiu, 2023).

However, conventional teaching models that rely solely on transmitting environmental facts are insufficient for addressing the complexity of today's environmental issues. Instead, educational approaches must develop both eco-literacy the ability to understand ecological systems and human environment interactionsand critical thinking skills, which enable learners to analyze and make ethical, evidence-based decisions about environmental problems (Desmarais, 2024; Kartini et al., 2019; Kerçin & Demir, 2024). In addition, critical thinking skills are essential for enabling learners to analyze, evaluate, and make decisions based on scientific and ethical considerations regarding environmental issues. The combination of ecological literacy and critical thinking thus forms an essential capacity for individuals who wish to contribute to solving future environmental problems (Guerrero & Sjöström, 2025; Shutaleva, 2023).

To foster these competencies, the Eco-design and Socio-Scientific Issues (SSI) approaches offer innovative and relevant frameworks. Integrating Eco-design with SSI allows students to connect ethical reasoning and scientific knowledge to real-world environmental challenges, translating reflection into concrete design solutions (Maher et al., 2018; Songer & Ibarrola Recalde, 2021). Eco-design promotes sustainable thinking in product and system development by incorporating environmental principles into design processes (Noureddine Dahmani et al., 2021; Keivanpour, 2022; Sierra-Pérez et al., 2021). Meanwhile, the SSI approach situates learning in socially and ethically charged contexts, encouraging learners to explore multiple perspectives and engage with complex sustainability dilemmas (Falah et al., 2024; Högström et al., 2024). When combined, these two pedagogical models can enhance learners' eco-literacy and critical thinking through active, inquiry-based engagement with authentic sustainability problems.

Although prior research has discussed the application of Eco-design or SSI within educational settings, comprehensive analyses mapping research trends and conceptual linkages in this area remain scarce. Existing studies have yet to systematically examine how these two frameworks intersect within environmental education, especially through the lens of bibliometric analysis. Bibliometric mapping enables the identification of emerging themes, author collaborations, and intellectual structures within a field, thereby offering a clearer picture of research evolution and gaps (Donthu et al., 2021).

Although several studies have explored either Eco-design or Socio-Scientific Issues (SSI) in educational contexts, the integrative relationship between these two frameworks remains underexplored, particularly within the field of environmental education. The novelty of this research lies in its comprehensive and systematic exploration of how Eco-design and SSI intersect through a bibliometric approach an analytical perspective that has not been extensively applied in previous studies. Unlike earlier works that examined these pedagogical models separately, this study employs bibliometric mapping using VOSviewer to identify conceptual linkages, thematic trends, and research gaps within this interdisciplinary domain. Such an approach provides new insights into the intellectual structure and evolution of research connecting Eco-design and SSI, highlighting how their integration can advance eco-literacy and critical thinking in sustainability-oriented education (Donthu et al., 2021; Kurtuluş & Tatar, 2021).

Therefore, this study aims to map and analyze research trends on Eco-design and Socio-Scientific Issues (SSI) in environmental education through bibliometric analysis using VOSviewer. Specifically, this study focuses on mapping the development of research related to Eco-design and Socio-Scientific Issues (SSI) within the field of environmental learning. It examines publication trends and the conceptual structures that have emerged over time to reveal how these two approaches have been explored and connected in previous studies. In addition, the study identifies key themes and patterns through an analysis of keywords, as well as the collaboration networks among authors and institutions, using the bibliometric visualization tool VOSviewer. The findings are then interpreted to provide insights into how current research trends can contribute to strengthening learners' eco-literacy and critical thinking skills, particularly within the context of sustainable and inquiry-based education. Academically, this study enriches the interdisciplinary discourse between environmental education and bibliometric research. Practically, it offers insights for educators and policymakers in designing learning strategies that foster eco-literacy and critical thinking.

Method

This study employs a quantitative approach using the bibliometric method, aiming to map research trends, collaboration patterns, and conceptual structures of studies on eco-design and Socio-Scientific Issues (SSI) within the context of environmental education. The bibliometric approach was chosen because it allows for an objective analysis of scientific development, dominant keywords, and intertopic relationships within a research domain through publication metadata (Hassan & Duarte, 2024; Mejia et al., 2021).

The research data was drawn from the Scopus database, recognized as one of the most comprehensive and credible sources of peer-reviewed scientific publications.

The data collection process was conducted in September 2025, covering publications indexed from 2013 to 2024. This timeframe ensured that only articles already available and indexed in Scopus at the time of data collection were included.

The data search process was conducted systematically by combining relevant keywords and Boolean operators (AND, OR) to ensure that the retrieved publications aligned closely with the research objectives. The search strategy was designed to capture studies positioned at the intersection of eco-design, Socio-Scientific Issues (SSI), and environmental education. To enhance clarity and search efficiency, the keywords were refined and simplified into "Eco-design," "Socioscientific Issues," "Environmental Education," "Eco-literacy," and "Critical Thinking." This formulation allowed for the retrieval of a focused yet comprehensive set of studies exploring the relationship between eco-design, SSI-based learning, and the development of eco-literacy and critical thinking within environmental education contexts.

The search employed Boolean operators to refine the scope and ensure the inclusion of relevant studies. Only publications written in English, categorized as journal or conference papers, and published between 2013 and 2024 within the field of education or environmental learning were considered. Bibliographic data were retrieved from the Scopus database and exported in CSV format, containing essential metadata such as author names, titles, publication years, affiliations, abstracts, and keywords.

Subsequent data analysis was performed using the latest version of VOSviewer to visualize bibliometric networks and identify patterns within the research landscape. The analysis involved mapping co-authorship to reveal collaborative relationships among authors and institutions, co-occurrence of keywords to determine dominant research themes, and citation and co-citation analyses to identify influential authors and sources in the field. An overlay visualization was also generated to illustrate the temporal evolution of research trends. The validation process was carried out by examining the relevance of the mapping results to the broader context of environmental education research, ensuring that the visual patterns reflected meaningful connections within the discipline.

The resulting visualizations were then analyzed descriptively to uncover the dynamics of research development, collaboration networks, and thematic clusters that reflect emerging areas of interest. These insights were further interpreted in relation to how they contribute to the advancement of eco-literacy and critical thinking in environmental learning (Arruda et al., 2022; van Eck & Waltman, 2010). This study was limited to Scopus-indexed publications, excluding data from other databases such as Web of Science or Google Scholar. Additionally, the analysis was based solely on metadata titles, abstracts, and keywords rather than full-text content, meaning that the thematic interpretations remain general and may require further, more detailed content analysis in subsequent research.

To enhance methodological clarity, the bibliometric process follows the flow described below:

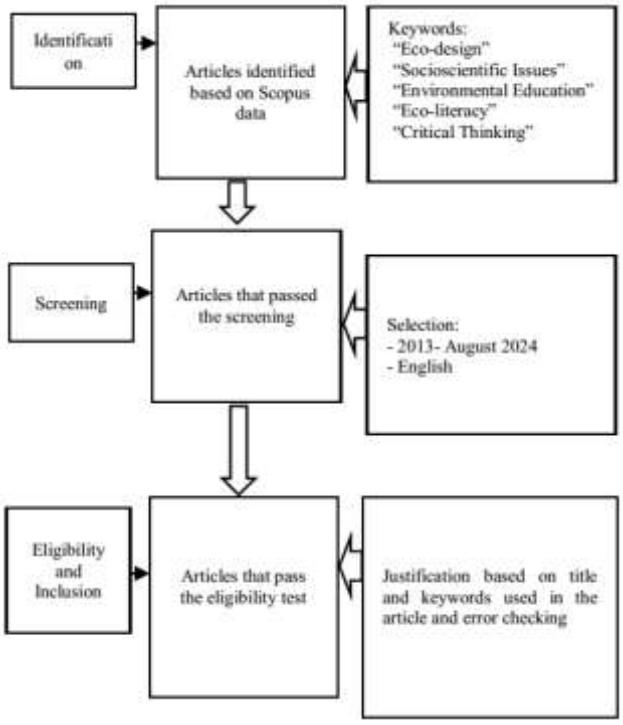

Figure 1. Research flowchart

Result and Discussion

To obtain a comprehensive overview of research developments on the topic of eco-design and socio-scientific issues (SSI) in the context of environmental learning, a bibliometric analysis was conducted using

VOSviewer software. This analysis aims to map research trends, interconnections between concepts, and scientific collaborations that contribute to strengthening eco-literacy and critical thinking skills in education. Through a bibliometric approach, each relevant scientific publication is identified based on keywords, authors, journal sources, and citation networks, allowing for a visual and systematic understanding of the direction of scientific development.

The visualization results presented below provide a conceptual mapping and thematic relationships between studies, which serve as a basis for developing further research directions in the field of environmental education based on ecological literacy and socio-scientific issues.

Network Visualization

The initial stage of bibliometric analysis was conducted by mapping the interrelationships between concepts using the Network Visualization feature in VOSviewer software. This visualization serves to show the relationships between keywords that frequently appear together (co-occurrence) in scientific publications related to eco-design and socio-scientific issues in the context of environmental learning. Each node on the map represents a keyword, while the connecting lines illustrate the level of interconnection or association between research topics.

The resulting network map shows how concepts such as eco-literacy, critical thinking, environmental education, and sustainability are interconnected and form specific clusters. These clusters indicate the thematic focus and direction of scientific research development in this field. Thus, network visualization is a crucial step in understanding the conceptual structure of research and identifying areas open for further exploration.

The following network visualization results provide an overview of the interconnectedness of research themes, which form the conceptual basis for strengthening eco-literacy and critical thinking skills in environmental-based learning.

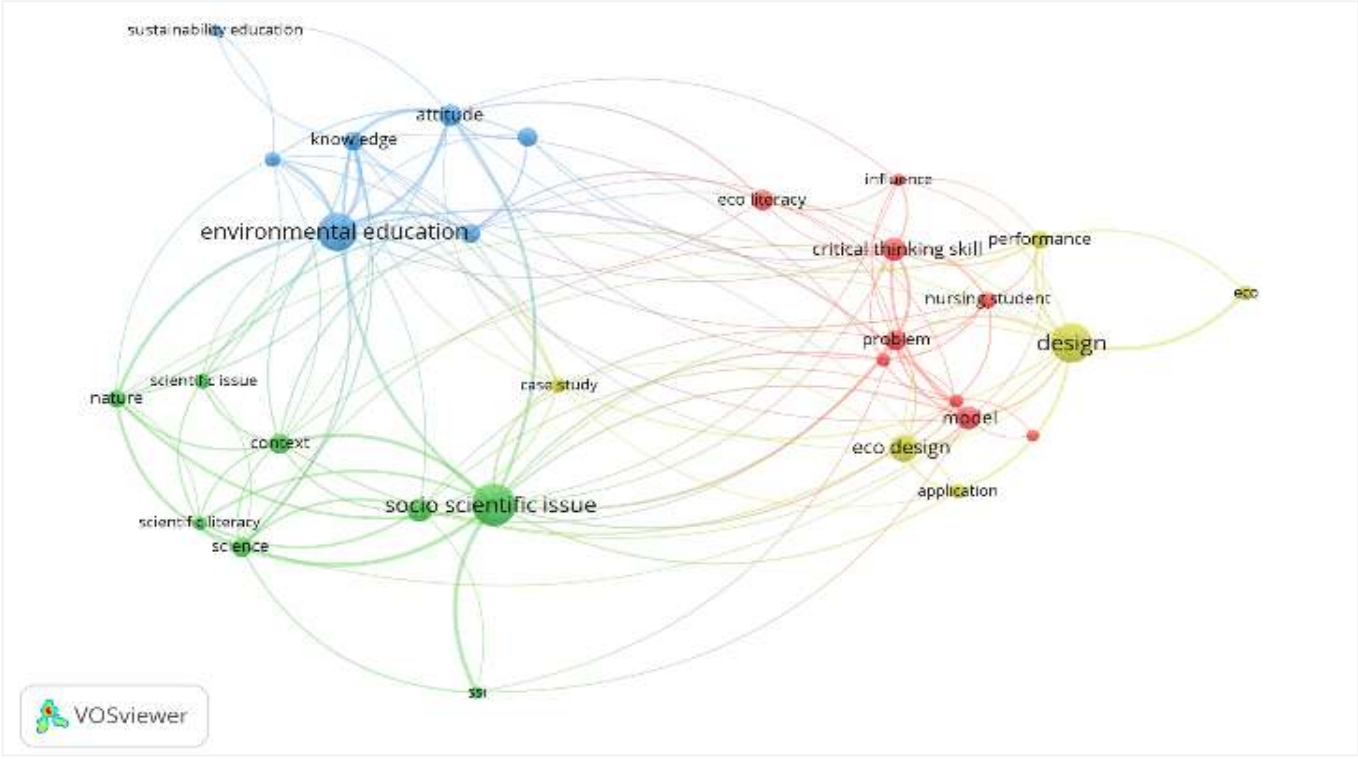

Figure 2. Network visualization

The results of a bibliometric analysis using Network Visualization using VOSviewer indicate the existence of four main clusters that illustrate the conceptual linkages between research topics in the field of eco-design and socio-scientific issues in environmental learning. Each cluster represents an interconnected research theme and indicates the direction of scientific development in environmental education based on ecological literacy and critical thinking. The blue cluster connects the keywords environmental education, knowledge, attitudes, and sustainability, reflecting research centered on environmental awareness and value formation (Cebrián et al., 2021; Marouli, 2021). This indicates that most research focuses on strengthening environmental

awareness, knowledge, and attitudes as the basis for developing sustainable behavior in students.

The green cluster includes socio-scientific issues, scientific literacy, and context, emphasizing the integration of real-life issues into science education (Falah et al., 2024; Högström et al., 2024). This theme emphasizes the importance of utilizing socio-scientific issues as a context for science learning to enhance students' critical thinking skills and scientific literacy. The strong connection between socio-scientific issues and environmental education and eco-design indicates that SSI serves as a conceptual link between the dimensions of values, science, and the application of environmentally friendly design. The yellow cluster, dominated by eco-design, models, and application, focuses on design-based pedagogies and innovation in sustainability education (Geitz & de Geus, 2019; Songer & Ibarrola Recalde, 2021). This theme reflects a more applied and innovative research direction in integrating sustainability principles into the design of learning activities.

Finally, the red cluster links critical thinking, eco-literacy, and problems, showing the growing trend of combining cognitive and ecological competencies (Guerrero & Sjöström, 2025; Maratkyzy et al., 2025). This cluster illustrates the research focus that assesses how the application of eco-design and socio-scientific issues can strengthen students' critical thinking skills and ecological awareness. The close proximity of eco-literacy and critical thinking skills indicates that both are integrative focuses in contemporary environmental education research. Overall, the mapping results demonstrate a synergistic relationship between environmental education, socio-scientific issues, and eco-design as three main axes in building a learning system that fosters environmental awareness, critical thinking, and pedagogical innovation.

Thus, the network visualization results using VOSviewer indicate that research in the field of eco-design and socio-scientific issues has moved from conceptual studies to a more implementable direction. The focus is no longer solely on ecological awareness, but also on strengthening critical thinking skills and developing contextual and sustainable learning strategies. This relationship map serves as an important conceptual foundation for guiding further research, particularly in developing learning models that integrate ecological values, socio-scientific issues, and foster critical thinking in students.

Overlay Visualization

After mapping the relationships between concepts using network visualization, the next step is an Overlay Visualization analysis using VOSviewer software. This visualization is used to display shifts in research trends over time based on publication year and keyword frequency. The colors on the overlay map depict the chronology of topic development, with blue indicating earlier research themes, while green and yellow indicate newer and emerging topics.

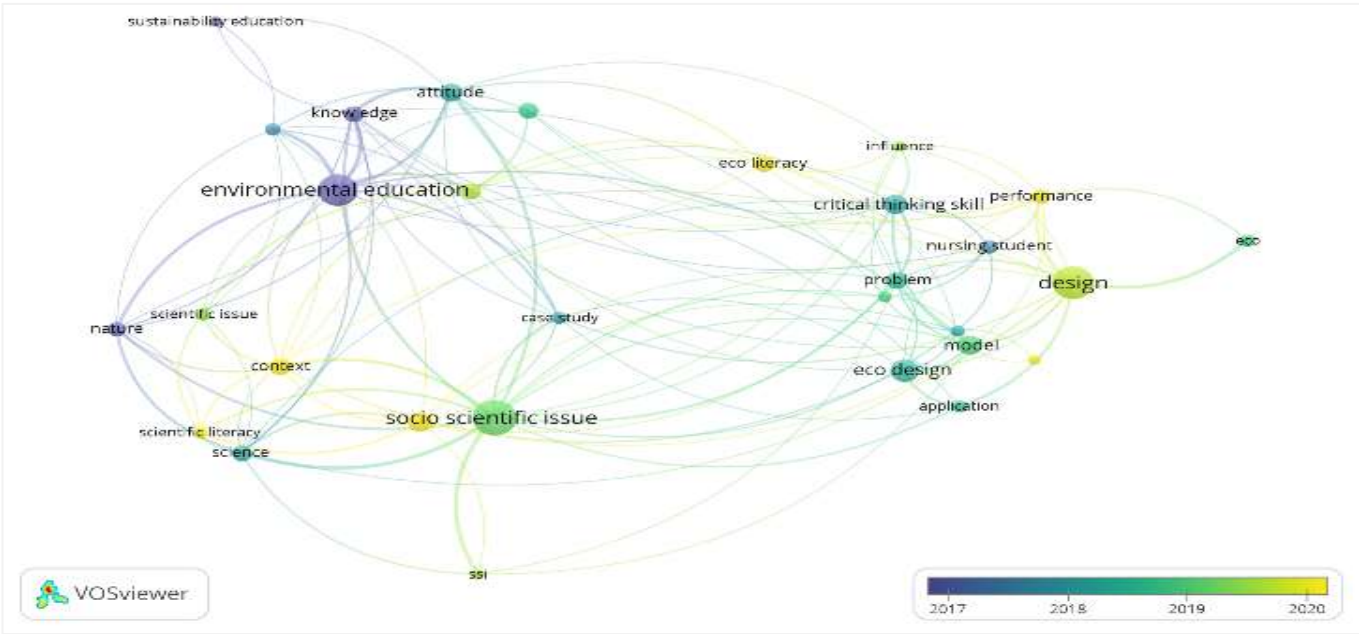

Figure 3. Overlay visualization

The overlay visualization analysis provides important information regarding the evolution of research on eco-design and socio-scientific issues in environmental learning. This map reveals how the focus

of studies has shifted from basic themes such as environmental education and scientific literacy to more sophisticated themes such as eco-literacy, critical thinking skills, and sustainability education. The color shifts between clusters indicate a dynamic knowledge shift that increasingly focuses on the integration of ecological awareness, innovative learning design, and strengthening students' critical thinking skills.

Thus, overlay visualization plays a crucial role in indicating the direction of research development and identifying potential new research areas. The following visualization results provide a chronological overview of how research in the field of eco-design and socio-scientific issues continues to evolve towards a more reflective, contextual, and sustainability-oriented environmental learning paradigm.

The Overlay Visualization results provide a dynamic overview of research developments on eco-design and socio-scientific issues in the context of environmental learning during the 2017–2020 period. The colors on the map indicate the chronological order of research development, with blue depicting earlier themes, while green and yellow highlight more recent and trending topics. Early studies (2013–2016, shown in blue) primarily explored environmental education and sustainability awareness. This reflects researchers' initial focus on developing environmental knowledge, attitudes, and awareness as a foundation for developing sustainable education.

From 2017 to 2020 (green areas), there was a shift toward contextual learning and socioscientific engagement, indicating greater integration of real-world problems into environmental education. Topics such as context, case studies, and science emerged more frequently, demonstrating a shift from a conceptual approach to a contextual approach that connects students with environmental issues in society. This indicates that researchers are beginning to adopt issue-based and problem-solving learning models in an effort to increase the relevance and effectiveness of environmental learning.

More recent research (2021–2024, shown in yellow) emphasizes eco-design, critical thinking, and eco-literacy, signaling a move toward applied, innovation-driven education models (Braßler & Sprenger, 2021). The shift in color toward the right area of the map indicates increased attention to learning approaches that not only instill ecological awareness but also develop critical thinking skills and creativity in students. These themes reflect a new direction in environmental education, oriented toward innovation in sustainable learning design and strengthening higher-order thinking skills (Kwangmuang et al., 2021; Thomas, 2009). Furthermore, the close connection between eco-design and models and applications indicates a trend toward integrating technology and instructional design to support eco-literacy goals.

Overall, the results of this overlay visualization demonstrate that research in the field of eco-design and socio-scientific issues has evolved from conceptual studies to innovative and contextual pedagogical applications. The chronological shift from environmental education to eco-literacy and critical thinking skills indicates that the environmental education paradigm is increasingly focused on developing 21st-century competencies grounded in ecological awareness, reflective thinking, and social responsibility. Thus, this analysis not only reveals thematic trends but also demonstrates the strategic direction for the development of more transformative and sustainable environmental education research.

Density Visualization

After conducting network analysis and overlay visualization, the next step is to display the results of the Density Visualization using VOSviewer software. This visualization aims to show the intensity and density of keyword occurrences in the research field being studied. The higher the frequency of a keyword appearing in publications, the brighter the color displayed on the map (usually yellow), while darker colors indicate areas with lower research intensity.

Density visualization analysis plays a crucial role in identifying central themes and the most productive topics in eco-design and socio-scientific issues research in environmental learning. Through this map, it is possible to identify keywords that are the focus of researchers' attention and topics with potential for further development. Furthermore, density visualization also helps map the hierarchical relationships between key concepts such as environmental education, socio-scientific issues, eco-design, critical thinking skills, and eco-literacy.

Thus, density visualization provides a clearer picture of the strength of research focus in the field of environmental education based on social issues and ecological design. The following visualization results serve as a basis for analyzing the most intensive research directions and identifying opportunities for research development that are still open to strengthen eco-literacy and critical thinking skills in the future.

The Density Visualization results provide an overview of the density and dominance of research themes in the fields of eco-design and socio-scientific issues in the context of environmental learning. The densest areas—centered on socio-scientific issues, environmental education, and eco-design—indicate the dominance of these themes over the last decade. The concentration around eco-design and critical thinking suggests that design thinking and inquiry-based

learning are increasingly applied to foster eco-literacy (N. Dahmani et al., 2022; Maher et al., 2022). This high-density pattern supports the conclusion that environmental education research is moving toward interdisciplinarity, combining ethical reflection, design creativity, and scientific reasoning.

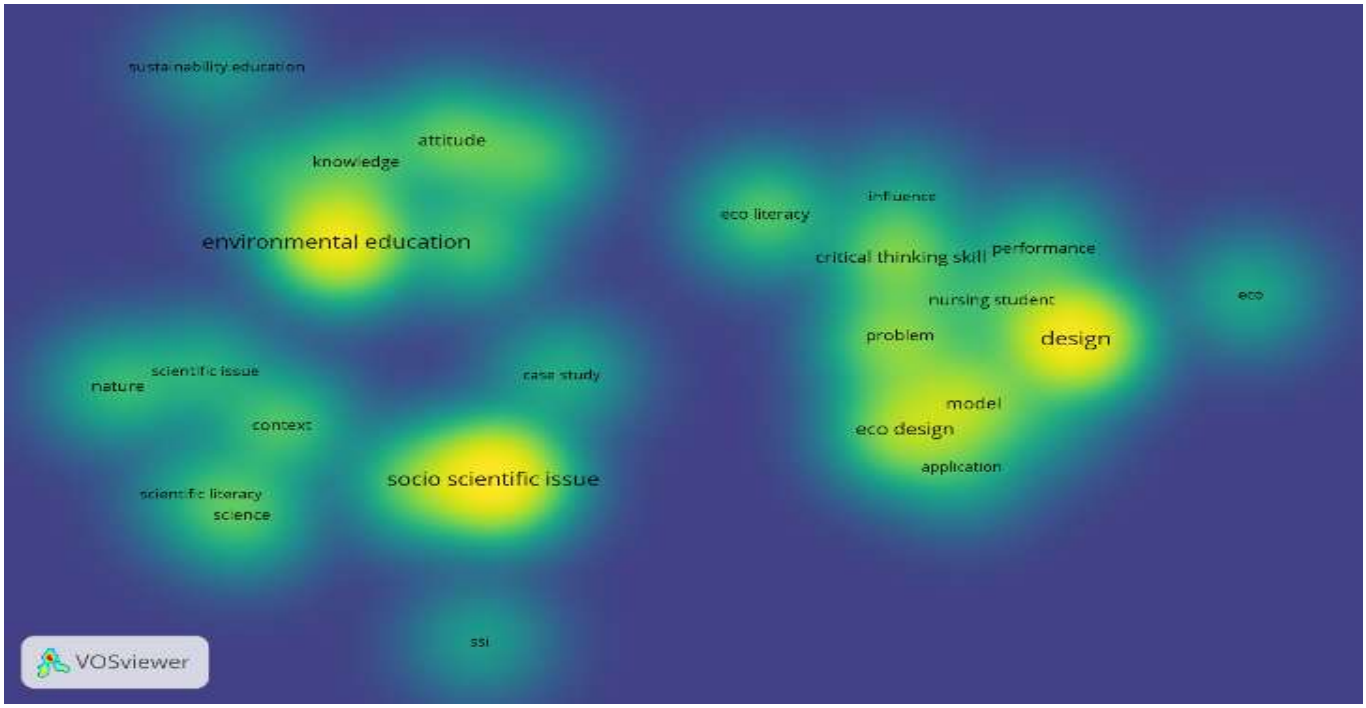

Figure 4. Density visualization

The high density of socio-scientific issues indicates that this theme is the most frequently studied focus in the context of science and environmental learning. Researchers have extensively explored SSI as an effective contextual approach to fostering students' scientific literacy and ecological awareness. Meanwhile, environmental education also exhibits significant density, reflecting a strong focus on the education of sustainable values, attitudes, and behaviors. This confirms that environmental education remains a key foundation for research related to strengthening eco-literacy.

Furthermore, the dense areas surrounding the keywords "design," "eco-design," and "model" indicate increased attention to the development of innovative, design-based learning strategies. Research focused on eco-design addresses not only the technical aspects of environmentally friendly design but also how these principles can be integrated into learning practices to foster students' ecological awareness and critical thinking skills. The close relationship between eco-design and critical thinking skills in the bright yellow area demonstrates that these two themes have been increasingly strong research directions in the last decade.

Overall, the results of this density visualization demonstrate a balance between three main focuses: environmental education as a conceptual foundation, socio-scientific issues as a learning context relevant to real life, and eco-design as an innovative pedagogical approach to strengthening eco-literacy and critical thinking skills. The density of these themes demonstrates that research in the field of environmental learning has moved toward integrating the dimensions of knowledge, ethics, and sustainable action. Thus, this density map confirms the position of eco-design and socio-scientific issues as two strategic pivots in realizing transformative environmental education oriented toward 21st-century ecological literacy.

The bibliometric mapping validates the growing intersection of eco-design and SSI within environmental learning. Supported by previous findings (Donthu et al., 2021; Yang & Xiu, 2023), this integration promotes a paradigm where students act as reflective designers and ethical problem-solvers. The observed conceptual evolution—from awareness-based education to design-oriented sustainability learning—illustrates a pedagogical transformation consistent with ecopedagogy principles.

Nevertheless, it should be noted that because the data collection ended in 2025, certain late-year publications may not yet be indexed in Scopus; thus, the visualized trends represent a general overview rather than an exhaustive picture. To ensure methodological validity, future studies should expand datasets and triangulate bibliometric mapping with qualitative

analyses. Overall, these findings strengthen the theoretical and practical basis for integrating eco-design and SSI into environmental education as complementary approaches that cultivate eco-literacy, critical thinking, and responsible citizenship.

The mapping results indicate that the literature in this field reinforces the view that eco-design and SSI function as complementary pedagogical strategies. Philosophically, eco-design emphasizes systemic, creative, and solution-oriented thinking skills regarding environmental issues, while SSI encourages students to think reflectively, ethically, and critically about social issues with a scientific dimension. The integration of the two indicates that modern environmental education is aimed at developing students who are not only sensitive to ecological issues but also capable of making decisions based on values and scientific reasoning (Monte & Reis, 2021; Shutaleva et al., 2023). Thus, this approach aligns with the transformative paradigm of environmental education, where learning does not stop at knowledge but continues to awareness and concrete action.

From a theoretical perspective, the interconnectedness patterns emerging through the VOSviewer analysis illustrate how environmental education research is now rooted in the concept of ecopedagogy. This concept positions ecological awareness as an ethical dimension of the learning process. The ecopedagogy approach combines the principles of critical pedagogy (Freire) with the values of sustainability (Fatahidin et al., 2025; Ke & Chen, 2025), requiring teachers and students to interpret socio-ecological realities critically and responsibly. In this context, eco-literacy not only means the ability to understand the environment scientifically, but also the ability to assess the social and moral implications of every action on nature (Amalia, 2024; Villarosa, 2025). Therefore, research that addresses eco-design and SSI makes an important contribution to strengthening the philosophical and axiological foundations of 21st-century education.

From a methodological perspective, literature trends indicate that environmental education research has shifted from a descriptive approach to one based on developmental models and problem-based learning. This shift demonstrates that researchers are not only seeking to explain phenomena but also to create learning innovations that can be directly implemented in the classroom. By using eco-design as a framework and socio-scientific issues as a learning context, educators can facilitate more authentic and contextual learning experiences. This approach supports the development of higher-order thinking skills, particularly critical thinking skills, which are now a global competency requirement in addressing the complexity of environmental and social issues.

In the context of curriculum development, the results of this study emphasize the importance of integrating science, social values, and design creativity in the learning process. This integration requires teachers to act not merely as conveyors of information, but as facilitators of reflection and agents of change, guiding students to become eco-literate citizens. To achieve this, a learning model is needed that focuses not only on factual knowledge but also on the development of values, attitudes, and critical thinking skills in resolving complex issues (Purwanto et al., 2022; Wenno et al., 2021). An eco-design-based approach and SSI can thus create a more dialogic, reflective, and solution-oriented environmental education.

Philosophically, the findings of this bibliometric study suggest that future research needs to place environmental education within a more transdisciplinary framework. Synergy between science, technology, design, and the humanities is key to building sustainable and ecologically just education (Alahira et al., 2024; Tao & Tao, 2024). By utilizing the results of this bibliometric analysis, researchers and education practitioners can map opportunities for cross-disciplinary collaboration and expand pedagogical approaches toward holistic learning models. This aligns with the spirit of Education for Sustainable Development (ESD), which places ecological awareness, social responsibility, and critical thinking skills as foundations for sustainable human development (Ekamilasari et al., 2021; Yadav et al., 2022).

Thus, this discussion confirms that the integration of eco-design and socio-scientific issues is not merely a research trend, but rather a reflection of the epistemological and moral needs of contemporary education. The new paradigm of environmental education demands teachers and students who are able to think critically, act ethically, and design innovative solutions for the planet's sustainability. Therefore, the results of this bibliometric analysis can serve as a strategic foundation for developing environmental education research and practices that are more contextual, adaptive, and oriented toward strengthening eco-literacy and critical thinking skills at various levels of education.

Conclusion

Based on the bibliometric analysis using VOSviewer, this study concludes that research on eco-design and socio-scientific issues (SSI) in environmental learning shows a growing tendency toward integrative and contextual approaches that emphasize the development of eco-literacy and critical thinking. Although the dataset may not fully capture the most recent publications, the identified trends still provide a

general overview of the conceptual direction in this field. The findings highlight that eco-design and SSI are increasingly regarded not only as learning content but as pedagogical strategies aligned with the principles of ecopedagogy and Education for Sustainable Development (ESD), which integrate moral reflection, creativity, and scientific reasoning. This study underscores the importance of interdisciplinary collaboration and the continuous refinement of research methods to ensure more valid and comprehensive mapping in future studies. Strengthening eco-literacy and critical thinking in environmental education thus requires reflective, innovative, and action-oriented learning models that prepare students to become responsible and solution-driven global citizens.

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Author Contributions

Conceptualization, E.A and E.J.W; methodology, E.A; software, E.J.W; validation, A.H, M, and U.Y; formal analysis, E.A; investigation, E.J.W; resources, A.H; data curation, M; writing—original draft preparation, E.A; writing—review and editing, E.J.W and U.Y; visualization, E.J.W; supervision, A.H; project administration, E.A; funding acquisition E.A. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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