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Integrating ESD in Science Education to Enhance Understanding of SDGs and Sustainability Awareness: A Systematic Literature Review

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Abstract

Background: The growing intricacy of worldwide environmental, social, and economic issues underscores the immediate necessity to bolster Education for Sustainable Development in the realm of science education. Incorporating ESD is vital to improve learners' comprehension of the Sustainable Development Goals and to cultivate awareness of sustainability in light of challenges like climate change, environmental harm, and the depletion of resources.
Methods: This study employed a Systematic Literature Review using the PRISMA framework to identify, screen, and analyze relevant studies on ESD integration in science education. Articles were collected from databases such as Scopus, and Google Scholar with inclusion criteria focusing on peer-reviewed research published between 2016 and 2025. Data analysis was conducted using qualitative content analysis to identify patterns, instructional approaches, impacts, and challenges.
Results: The findings indicate that ESD integration in science education significantly improves students' understanding of SDGs and sustainability awareness. Student-centered approaches such as Problem-Based Learning, Project-Based Learning, inquiry-based learning, and contextual learning are the most effective strategies. These approaches enable learners to connect scientific concepts with real-world sustainability issues, including climate change, renewable energy, and environmental conservation.
Conclusion: The integration of ESD into science education plays a crucial role in strengthening students' cognitive, affective, and behavioral competencies related to sustainability. By linking scientific knowledge with real-world environmental and social issues, ESD fosters deeper SDGs understanding and enhances sustainability awareness. Therefore, strengthening teacher capacity, developing contextual learning resources, and improving curriculum support are essential to optimize the implementation of ESD in science education for sustainable development goals.

INTRODUCTION

The increasing complexity of global environmental, social, and economic challenges has strengthened the urgency of transforming education into a tool for sustainable development. Problems such as climate change, biodiversity loss, environmental pollution, resource depletion, and unsustainable consumption patterns have become major global concerns that directly affect human well-being and future generations. According to UNESCO (2020), these global issues cannot be solved solely through technological advancement or economic growth, but also require changes in human behavior, awareness, and values toward sustainability. Therefore, education plays a crucial role in preparing individuals to understand sustainability challenges and participate actively in solving them (Corresa et al, 2024).

Education for Sustainable Development (ESD) has emerged as a progressive educational approach that integrates sustainability principles into teaching and learning processes. Its main objective is to equip students with the knowledge, skills, attitudes, and values needed to support sustainable societies and maintain balance among environmental, social, and economic dimensions (Kioupi & Voulvoulis, 2022). Unlike conventional education that mainly emphasizes knowledge acquisition, Education for Sustainable Development (ESD) promotes critical thinking, systems thinking, collaboration, and responsible decision-making (Brundiers et al, 2021). UNESCO (2020) also emphasized that ESD encourages learners to become active global citizens who are capable of addressing sustainability challenges through interdisciplinary understanding and participation. The growing importance of ESD is closely related to the implementation of the Sustainable Development Goals (SDGs), which were adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs consist of 17 interconnected goals addressing global challenges such as poverty, inequality, environmental degradation, climate change, and quality education. In this framework, education is specifically emphasized in SDG 4, which aims to ensure inclusive and equitable quality education while promoting sustainable development principles in educational systems (García-González et al., 2017). Therefore, educational institutions are increasingly encouraged to integrate SDG-related competencies into learning activities.

Science education has strong potential to support the achievement of the SDGs because science learning naturally discusses environmental phenomena, technological development, and human interaction with nature. However, traditional science education often focuses primarily on conceptual understanding and theoretical knowledge without sufficiently connecting learning to real-world sustainability issues (Nugroho et al., 2025). As a result, students may understand scientific concepts but fail to recognize their relevance to environmental and social challenges. Integrating ESD into science education can contextualize scientific concepts through sustainability topics such as climate change, renewable energy, biodiversity conservation, and waste management.

Several studies have shown that integrating ESD into science education provides significant educational benefits. Walter Leal Filho et al. (2018) argued that ESD promotes interdisciplinary learning and strengthens sustainability competencies, including systems thinking, critical thinking, and collaborative problem-solving skills. Similarly, Harianto et al. (2026) reported that sustainability-oriented learning media could enhance students' sustainability awareness and scientific literacy. Environmental literacy is important because it helps students scientifically understand environmental issues and encourages environmentally responsible behavior. Student-centered learning approaches are widely recognized as effective strategies for implementing ESD in science education. Approaches such as Problem-Based Learning (PBL), Project-Based Learning (PjBL), inquiry-based learning, and flipped classrooms actively involve students in sustainability-

related problem-solving activities. Agusti, Wijaya, and Tarigan (2019) reported that PBL integrated with ESD significantly improved students' critical thinking skills and sustainability awareness regarding global warming issues. Likewise, Ekselsa et al. (2023) found that project-based learning integrated with ESD enhanced students' systems thinking skills and understanding of sustainability concepts. Education for Sustainable Development (ESD) supports the development of sustainability competencies and encourages students to actively participate in solving environmental problems (Olsson & Gericke, 2023; Veidemane, 2022).

Technological advancement has also contributed to the development of innovative ESD learning environments. Digital platforms, online learning systems, and interactive multimedia can increase student engagement and facilitate collaborative sustainability learning. Clarisa et al. (2020) demonstrated that flipped classroom learning integrated with ESD improved students' cognitive achievement and sustainability awareness. Technology-supported learning also enables students to independently access information, participate in collaborative discussions, and explore sustainability issues more deeply. Another important contribution of ESD integration is the development of sustainability awareness. Sustainability awareness refers to students' understanding, attitudes, and behaviors related to environmental protection and sustainable lifestyles. According to Mahat et al. (2016), sustainability education positively influences students' environmental attitudes and encourages responsible environmental behavior. Through ESD-based learning, students not only gain knowledge about sustainability but also develop empathy, responsibility, and willingness to take action in addressing environmental problems (Saleem & Dare, 2023).

Despite these benefits, the implementation of ESD in science education remains inconsistent across different educational contexts. Several studies identified challenges such as limited teacher readiness, insufficient understanding of sustainability concepts, lack of instructional resources, and curriculum constraints (Kioupi & Voulvoulis, 2022). Teachers often experience difficulties integrating sustainability issues into science lessons because curricula frequently emphasize content mastery and preparation for standardized assessments. As a result, sustainability-related topics are often treated as supplementary rather than integral components of science learning. In addition, limited instructional resources and teaching materials aligned with the Sustainable Development Goals (SDGs) further constrain teachers' ability to implement sustainability-oriented learning effectively (Munasi, 2024).

Another challenge is related to assessment practices in science education. Assessment systems often focus mainly on cognitive achievement while neglecting affective and behavioral dimensions of sustainability awareness. Consequently, students' environmental attitudes and sustainable behaviors are rarely evaluated systematically. Nugroho et al. (2025) emphasized the importance of curriculum reform, teacher professional development, and contextual learning resources to strengthen ESD implementation in science education. Given the increasing importance of sustainability education and the challenges of implementation, it is necessary to systematically examine how ESD has been integrated into science education and how it influences students' understanding of the SDGs and sustainability awareness. Therefore, this study applies a Systematic Literature Review (SLR) approach to synthesize findings from previous studies concerning ESD integration in science learning. The review aims to analyze trends, identify instructional approaches, evaluate the effectiveness of ESD implementation, and examine challenges in integrating sustainability into science education.

Specifically, this study has three objectives: (1) to analyze how ESD is integrated into science education, (2) to examine the impact of ESD integration on students' understanding of the SDGs, and (3) to evaluate the effectiveness of ESD in improving sustainability awareness. In addition, this study seeks to identify effective instructional strategies and best practices that

support meaningful sustainability-oriented science learning. Ultimately, integrating ESD into science education is expected to strengthen students' understanding of sustainability issues, encourage environmentally responsible behavior, and contribute to the achievement of sustainable development goals.

METHODS

This research utilizes a Systematic Literature Review (SLR) methodology to methodically discover, assess, and combine prior studies regarding the incorporation of Education for Sustainable Development (ESD) into scientific teaching, specifically aimed at improving learners' comprehension of the Sustainable Development Goals (SDGs) and awareness of sustainability. The SLR approach is chosen as it offers an organized, clear, and repeatable research process (Chien & Knoble, 2024). The scope of this review includes scholarly articles that examine the implementation of ESD in science education, especially those addressing SDGs comprehension and sustainability awareness. The data sources consist of peer-reviewed journal articles retrieved from databases such as Scopus and Google Scholar. The inclusion criteria are: (1) articles published between 2016 and 2025, (2) studies focusing on ESD in science education, (3) research related to SDGs or sustainability awareness, and (4) articles written in English. In contrast, the exclusion criteria include non-peer-reviewed publications, conference abstracts without full papers, and studies that are not aligned with the objectives of this review (Nugroho et al., 2025). The primary data in this study consist of selected journal articles that meet the established criteria. The instruments used include online academic databases, reference management tools such as Mendeley or Zotero, and data extraction sheets. The analysis process follows the PRISMA framework to ensure a systematic procedure for identification, screening, eligibility assessment, and inclusion of relevant studies (Sari et al., 2024).

Data collection is carried out through a structured search strategy using Boolean operators to obtain comprehensive results. The search strings are formulated using combinations of keywords such as ("Education for Sustainable Development" OR "ESD"), AND ("science education" OR "science learning"), AND ("SDGs" OR "Sustainable Development Goals"), and AND ("sustainability awareness" OR "environmental awareness").In some cases, the NOT operator is used to exclude irrelevant topics. These search strings are applied across selected databases to obtain relevant literature (Setiani et al., 2024). The operational definitions of the research variables are as follows: (1) ESD integration in science education refers to the incorporation of sustainability principles, SDGs contexts, and interdisciplinary approaches into science learning; (2) understanding of SDGs refers to students' cognitive comprehension of SDGs concepts and relevance; and (3) sustainability awareness refers to students' awareness including cognitive, affective, and behavioral aspects toward sustainability issues (Sari et al., 2024). The data analysis technique used is qualitative content analysis supported by descriptive analysis. The selected articles are categorized, coded, and analyzed to identify patterns, themes, and research trends. The findings are synthesized to determine effective strategies, impacts, and research gaps related to ESD integration in science education (Chien & Knoble, 2024). Through this systematic and structured approach, this study provides a comprehensive overview of current research and contributes to the development of effective strategies for integrating ESD into science education.

Table 1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Research articles discussing the integration of Education for Sustainable Development (ESD) in science education or science learning.	Articles not related to science education.
Articles addressing understanding of the Sustainable Development Goals (SDGs) or sustainability awareness.	Articles not related to improving students' understanding of SDGs or sustainability awareness.
Articles published in indexed scientific journals.	Articles that do not clearly present research data or findings.
Articles published within the period of 2016–2025.	Articles published outside the specified time range.
Articles written in English or Indonesian.	Articles not written in English or Indonesian.

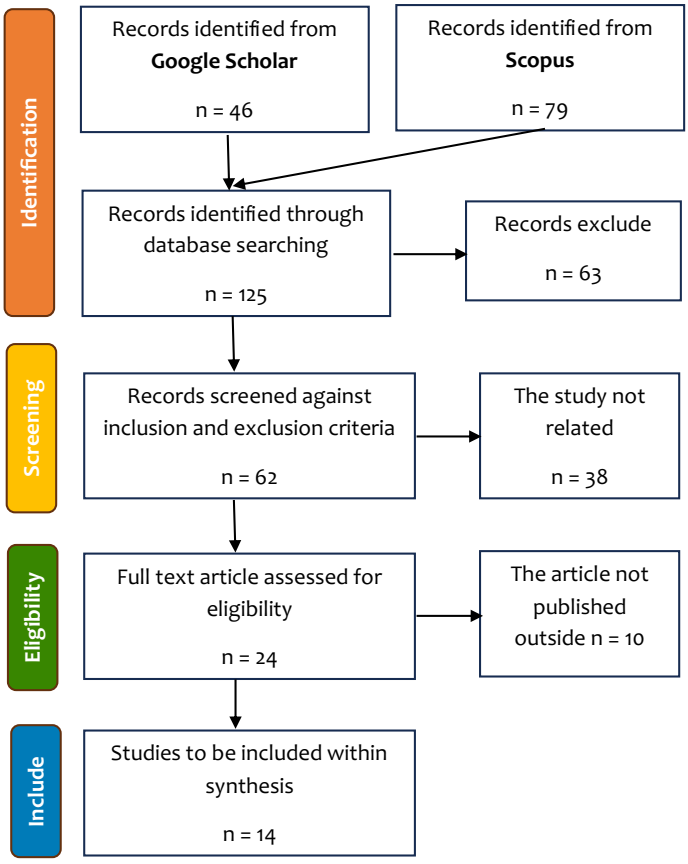

Figure 1. Diagram of a Prism

RESULT AND DISCUSSION

Table 2. Results of Article Analysis

Author	Year	Research Title	Research Results
Mahat et al.	2016	Sustainability Awareness and Education for Sustainable Development in Schools	ESD-based activities positively influenced sustainability attitudes and behaviors.
García-González et al.	2017	Education for Sustainable Development and the Sustainable Development Goals	SDG-based instruction enhanced sustainability values among students.
Leal Filho et al.	2018	Implementing and Operationalising Integrative Approaches to Sustainability in Higher Education	Science education integrated with ESD promoted sustainability awareness and interdisciplinary learning.
Agusti, Wijaya, & Tarigan	2019	Problem-Based Learning in the Context of Education for Sustainable Development (ESD) to Improve High School Students' Critical Thinking Skills and Sustainability Awareness on Global Warming Topics	Problem-based learning integrated with ESD improved students' critical thinking skills and sustainability awareness on global warming topics.
Cottafava et al.	2019	Education for Sustainable Development and Measuring Students' Sustainability Competencies	ESD instruction increased students' competencies related to sustainability and SDGs.
Wilujeng, Dwandaru, & Rauf	2019	The Effectiveness of Education for Environmental Sustainable Development to Enhance Environmental Literacy in Science Education: A Case Study of Hydropower	Environmental sustainable development learning improved students' environmental literacy and sustainability awareness in science education.
Clarisa, Danawan, Muslim, & Wijaya	2020	Implementation of Flipped Classroom in the Context of Education for Sustainable Development (ESD) to Improve Students' Cognitive Abilities and Build Sustainability Awareness	Flipped classroom integrated with ESD enhanced students' sustainability awareness and cognitive achievement.
Kioupi & Voulvoulis	2022	Education for Sustainable Development: A Systemic Framework for Connecting the SDGs to Educational Outcomes	ESD strengthened systems thinking and sustainability competencies in science education.
Ekselsa, R. A., Purwianingsih, W., Anggraeni, S., & Wicaksono, A. G. C.	2023	Developing System Thinking Skills through Project-Based Learning Loaded with Education for Sustainable Development	Project-based learning integrated with ESD improved students' systems thinking skills and sustainability understanding.

Author	Year	Research Title	Research Results
Uggla & Soneryd	2023	Possibilities and Challenges in Education for Sustainable Development: The Case of Higher Education	Sustainability learning fostered awareness of global environmental challenges.
Nugroho, Nugroho, Hayat, & Patonah	2024	Bridging Sustainability and Pedagogy: A Narrative Review of Education for Sustainable Development (ESD) Implementation in Indonesian Science Education	ESD implementation in Indonesian science education strengthened sustainability literacy and environmentally responsible learning practices.
Chen Guo, Ying Huang, Xiangdong Chen	2024	Research on Integration of the Sustainable Development Goals and Teaching Practices in a Future Teacher Science Education Course	Integration of SDGs into science learning improved pedagogical and sustainability competencies.
Xinqun Yuan et al.	2024	Promoting Education for Sustainable Development through the Green School Program to Achieve SDGs	Green School implementation increased students' sustainability awareness and SDG understanding.
Zulfah, Purnamasari, & Abdurrahman	2024	Implementation of Problem-Based Learning (PBL) Integrated with Education for Sustainable Development (ESD) on Students' Environmental Literacy in the Topic of Energy	PBL integrated with ESD enhanced students' environmental literacy and sustainability awareness in energy topics.

Employing the PRISMA framework in the process of conducting a systematic literature review, an initial count of 125 articles was gathered from various databases including Scopus, Web of Science, and Google Scholar. After eliminating duplicate entries and implementing established inclusion and exclusion criteria, a total of 32 articles were selected for the final review. The chosen analyses were published between the years 2016 and 2025 and mainly focused on the incorporation of Education for Sustainable Development (ESD) in science education, particularly its significance in enhancing learners' comprehension of the Sustainable Development Goals (SDGs) and promoting awareness of sustainability. The rise in publications post-2020 indicates a surge in academic interest regarding sustainability topics in education, spurred by pressing worldwide environmental and social challenges, which encompass climate change, loss of biodiversity, pollution, and patterns of unsustainable consumption (Kioupi & Voulvoulis, 2022).

Most of the reviewed studies employed qualitative, quantitative, and mixed-method approaches. The dominant instructional strategies identified were Problem-Based Learning (PBL), Project-Based Learning (PjBL), inquiry-based learning, contextual learning, and technology-supported learning. These approaches emphasize student-centered learning and encourage learners to actively engage with real-world sustainability problems. According to Leal Filho et al. (2018), integrative approaches in ESD are important because sustainability issues are interdisciplinary and require collaboration across scientific, environmental, economic, and social dimensions. Therefore, science education integrated with ESD should not merely focus on scientific concepts but also develop students' sustainability competencies, including critical thinking, systems thinking, collaboration, and responsible decision-making.

The reviewed studies demonstrate that ESD integration in science education can effectively improve students' sustainability awareness and understanding of global issues. Mahat et al. (2016) found that sustainability-based school activities positively influenced students' environmental attitudes and behaviors. Similarly, García-González et al. (2017) reported that SDG-

oriented instruction helped students develop sustainability values and a deeper awareness of global environmental challenges. These findings indicate that ESD is not only related to knowledge acquisition but also contributes to the formation of positive attitudes and behaviors toward sustainability.

The analysis revealed that ESD is integrated into science education through several important approaches, including contextual learning, interdisciplinary learning, project-based activities, and problem-solving instruction. Many studies have emphasized the importance of connecting science topics with real-world sustainability issues, such as climate change, renewable energy, waste management, ecosystems, and biodiversity conservation. Integrating these issues into science learning helps students understand the relevance of scientific concepts to contemporary global challenges, enhances environmental literacy, and fosters critical thinking and responsible decision-making needed to support sustainable development (Ghazian & Lortie, 2024). Nugroho et al. (2024) explained that integrating sustainability issues into science lessons helps students understand the relevance of scientific knowledge to everyday environmental and social problems.

One of the most commonly adopted methods was Problem-Based Learning (PBL). Agusti, Wijaya, and Tarigan (2019) demonstrated that the combination of PBL with Education for Sustainable Development (ESD) notably enhanced students' abilities in critical thinking and their awareness of sustainability regarding global warming issues. During PBL engagements, students were motivated to recognize environmental challenges, evaluate scientific information, and suggest solutions that adhere to principles of sustainability. This result aligns with the constructivist learning theory, which focuses on the active creation of knowledge via real-life experiences and problem-solving tasks. Project-Based Learning (PjBL) has also been recognized as a productive approach for incorporating ESD into science instruction. Ekselsa et al. (2023) discovered that merging project-based learning with ESD enhanced pupils' abilities in systems thinking as well as their comprehension of sustainability. Learners engaged in sustainability initiatives demonstrated a greater capacity to evaluate the interactions among environmental, social, and economic frameworks. Systems thinking is viewed as a fundamental skill in ESD since issues related to sustainability are intricate and interconnected (Kioupi & Voulvoulis, 2022).

In addition, inquiry-based learning and flipped classroom approaches were identified as innovative methods for supporting sustainability learning. Clarisa et al. (2020) reported that flipped classroom instruction integrated with ESD enhanced students' sustainability awareness and cognitive achievement. The use of digital learning resources allowed students to access sustainability-related materials independently before classroom discussions, making learning more interactive and student-centered. Similarly, Chen Guo, Ying Huang, and Xiangdong Chen (2024) emphasized that integrating SDGs into teacher science education courses improved both pedagogical competencies and sustainability competencies among future educators. The findings also indicate that contextual and local based learning plays a significant role in ESD implementation by enabling students to connect scientific concepts with sustainability issues that are directly relevant to their surrounding environment. Through the exploration of local environmental challenges, such as waste management, water conservation, and biodiversity protection, students can develop a deeper understanding of sustainability and apply their knowledge to real world situations. Wilujeng, Dwandaru, and Rauf (2019) demonstrated that hydropower-based environmental learning improved students' environmental literacy and sustainability awareness. By using local environmental issues as learning contexts, students were more engaged and able to connect scientific concepts with sustainability practices in their daily lives.

Table 3. Approaches to ESD Integration in Science Education

Approach	Description	Impact
Problem-Based Learning (PBL)	Students solve real-world sustainability problems	Enhances critical thinking and SDGs understanding
Project-Based Learning	Students conduct sustainability projects	Improves engagement and sustainability awareness
Inquiry-Based Learning	Scientific investigation of environmental issues	Strengthens conceptual understanding
Contextual Learning	Linking science topics to real-life issues	Increases relevance and motivation

These findings are consistent with previous research indicating that student-centered learning approaches are effective in integrating sustainability concepts into science education (Sihombing et al., 2024).

The reviewed studies consistently showed that integrating ESD into science education significantly improved students' understanding of the SDGs. Students who participated in ESD-based learning demonstrated better comprehension of sustainability concepts, environmental protection, social responsibility, and economic balance. García-González et al. (2017) explained that SDG-oriented learning helped students recognize the interconnectedness of global issues and understand the importance of collective action in achieving sustainable development.

Several studies indicated that students became more capable of connecting scientific concepts with specific SDGs after participating in ESD-integrated instruction. For example, climate change topics were associated with SDG 13 (Climate Action), ecosystem learning related to SDG 15 (Life on Land), and renewable energy topics connected with SDG 7 (Affordable and Clean Energy). Zulfah, Purnamasari, and Abdurrahman (2024) found that PBL integrated with ESD improved students' environmental literacy in energy topics, enabling them to understand sustainable energy use and environmental conservation more deeply.

Furthermore, technology-supported learning environments contributed significantly to improving SDG understanding. Clarisa et al. (2020) highlighted that digital learning resources and flipped classroom methods increased students' engagement and conceptual understanding. Similarly, Xinqun Yuan et al. (2024) reported that Green School programs promoted sustainability awareness and strengthened students' understanding of the SDGs through participatory environmental activities. These findings suggest that digital and experiential learning environments can strengthen sustainability-oriented science education.

The reviewed studies also emphasize that ESD encourages students to develop higher-order thinking skills. Cottafava et al. (2019) reported that ESD instruction improved students' sustainability competencies, including critical thinking, collaborative problem-solving, and decision-making skills. These competencies are essential for achieving the SDGs because sustainable development requires individuals who can critically analyze complex problems and develop innovative solutions.

Besides improving cognitive understanding, ESD integration in science education significantly enhanced students' sustainability awareness across cognitive, affective, and behavioral dimensions. Sustainability awareness refers not only to understanding sustainability concepts but also to developing positive attitudes and responsible behaviors toward the environment and society. Mahat et al. (2016) emphasized that sustainability education positively influenced students' environmental behaviors and encouraged them to adopt sustainable lifestyles.

Many reviewed studies showed that students who participated in ESD-based learning became more aware of environmental issues such as waste management, energy conservation, water pollution, and climate change mitigation. Wilujeng et al. (2019) found that environmental sustainable development learning increased students' environmental literacy and motivated them

to engage in environmentally responsible actions. Similarly, Uggla and Soneryd (2023) reported that sustainability learning fostered awareness of global environmental challenges and encouraged students to reflect on their personal responsibilities toward sustainability.

Project-based and problem-based learning approaches were especially effective in fostering sustainability awareness because they actively involved students in solving real environmental problems. Ekselsa et al. (2023) explained that sustainability projects encouraged students to develop systems thinking and understand the long-term impacts of human activities on the environment. Students became more responsible in their daily behaviors, including reducing waste, conserving energy, and supporting sustainable practices. The findings also indicate that sustainability awareness develops progressively through meaningful learning experiences. The conceptual framework derived from the reviewed studies suggests the following progression: Learning Approach-SDGs Understanding-Sustainability Awareness-Pro-environmental Behavior

This progression demonstrates that ESD integration not only improves students' conceptual understanding but also influences their attitudes and behaviors. In other words, ESD has a transformative role in shaping environmentally responsible citizens who are prepared to contribute to sustainable development goals.

Despite its significant benefits, several challenges in implementing ESD in science education were identified across the reviewed studies. One major challenge is limited teacher readiness. Many teachers still lack sufficient understanding of ESD concepts and effective strategies for integrating sustainability into science instruction. Nugroho et al. (2024) noted that many educators experience difficulties in connecting sustainability issues with existing science curricula due to limited training and instructional guidance.

Another challenge involves the lack of appropriate instructional materials and learning resources. Teachers often rely on conventional science textbooks that focus primarily on conceptual knowledge rather than sustainability issues. Consequently, opportunities to develop sustainability competencies are limited. In addition, assessment practices in science education still tend to prioritize cognitive achievement while neglecting affective and behavioral dimensions of sustainability awareness. Time constraints and curriculum overload also hinder effective ESD implementation. Teachers frequently struggle to balance curriculum demands with the integration of sustainability topics. According to Kioupi and Voulvoulis (2022), successful ESD implementation requires systemic changes in educational policies, curriculum structures, and teacher professional development programs.

Furthermore, technological limitations and unequal access to digital learning resources remain barriers in some educational contexts. Although digital tools can support sustainability learning, not all schools have adequate technological infrastructure. This condition affects the effectiveness of innovative ESD-based learning approaches such as flipped classrooms and online collaborative projects. The findings of this systematic literature review confirm that integrating ESD into science education is an effective strategy for improving students' understanding of the SDGs and enhancing sustainability awareness. This finding is consistent with UNESCO (2020), which emphasizes that ESD equips learners with the knowledge, skills, values, and attitudes needed to address sustainability challenges and contribute to achieving the SDGs. Student-centered learning approaches such as PBL, PjBL, inquiry learning, and flipped classrooms were found to be particularly effective because they encourage active participation, critical thinking, and contextual problem-solving. These findings support constructivist learning theory, which views learning as an active process in which learners construct knowledge through meaningful experiences and social interaction (Vygotsky, 1978).

The reviewed studies also highlight the importance of interdisciplinary learning in addressing sustainability challenges. Sustainability issues are inherently complex and interconnected; therefore, science education should integrate environmental, social, economic, and technological perspectives. Leal Filho et al. (2018) argued that interdisciplinary approaches are essential for developing sustainability competencies because they help students understand the

relationships between human activities and environmental systems. Moreover, the results indicate that ESD integration contributes not only to cognitive development but also to character building and environmental responsibility. Students who participate in ESD-based learning become more aware of sustainability challenges and more willing to engage in environmentally responsible behaviors. This finding is in line with Wals (2015), who emphasized that sustainability education can encourage environmental responsibility and promote behavioral change toward more sustainable lifestyles.

However, the challenges identified in this review indicate that successful implementation of ESD requires comprehensive support from educational institutions and policymakers. Teacher professional development programs are necessary to improve educators' understanding of sustainability concepts and innovative instructional strategies. Curriculum reforms are also needed to provide more opportunities for integrating SDGs and sustainability topics into science education. In addition, the development of contextual and technology-supported instructional materials is important for supporting meaningful sustainability learning experiences. Overall, the reviewed studies demonstrate that integrating ESD into science education has strong potential to support the achievement of the SDGs by developing students' sustainability competencies, awareness, and pro-environmental behaviors. This conclusion is supported by Rieckmann (2018), who argued that education plays a crucial role in developing key competencies required to address sustainability challenges and support sustainable development.

CONCLUSION

According to the findings of this systematic literature review, integrating Education for Sustainable Development (ESD) into science education improves students' understanding of the Sustainable Development Goals (SDGs) and sustainability awareness. ESD-based science learning also strengthens critical thinking, systems thinking, collaboration, and environmentally responsible behavior. These competencies are important for preparing students to address global sustainability challenges. The review also indicates that student-centered approaches, such as Problem-Based Learning (PBL), Project-Based Learning (PjBL), inquiry-based learning, and technology-enhanced learning, are effective in supporting ESD implementation. These approaches help students connect scientific concepts with real-world sustainability issues, including climate change, renewable energy, and environmental conservation. As a result, science learning becomes more meaningful and relevant to students' daily lives. Despite these benefits, several challenges still hinder effective ESD implementation in science education. Limited teacher readiness, lack of contextual learning resources, curriculum constraints, and assessment systems that mainly focus on cognitive achievement remain significant barriers. Therefore, stronger institutional support, curriculum development, and teacher professional training are needed to strengthen sustainability-oriented science education. Overall, this review confirms that integrating ESD into science education is an effective strategy for supporting SDG achievement and improving students' sustainability awareness. Future research is recommended to develop innovative learning models and assessment systems that support long-term sustainability competencies and environmentally responsible behavior.

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