
Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram
https://e-journal.undikma.ac.id/index.php/prismasains/index
e-mail: prismasains.pkpsm@gmail.com

July 2026. Vol. 14, No. 3
p-ISSN: 2338-4530
e-ISSN: 2540-7899
pp. 1478-1495

Environmental Literacy in Science Education: A Systematic Literature Review of Conceptual Emphases, Instructional Resources, and Methodological Trends

[1]*Ahmad Saputra, [2]Insih Wilujeng, [3]Antuni Wiyarsi

[1,2] Science Education Master Program, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

[3]Department of Chemistry Education, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

*Corresponding Author e-mail: ahmadsaputra.2025@student.uny.ac.id

Received: January 2026; Revised: June 2026; Published: July 2026

Abstract

The increasing complexity of environmental issues highlights the importance of environmental literacy as a key competence within science education; however, existing research remains fragmented in terms of conceptual emphases, instructional resources, and methodological practices. This study systematically examines research trends on environmental literacy in science education, focusing on investigated dimensions, learning materials and resources, methodological approaches, and data collection instruments. A systematic review was conducted following the PRISMA 2020 guidelines. Articles were retrieved from the Scopus database and screened through identification, screening, and eligibility stages, resulting in twenty-one peer-reviewed studies published between 2016 and 2025. The findings indicate that environmental literacy is predominantly conceptualized as a multidimensional construct encompassing cognitive, affective, and behavioral components, with a strong emphasis on cognitive aspects, particularly environmental knowledge and conceptual understanding. Experiential and technology-enhanced learning resources are most frequently employed, while traditional textbook-based materials are less common. Methodologically, quantitative approaches and questionnaire-based instruments dominate the field. Overall, this review reveals persistent conceptual and methodological imbalances and highlights the need for more integrated frameworks and diverse research approaches to support meaningful environmental literacy development through science education.

Keywords: Environmental literacy; Science education; Systematic literature review; Research trends; Learning resources

How to Cite: Saputra, A., Wilujeng, I., & Wiyarsi, A. (2026). Environmental Literacy in Science Education: A Systematic Literature Review of Conceptual Emphases, Instructional Resources, and Methodological Trends. *Prisma Sains: Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *14*(3), 1478–1495. https://doi.org/10.33394/j-ps.v14i3.19133

https://doi.org/10.33394/j-ps.v14i3.19133

Copyright© 2026, Saputra et al.
This is an open-access article under the CC-BY License

INTRODUCTION

The increasing complexity of environmental issues, ranging from climate change and pollution to ecosystem degradation, requires young generations to develop the ability to understand, analyze, and act in an environmentally responsible manner (Darfin & Kholifatun, 2025; Hohenhaus et al., 2023; Martha et al., 2025; Milandi et al., 2025). Within the educational context, environmental literacy represents a crucial competence, encompassing conceptual understanding of ecosystems, the development of positive environmental attitudes, as well as critical thinking and decision-making skills that support sustainability (Kaya & Elster, 2019; Miterianifa & Mawarni, 2024; Yuliastrin et al., 2023). By fostering environmental literacy, students are not only able to comprehend environmental phenomena theoretically but are also prepared to engage in actions that contribute positively to the environment (Novera et al., 2024; Novian & Sari, 2024).

Science education plays a strategic role in promoting environmental literacy, as it provides a conceptual framework and scientific practices that are relevant for understanding environmental phenomena in a holistic manner (Al-Barakat et al., 2025; Guerrero & Sjöström, 2025; Nurfaizah et al., 2025). Integrating environmental issues into science learning can enhance students' ecological understanding, strengthen critical thinking skills, and encourage pro-environmental behavior (Arisma et al., 2024; Azrai et al., 2024; Candra, 2025; Siswa et al., 2025). Teachers hold a central role in implementing interactive, contextual, and problem-based instructional strategies, while learning materials that link scientific concepts with real-world environmental issues, as well as the use of digital media or practical experiments, can enrich students' learning experiences and support the comprehensive development of environmental literacy (Gök & Boncukçu, 2023; Kuswandi et al., 2025; Rubini et al., 2023; Xiong et al., 2025). In this review, environmental literacy is operationalized using a multidimensional framework that integrates cognitive (knowledge and understanding), affective (attitudes and values), behavioral (action and participation), and skills-based components, consistent with widely adopted conceptualizations in environmental and science education research.

Despite the growing body of literature on environmental literacy in science education, existing studies remain fragmented in focus, methodology, and context. Consequently, understanding actual educational practices, the effectiveness of instructional strategies, the role of teachers, and student engagement in developing environmental literacy remains limited. Therefore, a systematic and integrative synthesis is needed to move the field beyond descriptive trends toward more theoretically and methodologically informed research directions by mapping research trends, identifying key themes, and examining the methods and instruments used in environmental literacy research within science education. Unlike previous reviews that focus on specific interventions or isolated dimensions, this systematic review integrates conceptual, instructional, and methodological perspectives to provide a comprehensive synthesis of environmental literacy research within science education.

Accordingly, this study employs a systematic literature review to analyze the existing literature and addresses four main research questions (RQ):

RQ1. What variables or aspects have been investigated in relation to the development of environmental literacy in science education?

RQ2. What types of learning materials or resources are used to support environmental literacy instruction?

RQ3. What methodological trends (research approaches, designs, and data analysis techniques) are applied in environmental literacy research in science education?

RQ4. What data collection tools are most commonly employed in studies on the implementation of environmental literacy in science education?

By addressing these questions, this review aims to provide a comprehensive understanding of research developments on environmental literacy in science education and serve as a reference for researchers, educators, and curriculum developers in designing effective science-based learning strategies to enhance students' environmental literacy. The findings are expected to reinforce the role of science education as a key means for fostering environmentally competent and responsible future generations.

METHOD

Research Design

This study employed a systematic literature review (SLR) design to synthesize empirical studies related to environmental literacy in science education. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, rigor, and reproducibility (Page et al., 2021). This review aimed to identify research trends and map evidence regarding environmental literacy dimensions, learning materials and resources, methodological approaches, and data collection instruments in science education studies.

Database and Search Strategy

The literature search was conducted using the Scopus database, which provides extensive international coverage of peer-reviewed journal publications in education and environmental studies. Although this review relied on Scopus as a single database, Scopus has been widely used in systematic reviews due to its comprehensive indexing and citation coverage, particularly in education and environmental research. Scopus was selected as the primary database due to its broad international coverage of high-quality peer-reviewed journals in education and environmental studies. The search was performed on 15 December 2025 using the TITLE-ABS-KEY field to identify studies relevant to environmental literacy in science education. The Scopus search query applied was: TITLE-ABS-KEY (("environmental literacy" OR "eco literacy" OR "ecoliteracy") AND ("science education" OR "science learning" OR "science teaching")). To ensure relevance and publication quality, the search was limited to publications written in English, published between 2016 and 2025, indexed as journal sources, and categorized under the document type Article. The initial search yielded 572 records.

Eligibility Criteria

Eligibility criteria were defined before the screening process to reduce selection bias and ensure consistency. Studies were included if they explicitly focused on environmental literacy (or related terms such as ecoliteracy) and were conducted within science education contexts. Publications that were not peer-reviewed journal articles or were not directly related to science education were excluded. The inclusion and exclusion criteria are summarized in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
- Studies published between 2016-2025	- Studies published outside the defined time range
- Articles written in English	- Articles written in languages other than English
- Peer-reviewed journal articles indexed in Scopus	- Conference papers, book chapters, editorials, notes, and non-peer-reviewed publications
- Studies explicitly examining environmental literacy, eco literacy, or ecoliteracy	- Studies that do not focus on environmental literacy as the main construct
- Studies conducted in science education contexts (formal science education, non-formal science learning, or science teacher education)	- Studies conducted outside science education contexts (e.g., tourism, business, engineering, agriculture, general environmental management)
- Full-text articles accessible for screening and analysis	- Articles without accessible full text

Study Selection Process

The study selection process followed the PRISMA stages of identification, screening, eligibility, and inclusion. The initial database search identified 572 records. After applying publication year and language filters, 25 records were removed, leaving 547 records. Document type filtering was then applied to retain only journal articles, resulting in 112 records for title and abstract screening. During the screening stage, 57 records were excluded because they did not explicitly address environmental literacy within science education contexts. The remaining 55 articles were assessed through full-text screening, and 31 studies were excluded because they did not meet the operational definition of science education-based environmental literacy research. Finally, 21 studies met all eligibility criteria and were included in the systematic literature review. The complete selection procedure is presented in the PRISMA flow diagram (Figure 1).

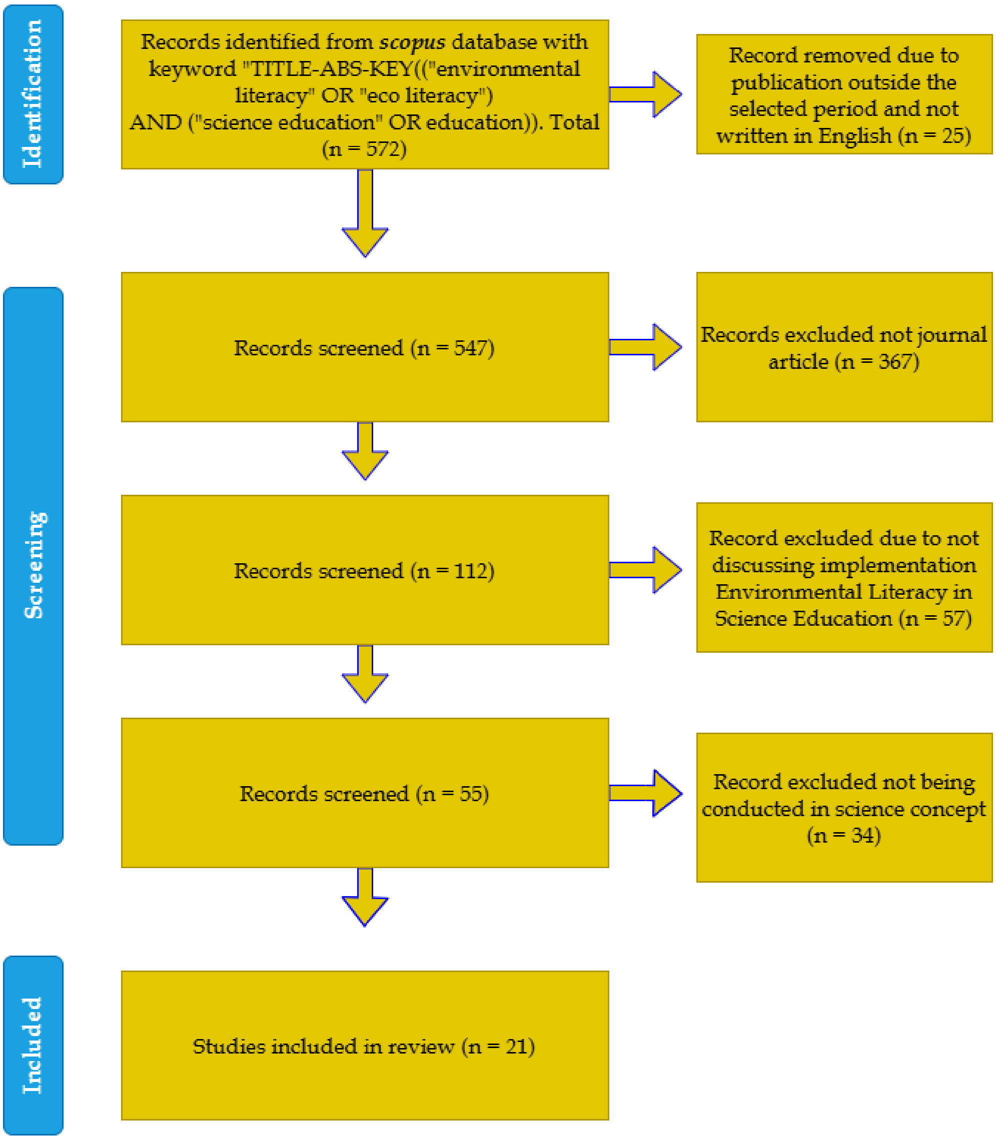

Figure 1. PRISMA flow diagram of the study selection process

Data Extraction

A structured data extraction form was developed to systematically collect relevant information from each included study. The extracted data covered bibliographic information (author(s) and publication year), country and educational context, participant characteristics, environmental literacy dimensions examined, learning materials and instructional resources, research approach and design, data collection instruments, and key findings related to environmental literacy outcomes. This extraction process ensured consistency in organizing evidence across studies and facilitated descriptive synthesis. The data extraction framework is presented in Table 2.

Table 2. Data Extraction Framework

Extracted Information	Description
- Author(s) and year	- Author names and publication year
- Country/region	- Location where the study was conducted
- Educational level/context	- Primary, secondary, higher education, teacher education, non-formal education
- Participants	- Participant type and sample size

Extracted Information	Description
- Environmental literacy dimensions	- Cognitive, affective, behavioral, skills, or other components
- Learning materials/resources	- Teaching materials, learning media, technology integration, modules, programs, etc.
- Research approach	- Quantitative, qualitative, or mixed-methods
- Research design	- Survey, experimental/quasi-experimental, case study, evaluation, etc.
- Instruments	- Test, questionnaire, interview, observation, document analysis
- Key findings	- Main outcomes and conclusions reported by the study

Quality Appraisal

To evaluate the methodological rigor of the included studies, a quality appraisal was conducted using the Mixed Methods Appraisal Tool (MMAT) 2018, which is suitable for systematic reviews involving qualitative, quantitative, and mixed-methods designs. Each included study was assessed based on the MMAT criteria relevant to its research design. The appraisal results were used to provide an overview of evidence quality and to support interpretation of findings in the synthesis stage. The quality appraisal was not used as an exclusion criterion but served to contextualize the strength of evidence and support cautious interpretation of the synthesized findings. The MMAT appraisal framework is summarized in Table 3.

Table 3. MMAT 2018 Quality Appraisal Framework

Study Design Category	MMAT Evaluation Criteria
- Qualitative studies	- Appropriateness of qualitative approach, adequacy of data collection, coherence between data and interpretation
- Quantitative randomized studies	- Randomization process, baseline comparability, completeness of outcome data, appropriateness of measurements
- Quantitative non-randomized studies	- Representativeness, confounding control, intervention integrity, completeness of outcome data
- Quantitative descriptive studies	- Sampling strategy, measurement validity, nonresponse bias, appropriateness of statistical analysis
- Mixed-methods studies	- Justification of mixed-methods design, integration of findings, coherence of interpretation

RESULTS AND DISCUSSION

Results

This section presents the findings of the systematic literature review on environmental literacy in science education. The results are organized based on the review focus, including (1) environmental literacy dimensions investigated, (2) learning materials and resources supporting environmental literacy instruction, (3) methodological trends, and (4) data collection instruments employed in the reviewed studies.

Environmental Literacy Dimensions Investigated

The reviewed studies conceptualized environmental literacy as a multidimensional construct, most commonly encompassing cognitive, affective, and behavioral components. Table 4 summarizes the main dimensions and variables investigated in the included studies.

Table 4. Environmental Literacy Dimensions and Variables Examined in Reviewed Studies

No	Author (Year)	Educational Context	Environmental Literacy Dimension	Variabel Investigated
1	Vojíř & Svobodová (2024)	Lower secondary science textbooks	Cognitive	Environmental processes and systems; curriculum representation

No	Author (Year)	Educational Context	Environmental Literacy Dimension	Variabel Investigated
2	Frensley et al. (2022)	Residential environmental education center (middle school)	Cognitive, Affective, Behavioral	Knowledge; attitudes; pro-environmental behavior outcomes
3	Christiansen (2020)	Primary education language textbooks (China)	Affective (ideological orientation)	Awareness; attitudes; values; environmental responsibility
4	Saribas et al. (2016)	Pre-service elementary teacher education	Cognitive, Affective	Climate change knowledge; attitudes; concern; perceptions
5	Arici (2024)	Elementary science education with AR technology	Cognitive, Affective, Behavioral, Skills	Knowledge; sensitivity; behavior; environmental skills
6	Hamilton & Polk (2023)	Middle school place-based science education	Cognitive, Affective, Behavioral	Great Lakes literacy; awareness; stewardship
7	Nacaroğlu & Göktaş (2025)	Preservice science teacher education (technology-supported inquiry)	Affective (Cognitive-implicit)	Attitudes; environmental awareness
8	Sorensen et al. (2016)	Undergraduate environmental science education	Cognitive (higher-order)	Systems thinking; socio-scientific reasoning
9	Bissinger & Bogner (2018)	Secondary education (Grade 10), botanical garden-based learning	Cognitive, Affective, Behavioral	Knowledge; attitudes; behavior intention
10	Kramar & Knez (2025)	Secondary education (ages 13–15), cross-cultural (Europe & Middle East)	Cognitive, Affective, Behavioral (engagement)	Hydrogen literacy; sustainability awareness; engagement
11	Pan & Hsu (2020)	Nonformal environmental education (nature center), elementary level (Grade 6)	Cognitive, Affective, Behavioral, Retention	Knowledge; attitudes; locus of control; responsibility; action
12	Carmi & Alkaher (2019)	Higher education	Cognitive (risk literacy), Affective-perceptual	Risk literacy; ecological risk perception
13	Liu et al. (2019)	Higher education (university students)	Affective-moral, Attitudinal, Cognitive (implicit)	Environmental ethics; moral awareness; literacy
14	Herlanti et al. (2025)	School science learning (online, Indonesia)	Knowledge, awareness, attitudes, skills, participation	Knowledge; awareness; attitudes; skills; participation
15	Svensson et al. (2022)	Higher education	Cognitive (supporting literacy skills)	Information literacy; source evaluation; critical thinking
16	Dada et al. (2017)	Preservice teacher education	Cognitive, Affective	Knowledge; dispositions; preparedness
17	(Kocak & Celik, 2023)	STEM-based preservice teacher education	Cognitive, Affective, Behavioral	Knowledge; attitudes; awareness; behavior

No	Author (Year)	Educational Context	Environmental Literacy Dimension	Variabel Investigated
18	(Rasis & Kuswanto, 2023)	Preservice biology teacher education	Cognitive, Affective, Behavioral	Knowledge; attitudes; behavior
19	(Bloom & Fuentes, 2019)	Inservice science teacher professional development	Cognitive, Affective	Energy literacy; sustainability perspectives
20	(Chen et al., 2020)	Higher education students (design university)	Cognitive, Affective, Behavioral	Literacy; awareness; attitudes; outcomes
21	(Cincera et al., 2023)	Lower secondary education (formal & non-formal)	Cognitive, Affective, Behavioral	Knowledge; beliefs; locus of control; behavior

Overall, the cognitive dimension was the most frequently examined component, mainly operationalized through variables such as environmental knowledge, understanding of environmental systems, systems thinking, and risk literacy. Affective components were also commonly addressed through attitudes, awareness, values, and moral responsibility. Behavioral aspects were included less consistently and were mainly measured through pro-environmental behavior, stewardship, and participation indicators. Only a small number of studies explicitly examined skills-related dimensions such as inquiry skills, problem-solving skills, and information literacy. To provide a clearer quantitative overview, the frequency of environmental literacy dimensions is summarized in Figure 2.

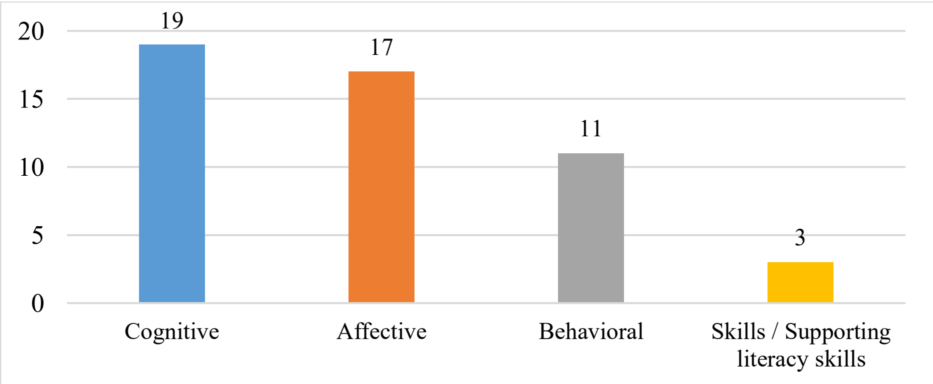

Figure 2. Distribution of Environmental Literacy Dimensions Across Reviewed Studies

Learning Materials and Resources Supporting Environmental Literacy Instruction

The reviewed studies reported diverse learning materials and instructional resources used to support the development of environmental literacy in science education. Based on the synthesis, the reported resources were classified into seven main categories: (1) experiential and program-based learning environments, (2) digital and technology-enhanced materials, (3) place-based and outdoor learning resources, (4) inquiry-oriented learning kits and STEM resources, (5) curriculum/textbook-based materials, (6) simulation/model-based learning resources, and (7) information literacy and academic resources. The distribution of these learning resources is summarized in Table 5.

Table 5. Learning Materials and Resources Supporting Environmental Literacy Instruction

Category of Learning Resource	Examples of Resources Reported	Frequency (n)
- Experiential and program-based learning environments	- Residential environmental education, botanical gardens, nature centers, environmental education programs	8

Category of Learning Resource	Examples of Resources Reported	Frequency (n)
- Digital and technology-enhanced materials	- AR, VR, computer-aided instruction, online learning platforms	6
- Place-based and outdoor learning resources	- Place-based learning in local ecosystems, outdoor contextual learning	3
- Inquiry-oriented learning kits and STEM resources	- Guided inquiry materials, STEM microcontroller kits, open inquiry kits	3
- Curriculum/textbook-based materials	- Printed textbooks, curriculum integration	2
- Simulation/model-based learning resources	- Simulation games, decision-making tools, model-based reasoning	2
- Information literacy and academic resources	- Searching, evaluating sources, academic environmental resources	1

To facilitate interpretation of the dominant instructional resources reported across the reviewed studies, the frequency distribution is illustrated in Figure 3. Because several studies employed more than one learning resource, the total frequency exceeds the number of included studies.

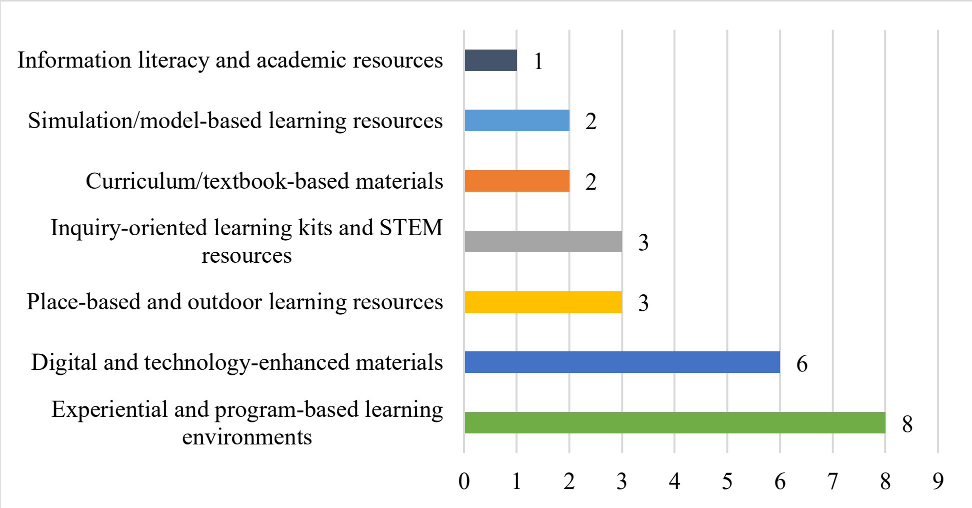

Figure 3. Frequency Distribution of Learning Materials and Resources Supporting Environmental Literacy Instruction

As shown in Figure 3, experiential and program-based learning environments represent the most frequently reported category (n = 8), indicating a strong emphasis on contextual and authentic learning experiences such as residential environmental education programs, botanical gardens, and nature centers. Digital and technology-enhanced materials are also widely employed (n = 6), including augmented reality, virtual reality, computer-aided instruction, and online learning platforms. Place-based and outdoor learning resources (n = 3) and inquiry-oriented learning kits and STEM resources (n = 3) appear in a moderate number of studies, suggesting increasing attention to inquiry-based and locally relevant environmental learning. In contrast, curriculum/textbook-based materials (n = 2) and simulation/model-based learning resources (n = 2) are less frequently reported, while information literacy and academic resources appear only in a limited number of studies (n = 1).

Methodological Trends in Environmental Literacy Research

The methodological characteristics of the reviewed studies indicate that quantitative approaches dominate environmental literacy research in science education. The distribution of research approaches across the included studies is presented in Figure 4.

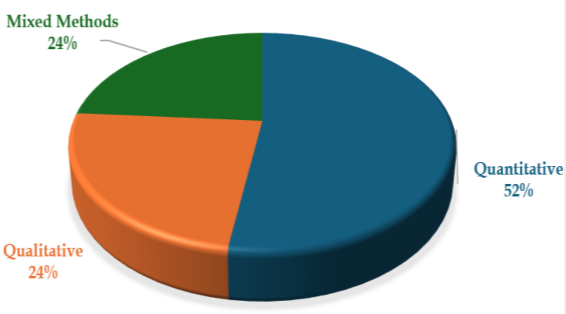

Figure 4. Distribution of Research Approaches in Environmental Literacy

As shown in Figure 4, quantitative methods represent the largest proportion of studies (52%), while qualitative and mixed-methods approaches are less frequently employed (24% each). To provide further detail, the research designs reported in the reviewed studies are summarized in Table 7.

Table 7. Research Designs in Reviewed Studies

Research Design	Frequency (n)
Quasi-experimental	6
Survey research	5
Case study	4
Experimental	3
Design-based / Program evaluation	3
Total	**21**

Table 7 shows that quasi-experimental designs are the most frequently applied research design (n = 6), followed by survey-based studies (n = 5) and case studies (n = 4). Experimental studies (n = 3) and design-based/program evaluation approaches (n = 3) appear less frequently. In addition, participant characteristics across the reviewed studies are summarized in Figure 5.

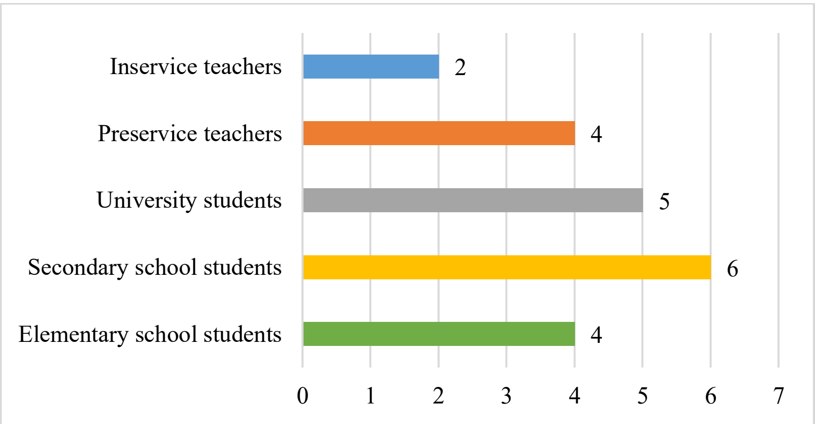

Figure 5. Distribution of Participant Groups Across Reviewed Studies

As shown in Figure 5, most studies were conducted with secondary school students (n = 6) and university students (n = 5). Preservice teachers and elementary school students were also frequently involved (n = 4 each), indicating that environmental literacy research is commonly implemented in both school and teacher education contexts. In contrast, inservice teachers were the least represented participant group (n = 2), suggesting a limited focus on practicing teachers in environmental literacy research within science education. The data analysis techniques reported in the reviewed studies are summarized in Table 8.

Table 8. Data Analysis Techniques in Reviewed Studies

Data Analysis Technique	Frequency (n)
Descriptive statistics	12
Inferential statistics	8

Data Analysis Technique	Frequency (n)
Qualitative thematic analysis	5
Mixed analysis (integration of quantitative and qualitative findings)	5

As shown in Table 8, descriptive statistical analysis was the most commonly applied technique (n = 12), followed by inferential statistical methods such as t-tests, ANOVA, and regression analysis (n = 8). Qualitative thematic analysis was reported in several studies (n = 5), while mixed analysis integrating quantitative and qualitative findings was also used in a number of studies (n = 5), indicating that some studies combined quantitative results with qualitative interpretation to strengthen the robustness of findings.

Data Collection Instruments

The reviewed studies employed various data collection instruments to assess environmental literacy outcomes. The frequency distribution of the instruments reported across the included studies is presented in Table 9.

Table 9. Data Collection Instruments Used in Reviewed Studies

Instrumen Type	Frequency
Questionnaires / Tests	13
Interviews	5
Observations	4
Document analysis	3

As shown in Table 9, questionnaires and tests were the most frequently used instruments (n = 13), primarily applied to measure environmental knowledge, attitudes, and self-reported behavioral tendencies. Interviews (n = 5) were used to explore participants' perceptions and learning experiences in greater depth. Observations (n = 4) and document analysis (n = 3) were less frequently employed, indicating that fewer studies relied on direct behavioral evidence or curriculum-based analysis to evaluate environmental literacy development. Taken together, these results indicate that current environmental literacy research in science education is characterized by strong conceptual attention to knowledge acquisition, increasing reliance on experiential and technology-enhanced learning resources, and a predominant use of quantitative methodologies, while issues related to behavioral enactment, skills development, and long-term impact remain comparatively underexplored.

Discussion

By integrating conceptual, instructional, and methodological perspectives, this review extends prior environmental literacy syntheses by providing a comprehensive meta-level understanding of how environmental literacy is currently operationalized and studied within science education. The findings of this systematic literature review demonstrate that research on environmental literacy in science education has predominantly conceptualized environmental literacy as a multidimensional construct, integrating cognitive, affective, and behavioral dimensions (Sanchez et al., 2025; Xiong et al., 2025). However, the synthesis also reveals a clear imbalance in emphasis, with the cognitive dimension receiving substantially greater attention than affective and behavioral components (Khoirunnisa et al., 2023; Komang et al., 2024; Maurer & Bogner, 2020). Environmental literacy is most frequently operationalized through measures of environmental knowledge, understanding of environmental systems, systems thinking, and scientific reasoning (Al-Barakat et al., 2025; McBride et al., 2013). While affective variables such as attitudes, awareness, values, and moral responsibility are also commonly included, behavioral aspects particularly those related to sustained pro-environmental action and participation are addressed less consistently (J. Liu & Green, 2024; L. Liu & Tobias, 2024). This pattern suggests that, although science education has been effective in strengthening students' conceptual understanding of environmental issues, translating this understanding into concrete and sustained behavioral engagement remains a persistent challenge (Alshehri, 2024; Ardoin et al., 2020; Portus et al., 2024; Yang et al., 2025). These findings reflect longstanding concerns in environmental education research regarding the gap between environmental knowledge and environmentally responsible behavior.

Importantly, this imbalance indicates that many studies may still treat environmental literacy primarily as an "academic outcome" rather than a transformative competence that influences students' real-life decision-making. While knowledge is a fundamental foundation, environmental literacy is ultimately meaningful when learners demonstrate the willingness and capacity to act responsibly in daily life and civic contexts. Therefore, research that focuses heavily on cognitive measures without equally examining behavioral enactment risks producing an incomplete picture of environmental literacy development. This trend also aligns with the widely discussed "knowledge–action gap," where learners may understand environmental issues but do not consistently engage in environmentally responsible behavior. This gap may be influenced by factors such as limited opportunities for authentic action, lack of social and institutional support, weak environmental identity, and contextual constraints (e.g., school culture, family habits, community infrastructure). Thus, future science education research should not only measure environmental knowledge but also explore how science learning experiences shape environmental identity, agency, and sustained participation in environmental action.

The review further indicates a notable shift in instructional approaches supporting environmental literacy, with experiential, program-based, and technology enhanced learning resources appearing more frequently than traditional textbook-based instruction. Learning environments such as residential environmental education programs, botanical gardens, nature centers, and place-based outdoor settings are widely employed, highlighting an increasing recognition of the value of contextualized and authentic learning experiences in science education (Klopčič & Torkar, 2025; Trina et al., 2024; Yilmaz et al., 2023). In parallel, digital learning materials including augmented reality, virtual reality, computer-aided instruction, and online learning platforms are increasingly integrated to support the visualization of complex environmental systems and inquiry oriented learning processes. The relatively limited reliance on printed textbooks suggests a gradual move away from static instructional materials toward more interactive and experiential resources that are better suited to addressing the complexity and interdisciplinary nature of environmental issues.

This shift has important pedagogical implications. Experiential and outdoor learning environments provide opportunities for learners to directly interact with ecological systems, observe environmental degradation, and engage in authentic inquiry. Such experiences may strengthen emotional connection to nature, which has been reported as an important predictor of environmental concern and stewardship behaviors. Similarly, technology-enhanced tools such as AR and VR may improve learners' ability to visualize invisible environmental processes (e.g., pollution diffusion, climate system interactions, biodiversity loss), making abstract environmental concepts more accessible and engaging. However, the dominance of experiential and digital learning resources also suggests that environmental literacy instruction may increasingly require schools to provide adequate infrastructure, teacher training, and access to technology. Without sufficient support, the use of AR/VR or inquiry-based STEM kits may remain limited to well-resourced institutions, potentially creating inequity in environmental literacy development across different regions and socioeconomic contexts. Therefore, future research should also examine accessibility and feasibility issues, particularly in developing countries and rural school settings.

From a methodological perspective, the reviewed studies reveal a strong dominance of quantitative research approaches, particularly quasi-experimental designs and survey-based studies (Hudha et al., 2023; Rofiqi, 2024). While these approaches provide important evidence regarding instructional effectiveness and allow for broader generalization, the limited use of qualitative and mixed-methods designs indicates that contextual, process-oriented, and longitudinal dimensions of environmental literacy development remain underexplored (Xiong et al., 2025; Zhang & Jung, 2025). The heavy reliance on questionnaires and standardized tests may not fully capture students' decision-making processes, behavioral enactment, or long-term engagement with environmental issues (Ballard et al., 2024; Rofiqi, 2024) Furthermore, the relatively small number of studies involving inservice teachers highlights a research gap related to how environmental literacy is implemented, sustained, and negotiated within everyday classroom practice. Addressing these limitations will require greater methodological diversity, including qualitative inquiry, classroom-based observations, and design-based research that can illuminate how environmental literacy develops across time and learning contexts.

A key concern emerging from the methodological synthesis is the overdependence on self-reported questionnaire measures. Although questionnaires are efficient for assessing attitudes and perceived behaviors, they may not accurately represent real behavioral engagement due to social desirability bias and the limited ability of students to evaluate their own long-term actions. Therefore, future studies should expand the use of triangulated instruments such as classroom observation protocols, student reflective journals, learning portfolios, and performance-based assessments. Such approaches may provide richer evidence regarding how environmental literacy competencies are enacted during scientific inquiry, group discussions, and problem-solving activities. Additionally, the limited use of longitudinal research designs indicates that the sustainability of environmental literacy outcomes remains unclear. Many quasi-experimental studies evaluate short-term learning gains, but environmental literacy is a competence that develops progressively and is shaped by repeated exposure to environmental issues and civic action. Thus, longitudinal and follow-up studies are strongly recommended to evaluate whether science education interventions lead to lasting changes in environmental responsibility and lifestyle practices.

Overall, this review contributes to the field by systematically mapping conceptual emphases, instructional resources, and methodological patterns in environmental literacy research within science education. By synthesizing evidence across these dimensions often examined separately in prior studies this review provides an integrated perspective that clarifies current research trends and identifies key gaps for future investigation. The findings underscore the need for more balanced approaches that intentionally integrate cognitive, affective, and behavioral dimensions of environmental literacy, as well as instructional designs that explicitly support the translation of scientific understanding into meaningful environmental action. For researchers, this review highlights the importance of expanding methodological approaches and strengthening attention to teachers' roles and classroom implementation. For educators and curriculum developers, the results emphasize the potential of experiential and technology-enhanced learning resources to foster meaningful environmental literacy. Ultimately, strengthening the alignment between scientific knowledge, environmental values, and responsible action is essential if science education is to play a transformative role in preparing environmentally literate and responsible future generations.

Despite these contributions, this review has several limitations that should be acknowledged. First, this systematic review relied on Scopus as a single database. Although Scopus has been widely used in systematic reviews due to its comprehensive indexing and citation coverage, particularly in education and environmental research, relevant studies indexed in other databases such as Web of Science or ERIC may not have been captured. Second, the review included only peer-reviewed journal articles published in English, which may limit the representation of regional, practice-oriented, or non-English studies. Consequently, the findings should be interpreted as reflecting dominant research trends rather than providing an exhaustive overview of all environmental literacy research in science education.

In addition to mapping current trends, this review provides a future research agenda that highlights several priority directions for advancing environmental literacy research in science education. First, future studies should adopt more comprehensive environmental literacy frameworks that explicitly integrate knowledge, attitudes, skills, and action competence, rather than emphasizing isolated cognitive outcomes. Second, research should further explore how instructional strategies such as socioscientific issue (SSI)-based learning, project-based learning, and citizen science participation can strengthen students' environmental agency and civic engagement. Third, greater attention should be given to inservice teachers, as their classroom practices and pedagogical beliefs play a critical role in determining whether environmental literacy becomes meaningfully embedded in everyday science instruction. Finally, expanding cross-cultural and contextual comparisons is essential to better understand how local environmental challenges, curriculum systems, and cultural values shape the development of environmental literacy across diverse educational settings. Taken together, these directions underscore that environmental literacy in science education should not be viewed merely as content mastery, but as a long-term educational investment aimed at empowering learners to participate in sustainable development and environmental problem-solving. Achieving this goal requires not only innovative learning resources, but also stronger conceptual balance and greater methodological rigor in future research.

CONCLUSION

This systematic literature review demonstrates that research on environmental literacy in science education continues to prioritize cognitive dimensions, while behavioral and skills-based aspects receive comparatively limited attention, reflecting a persistent knowledge–action gap. Instructionally, experiential, program-based, and technology-enhanced learning resources dominate the literature, indicating a shift toward more contextualized and interactive learning environments, whereas traditional textbook-based materials are less frequently employed. Methodologically, the field is largely characterized by quantitative and quasi-experimental designs with a strong reliance on questionnaire-based instruments, suggesting insufficient attention to contextual, process-oriented, and long-term development of environmental literacy. These patterns underscore the need for future research to adopt more balanced conceptual frameworks that integrate knowledge, attitudes, skills, and action, alongside more diverse methodological approaches, including qualitative, mixed-methods, and longitudinal designs. Although this review is limited to Scopus-indexed journal articles, it provides a coherent synthesis of current trends and research gaps and offers a valuable foundation for guiding future studies and strengthening the transformative role of science education in fostering environmentally literate and responsible learners.

RECOMMENDATION

Based on the synthesized findings of this systematic literature review, future research should adopt more balanced conceptual perspectives on environmental literacy by giving comparable attention to cognitive, affective, and behavioral dimensions within science education. Further studies are encouraged to examine how specific instructional strategies and learning resources support students in translating environmental understanding into environmentally responsible actions. Methodological diversification is also strongly recommended, particularly through qualitative, mixed-methods, and longitudinal designs, to generate deeper insights into learning processes, classroom implementation, and contextual influences that may not be adequately captured through questionnaire-based measures alone. In addition, greater involvement of inservice teachers, along with more systematic examination of experiential, place-based, and technology-enhanced learning resources, is essential for understanding how environmental literacy is developed and sustained over time, while accounting for constraints related to measurement approaches, contextual variation, and instructional conditions.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support provided by the PMDSU *(Pendidikan Magister Menuju Doktor untuk Sarjana Unggul)* scholarship program from the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia

AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ahmad Saputra	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Insih Wilujeng		✓		✓	✓	✓	✓	✓	✓	✓		✓		
Antuni Wiyarsi	✓			✓	✓		✓			✓		✓		

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data supporting the findings of this study are derived from publicly available sources. The extracted and synthesized datasets generated during the current review are available from the corresponding author upon reasonable request.

REFERENCES

Al-Barakat, A., AlAli, R., Alotaibi, S., Alrashood, J., Abdullatif, A., & Zaher, A. (2025). Science Education as a Pathway to Sustainable Awareness: Teachers' Perceptions on Fostering Understanding of Humans and the Environment: A Qualitative Study. *Sustainability (Switzerland)*, *17*(15), 1–19. https://doi.org/10.3390/su17157136

Alshehri, S. Z. (2024). Exploring students ' pro -environmental knowledge and behaviour perceptions : a mixed methods investigation. *Journal of Turkish Science Education*, *21*(3), 389–409. https://doi.org/10.36681/tused.2024.021

Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). Environmental education outcomes for conservation : A systematic review. *Biological Conservation*, *241*(August 2019), 108224. https://doi.org/10.1016/j.biocon.2019.108224

Arici, F. (2024). Investigating the Effectiveness of Augmented Reality Technology in Science Education in Terms of Environmental Literacy, Self-Regulation, and Motivation to Learn Science. *International Journal of Human–Computer Interaction*, *40*(24), 8476–8496. https://doi.org/10.1080/10447318.2024.2310921

Arisma, N., Septiani, R., Husna, A. R., Rifa, A., & Erika, F. (2024). Literature Review Penerapan Pembelajaran Sains Berbasis Lingkungan untuk Meningkatkan Sikap Peduli Lingkungan Siswa. *INKUIRI: Jurnal Pendidikan IPA*, *13*(1), 53–62. https://doi.org/10.20961/inkuiri.v13i1.81474

Azrai, E. P., Heryanti, E., Ramadhani, V., Ilyas, M., Education, B., Science, N., & Jakarta, U. N. (2024). Enhancing students' pro-environmental behavior through project-based learning. *Biosfer : Jurnal Pendidikan Biologi*, *17*(2), 317–325. https://doi.org/10.21009/biosferjpb.28352

Ballard, H. L., Lindell, A. J., Jadallah, C. C., Ballard, H. L., Lindell, A. J., & Jadallah, C. C. (2024). Environmental education outcomes of community and citizen science : a systematic review of empirical research. *Environmental Education Research*, *30*(6), 1007–1040. https://doi.org/10.1080/13504622.2024.2348702

Bissinger, K., & Bogner, F. X. (2018). Environmental literacy in practice: education on tropical rainforests and climate change. *Environment, Development and Sustainability*, *20*, 2079–2094. https://doi.org/10.1007/s10668-017-9978-9

Bloom, M., & Fuentes, S. Q. (2019). Experiential Learning for Enhancing Environmental Literacy Regarding Energy : A Professional Development Program for Inservice Science Teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(6), 1–17. https://doi.org/10.29333/ejmste/103571

Candra, M. (2025). Belajar IPA Dari Alam : Strategi Observasi Lingkungan Untuk Menumbuhkan Kepedulian Siswa. *Intelektual: Jurnal Ilmiah Multidisiplin Mahasiswa dan Akademik*, *1*(2), 60–70. https://doi.org/10.64690/intelektual.v1i2.146

Carmi, N., & Alkaher, I. (2019). Risk Literacy and Environmental Education : Does Exposure to Academic Environmental Education Make a Di ff erence in How Students Perceive Ecological Risks and Evaluate Their Risk Severity ? *Sustainability (Switzerland)*, *11*(22), 1–19. https://doi.org/10.3390/su11226350

Chen, C. W. K., Chen, C., & Shieh, C. (2020). A Study on Correlations between Computer-Aided Instructions Integrated Environmental Education and Students ' Learning Outcome and Environmental Literacy. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(6), 1–7. https://doi.org/10.29333/ejmste/8229

Christiansen, X. L. C. (2020). Environmental literacy: raising awareness through Chinese primary education textbooks. *Language, Culture and Curriculum*, *34*(2), 147–162. https://doi.org/10.1080/07908318.2020.1797078

Cincera, J., Kroufek, R., & Bogner, F. X. (2023). The perceived effect of environmental and sustainability education on environmental literacy of Czech teenagers. *Environmental Education Research*, *29*(9), 1276–1293. https://doi.org/10.1080/13504622.2022.2107618

Dada, D. O., Eames, C., & Calder, N. (2017). Impact of Environmental Education on Beginning Preservice Teachers' Environmental Literacy. *Australian Journal of Environmental Education*, *33*(3), 201–222. https://doi.org/10.1017/aee.2017.27

Darfin, S. A., & Kholifatun, U. N. (2025). Science Literacy and Climate Change Issues in Elementary School Science Learning as a Green Education Effort. *Journal of Humanities, Social Sciences, And Education (JHUSE)*, *1*(2), 55–68. https://doi.org/10.64690/jhuse.v1i2.34

Frensley, B. T., Stern, M. J., Powell, R. B., & Sorice, M. G. (2022). Investigating the relationships among students basic psychological needs, engagement, and environmental literacy at a residential environmental education center. *The Journal of Environmental Education*, *53*(4), 186–198. https://doi.org/10.1080/00958964.2022.2081654

Gök, G., & Boncukçu, G. (2023). The Effect of Problem-Based Learning on Middle School Students ' Environmental Literacy and Problem-Solving Skills. *Journal of Science Learning*, *6*(4), 414–423. https://doi.org/10.17509/jsl.v6i4.62781

Guerrero, G., & Sjöström, J. (2025). Studies in Science Education Critical scientific and environmental literacies : a systematic and critical review. *Studies in Science Education*, *61*(1), 41–88. https://doi.org/10.1080/03057267.2024.2344988

Hamilton, E., & Polk, L. M. (2023). The impact of place-based education on middle school students' environmental literacy and stewardship. *Cogent Education*, *10*(1), 1–30. https://doi.org/10.1080/2331186X.2022.2163789

Herlanti, Y., Nobira, S., Kuboki, Y., & Qumilaila, Q. (2025). Online lesson study design: integrating environmental issues with science learning to enhance students' environmental literacy. *International Journal for Lesson and Learning Studies*, *14*(1), 27–40. https://doi.org/10.1108/IJLLS-08-2024-0169

Hohenhaus, M., Boddy, J., Rutherford, S., Roiko, A., & Hennessey, N. (2023). Engaging Young People in Climate Change Action : A Scoping Review of Sustainability Programs. *Sustainability*, *15*(5), 1–20. https://doi.org/10.3390/su15054259

Hudha, M. N., Hamidah, I., & Permanasari, A. (2023). Trends of environmental literacy research: A systematic review of the literature. *AIP Conference Proceedings*. https://doi.org/10.1063/5.0113171

Kaya, V. H., & Elster, D. (2019). A critical consideration of environmental literacy: Concepts, contexts, and competencies. *Sustainability (Switzerland)*, *11*(6), 1–20. https://doi.org/10.3390/su11061581

Khoirunnisa, D., Yusal, Y., & Wulandari, R. W. (2023). Literasi Lingkungan Siswa SMP: Pengetahuan Ekologi, Keterampilan Kognitif, Sikap Peduli Lingkungan, dan Perilaku Tanggung Jawab. *Jurnal Guru Membangun*, *42*(2), 53–58.

https://doi.org/10.26418/gm.v42i2.72232

Klopčič, M., & Torkar, G. (2025). Emerging themes of empirical research into outdoor science teaching : A systematic literature review. *Journal of Outdoor and Environmental Education*, 1–23. https://doi.org/10.1007/s42322-025-00215-6

Kocak, E., & Celik, A. Y. (2023). Pre-service Teachers ' Environmental Literacy : The Role of STEM-Based Environmental Education with Microcontrollers Edanur Kocak Celebi Uluyol. *Participatory Educational Research (PER)*, *10*(5), 233–247. https://doi.org/10.17275/per.23.84.10.5

Komang, N., Dewi, S., Parmiti, D. P., & Werang, B. R. (2024). Science Literacy Aspects of Environmental Awareness of Fifth- Grade Students Influenced by The Creative Problem-Solving (CPS) Learning Model. *Jurnal Imiah Pendidikan dan Pembelajaran*, *8*(2), 367–378. https://doi.org/10.23887/jipp.v8i2.71504

Kramar, U., & Knez, M. (2025). Gamified Learning for Sustainability : An Innovative Approach to Enhance Hydrogen Literacy and Environmental Awareness Through Simulation-Based Education. *Sustainability*, *17*(6), 1–25. https://doi.org/doi.org/10.3390/su17062694

Kuswandi, N. F., Meriza, N., Maulina, D., & Utami, G. N. (2025). Enhancing Students ' Scientific Literacy on Environmental Pollution through Problem-Based Learning and Interactive Digital Modules. *TADRIS: Jurnal Keguruan dan Ilmu Tarbiyah*, *10*(1), 39–49. https://doi.org/10.24042/tadris.v10i1.21343

Liu, J., & Green, R. J. (2024). Children's pro-environmental behaviour: A systematic review of the literature. *Resources, Conservation and Recycling*, *205*(March), 107524. https://doi.org/10.1016/j.resconrec.2024.107524

Liu, L., & Tobias, G. R. (2024). The impact of environmental literacy on residents' green consumption : Experimental evidence from China. *Cleaner and Responsible Consumption*, *12*(February 2023), 100165. https://doi.org/10.1016/j.clrc.2023.100165

Liu, Q., Cheng, Z., & Chen, M. (2019). Effects of environmental education on environmental ethics and literacy based on virtual reality technology. *The Electronic Library*, *37*(5), 860–877. https://doi.org/10.1108/EL-12-2018-0250

Martha, E., Zainita, U. H., Rilfi, N. A., & Aminudin, S. A. (2025). Adolescents ' Knowledge on Climate Change : A Nationwide Study in Indonesia. *International Journal of Environmental Research and Public Health*, *22*(4), 1–16. https://doi.org/10.3390/ijerph22040571

Maurer, M., & Bogner, F. X. (2020). Modelling environmental literacy with environmental knowledge, values and (reported) behaviour. *Studies in Educational Evaluation*, *65*. https://doi.org/10.1016/j.stueduc.2020.100863

McBride, B. B., Brewer, C. A., Berkowitz, A. R., & Borrie, W. T. (2013). Environmental literacy , ecological literacy , ecoliteracy : What do we mean and how did we get here ? *Ecosphere*, *4*(5), 1–20. https://doi.org/10.1890/ES13-00075.1

Milandi, S. D., Akbar, H., & Maeva, L. A. C. (2025). Peran pemuda sebagai generasi peduli lingkungan dalam meningkatkan kesadaran konservasi melalui pendidikan lingkungan hidup. *Jurnal Sosial dan Pengabdian Masyarakat Volume*, *3*(1), 1–9. https://doi.org/10.59966/semar.v3i1.900

Miterianifa, M., & Mawarni, M. F. (2024). Application of Environmental Literacy Learning Model in Improving Environmental Knowledge and Awareness. *Jurnal Sains dan Edukasi Sains*, *7*(1), 68–73. https://doi.org/10.24246/juses.v7i1p68-73

Nacaroğlu, O., & Göktaş, O. (2025). The Effect of Technology Supported Guided Inquiry Environmental Education on Preservice Science Teachers' Attitudes Towards Sustainable Environment, Environmental Education Self-Efficacy and Digital Literacy. *Journal of Science Education and Technology*, *34*, 298–313. https://doi.org/10.1007/s10956-024-10188-8

Novera, C. N., Ifti, M. H., Huynh, A. N. Q., Sadiq, I., & Azad, A. K. (2024). Research Synthesis in Pro-environmental Behaviour in Education: A Text Mining Approach. *Managing Global Transitions*, *22*(3), 231–251. https://doi.org/10.26493/1854-6935.22.231-251

Novian, T., & Sari, I. (2024). Pemetaan Literasi Lingkungan Siswa SMA dalam Pembelajaran Biologi Ditinjau dari Perbedaan Gender. *Jurnal Pendidikan dan Pembelajaran Sains Indonesia*, *7*(2), 87–98. https://doi.org/10.23887/jppsi.v7i2.78912

Nurfaizah, D. A., Uwais, M., & Qorni, A. (2025). Penelitian Literasi Sains dalam Pendidikan Sains (2004- 2024): Studi Bibliometrik tentang Perkembangan dan Tren. *Proceedings Series of Educational Studies*, 58–68.

Page, M. J., Mckenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-wilson, E., Mcdonald, S., … Moher, D. (2021). The PRISMA 2020 statement : an updated guideline for reporting systematic reviews Systematic reviews and Meta-Analyses. *Research Methods & Reporting*, *372*(71), 1–9. https://doi.org/10.1136/bmj.n71

Pan, C., & Hsu, S.-J. (2020). Effects of a One-day Environmental Education Program on Sixth-Graders ’ Environmental Literacy at a Nature Center in Eastern Taiwan. *Sustainability (Switzerland)*, *12*(12), 1–14. https://doi.org/10.3390/su12125043

Portus, R., Aarnio-linnanvuori, E., Dillon, B., Fahy, F., Gopinath, D., Mansikka-aho, A., Williams, S., Reilly, K., Mcewen, L., Portus, R., Aarnio-linnanvuori, E., Dillon, B., Gopinath, D., Mansikka-aho, A., Williams, S., & Reilly, K. (2024). Exploring the environmental value action gap in education research : a semi-systematic literature review. *Environmental Education Research*, *30*(6), 833–863. https://doi.org/10.1080/13504622.2024.2314060

Rasis, R., & Kuswanto, H. (2023). The Effect of Environmental Education Open Inquiry Learning Kits on the Environmental Literacy of Pre-service Biology Teachers. *Journal of Teacher Education for Sustainability*, *25*(1), 40–63. https://doi.org/10.2478/jtes-2023-0004

Rofiqi, A. (2024). Environmental literacy research trends in education : A systematic literature review. *Assimilation: Indonesian Journal of Biology Education*, *7*(2), 81–94. https://doi.org/10.17509/aijbe.v7i2.69055

Rubini, B., Pursitasari, I. D., Suriansyah, M. I., Ramadhanti, G. N., Rachman, I., Program, S. E., Pakuan, U., Program, C. S., & Pakuan, U. (2023). Improving Students ’ Eco-literacy through the Development of Electronic Interactive Teaching Materials on Climate Change. *Jurnal Penelitian dan Pembelajaran IPA*, *9*(2), 288–308. https://doi.org/10.30870/jppi.v9i2.20051

Sanchez, S. J., Piedrahita Guzman, Y., Sosa-Molano, J., Robertson, D., Ahern, S., & Garza, T. (2025). Systematic literature review: a typology of Sustainability Literacy and Environmental Literacy. *Frontiers in Education*, *10*, 1–11. https://doi.org/10.3389/feduc.2025.1490791

Saribas, D., Kucuk, Z. D., & Ertepinar, H. (2016). Implementation of an environmental education course to improve pre-service elementary teachers’ environmental literacy and self-efficacy beliefs. *International Research in Geographical and Environmental Education*, *26*(4), 311–362. https://doi.org/10.1080/10382046.2016.1262512

Siswa, L., Pada, S. M. P., & Ekosistem, M. (2025). Efektivitas Model Peembelajaran Berbasis Proyek Terhadap Kemampuan Kolaborasi dan Literasi Lingkungan Siswa SMP pada Materi Ekosistem. *Jurnal Pendidikan Biologi dan Sains (BIOEDUSAINS)*, *8*(5), 777–797. https://doi.org/10.31539/z0tf9e98

Sorensen, A. E., Jordan, R. C., Shwom, R., May, D. E., Isenhour, C., McCright, A. M., & Robinson, J. M. (2016). Model-based reasoning to foster environmental and socio-scientific literacy in higher education. *Journal of Environmental Studies and Sciences*, *6*, 287–294. https://doi.org/10.1007/s13412-015-0352-7

Svensson, T., Wilk, J., & Aman, K. G. (2022). Information literacy skills and learning gaps–Students' experiences and teachers' perceptions in interdisciplinary environmental science. *The Journal of Academic Librarianship*, *48*(1). https://doi.org/10.1016/j.acalib.2021.102465

Trina, N. A., Monsur, M., Cosco, N., Shine, S., Loon, L., & Mastergeorge, A. (2024). education sciences How Do Nature-Based Outdoor Learning Environments Affect Preschoolers ' STEAM Concept Formation ? A Scoping Review. *Education Sciences*, *14*, 1–21. https://doi.org/10.3390/ educsci140606273

Vojíř, K., & Svobodová, S. (2024). Environmental literacy curriculum: an analysis of science textbooks for lower secondary education. *Journal of Biological Education*, *59*(5), 799–817. https://doi.org/10.1080/00219266.2024.2386275

Xiong, Z., Song, Y., & Zhu, R. (2025). Pedagogical Strategies for Teaching Environmental Literacy in Secondary School Education : A Systematic Review. *Sustainability*, *17*(20), 1–23. https://doi.org/10.3390/ su17209104

Yang, X., Chen, S., Liu, T., Luo, J., & Tang, Y. (2025). Practice Primacy : Revisiting the Knowledge – Action Gap in Pro-Environmental Behavior with eXplainable AI. *Sustainability (Switzerland)*, *1*, 1–30. https://doi.org/10.3390/ su17219916

Yilmaz, S., Vural, H., & Yilmaz, H. (2023). Effects of botanical gardens on student environmental perception. *Ecological Informatics*, *73*. https://doi.org/10.1016/j.ecoinf.2022.101942

Yuliastrin, A., Vebrianto, R., Ilhami, A., Lilandariati, F., & Berlian, M. (2023). Hubungan Literasi Lingkungan dan Kemampuan Berpikir Kritis pada Materi Pencemaran Lingkungan. *Jurnal basicedu*, *7*(6), 4226–4233. https://doi.org/10.31004/basicedu.v7i6.5204

Zhang, X., & Jung, W. (2025). Systematic Review of Environmental Education Teaching Practices in Schools : Trends and Gaps (2015–2024). *Sustainability*, 1–18. https://doi.org/10.3390/ su17198561