

Trend research and future directions of environmental literacy education in elementary school: A systematic literature review



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Abstract Environmental literacy is essential for addressing today's ecological challenges and ensuring a sustainable future. Recognizing its critical importance, fostering environmental literacy must commence early, particularly within elementary and early childhood education. This study examines environmental education (EE) trends within science classrooms and their impact on students' environmental literacy development. A systematic literature review (SLR) was conducted by screening 3,977 articles indexed in the Scopus and Web of Science databases, resulting in 28 studies selected through stringent inclusion and exclusion criteria based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A qualitative content analysis was then performed to synthesize and categorize the findings. The review indicates that various EE approaches, including digital learning activities, outdoor experiential education, and collaborative projects, effectively nurture students' environmental literacy. The findings underscore the necessity of cultivating cognitive knowledge, critical thinking skills, emotional engagement, and a robust sense of environmental stewardship among young learners. Developing these competencies is pivotal for shaping future citizens capable of driving positive ecological and societal change. Furthermore, integrating real-world environmental challenges into EE curricula significantly enhances students' engagement, contextualizes abstract scientific concepts, and strengthens problem-solving abilities. These insights highlight the urgency of designing experiential, contextually grounded, and action-oriented educational strategies to maximize the development of environmental literacy from an early age.

Keywords: eco-literacy, environmental education, environmental literacy, sustainability, SLR

1. Introduction

Environmental problems today are increasing and becoming more alarming. Climate change, pollution, and deforestation are caused by human activity, threatening life on Earth. Environmental education plays a pivotal role in addressing these challenges by fostering awareness and responsibility among individuals. The long-term impact of environmental education ensures that students develop environmental literacy, a critical skill to cultivate from a young age (Misawa, 2022).

Environmental literacy refers to the capacity to understand the natural world, recognize environmental issues, and take appropriate actions to mitigate their impact. Developing these abilities early through formal education, particularly in elementary schools, can nurture a lifelong commitment to environmental care (Curd-Christian, 2020). This process involves the curriculum and teaching models, assessment tools, and teaching strategies that focus on environmental learning (Solheri et al., 2022). Hands-on, interdisciplinary activities help students understand environmental concepts better and become better agents of the planet. Real-world environmental issues in the curriculum can make learning relevant and inspire students to act.

Designing elementary school education to foster environmental literacy requires an interdisciplinary approach, incorporating models that link ecological awareness with real-world activities. A well-structured curriculum, teaching methods that engage students practically, and appropriate assessment models are crucial to developing environmental consciousness in students. Integrating environmental education into the curriculum helps schools create environmentally conscious individuals who can positively impact society (Arga & Rahayu, 2019). This comprehensive approach benefits the planet and equips students with the knowledge and skills needed to create a more sustainable future for all. In addition, by emphasizing the importance of environmental stewardship, schools can empower students to become advocates for change in their communities and beyond. Ultimately, this integrated approach to education helps students develop a deep understanding of the interconnectedness between humans and the environment. This holistic education model encourages students to think



critically about their impact on the environment and inspires them to take action towards a more sustainable future (García-González et al., 2020).

Schools can mold the next generation of leaders by fostering responsibility and environmental awareness, emphasizing sustainability in their lives (Simsekli, 2015). It can lead to a ripple effect as students share their knowledge and passion with others, creating a more environmentally conscious society. Although environmental literacy is widely acknowledged as crucial for sustainable development, research predominantly targets older students or adults, with limited focus on elementary-age learners (Ardoin et al., 2020). Given that environmental attitudes and behaviors are significantly shaped during early childhood (Chawla, 1999), the lack of age-specific pedagogical models leaves a critical gap in nurturing long-term ecological responsibility (Asikin et al., 2025). Furthermore, current interventions often lack cultural contextualization and fail to account for developmental differences in cognitive and emotional readiness among young children.

The impact of schools on promoting sustainability goes beyond the classroom, influencing communities and industries to adopt more eco-friendly practices. By instilling values of conservation and stewardship early on, schools play a crucial role in shaping a greener and more sustainable world for years to come. Schools that include sustainability in their curriculum teach students responsibility and awareness early on. It benefits the environment and prepares students to tackle urgent global issues like climate change and resource depletion.

The concept of environmental literacy encompasses a wide range of elements, including knowledge of environmental concepts and issues, cognitive abilities, affective dispositions, and the confidence to apply this knowledge effectively in various environmental contexts (Arnett et al., 2020; Frensley et al., 2022). Research has emphasized the importance of cultivating environmental literacy through education, as it closely correlates with individuals' overall well-being and propensity to engage in pro-environmental behaviors (Kerret et al., 2020).

One key factor influencing environmental literacy is the integration of sustainability-oriented pedagogy in the curriculum (Craig & Allen, 2015). Studies have shown that the implementation of teaching approaches that prioritize environmental sustainability can significantly enhance students' environmental literacy, fostering their understanding of ecological systems, environmental issues, and the interconnectedness of human-environment interactions (Arnett et al., 2020; Febriasari & Supriatna, 2017; Kuswendi & Arga, 2020; Liu et al., 2015; Shakirova et al., 2024).

Many educational institutions have attempted to include environmental literacy, yet several challenges hinder its effective implementation. While teachers often possess strong ecological knowledge, they struggle with access to structured lesson plans, specialized environmental training, and resources such as children's literature on environmental topics (McClaren, 2019). A study by Stevenson et al. (2014) identified the most significant barriers as the lack of time and instructional materials, suggesting that the issue lies less in teachers' knowledge and more in the availability of practical tools and teaching support. These constraints highlight the need for well-organized curricular frameworks and accessible teaching strategies to empower educators in delivering environmental literacy effectively within their classrooms.

One persistent challenge is that environmental literacy is often confined to science instruction, restricting its interdisciplinary potential. Elementary school teachers find it natural to teach environmental topics within science lessons. However, they encounter difficulties integrating these topics across other essential subjects such as social studies, language arts, and mathematics (Costa et al., 2022). This compartmentalization limits the opportunities for students to see environmental issues from multiple perspectives. Teachers, therefore, need strategies that embed environmental literacy into frequently tested areas like reading and math without overloading their instructional schedules (Ardoin et al., 2023). Bridging this gap requires cross-disciplinary models considering environmental topics relevant to various academic subjects and real-life contexts.

Research trends indicate that environmental education is evolving toward a sustainability-focused model, encouraging students to act as change agents within their communities (Ardoin & Bowers, 2020). Many educational systems face difficulties fully integrating environmental literacy, especially in elementary grades. As Ardoin & Bowers (2020) observe, most research continues to focus on formal classroom settings, leaving critical questions unanswered about how cultural and socio-economic factors shape environmental learning. Addressing these gaps requires further studies that explore innovative, culturally responsive approaches to environmental literacy.

To effectively encourage environmental literacy, elementary education must adopt interdisciplinary curricula, learning models, and effective assessment instruments that connect ecological awareness with real-world activities. A holistic approach, incorporating science, technology, engineering, arts, and mathematics (STEAM), can bridge disciplinary boundaries while engaging students practically (Chamidah et al., 2024; Yulianti, et al., 2024; Situmorang, et al., 2024). Learning models must extend beyond the classroom to include family involvement and community-based projects, ensuring that environmental literacy promotes knowledge acquisition and meaningful action. The main goal is to develop students into environmentally literate and socially responsible individuals, equipping them with the tools and values to engage with environmental challenges actively and sustainably throughout their lives (Hamilton & Marckini-Polk, 2023).

A review of recent research on environmental literacy indicates several advances and gaps. Studies by Fakhriyah et al. (2024) emphasize the role of pre-service teacher education in promoting environmental knowledge. However, research specifically targeting elementary school students' environmental literacy remains limited. Much of the focus is on pre-service

teachers, with little attention given to young learners' distinct challenges. There is also a lack of studies that explore how environmental literacy evolves in children across different age groups and socio-cultural settings. Furthermore, the literature suggests an absence of practical frameworks to evaluate students' long-term environmental behavior and responsibility.

The primary research gap in the literature lies in the limited focus on environmental literacy development among elementary school students. While most studies emphasize the role of teachers and pre-service education, little attention is given to how environmental literacy can be effectively integrated into elementary school curricula. Specifically, several key areas require further exploration: 1) Curriculum Development remains underdeveloped, with few studies offering detailed frameworks that align with students' cognitive, emotional, and behavioral needs. There is also a lack of research identifying age-appropriate activities that can foster environmental responsibility from an early stage; 2) Assessment and Evaluation Tools are similarly insufficient. Existing methods focus primarily on immediate learning outcomes, neglecting the evaluation of long-term behavioral change. Practical tools are needed to assess how well environmental literacy objectives are achieved beyond knowledge acquisition; Moreover, 3) Interdisciplinary Learning Models that integrate environmental literacy across various subjects, such as science, mathematics, and social studies, are missing from the literature. These models are crucial for fostering a comprehensive understanding of environmental issues in young learners.

This paper attempts to fill the identified research gap by conducting a systematic literature review of environmental literacy education for elementary school students. Specifically, the objectives are:

1. How is the trend of environmental literacy research in elementary education?
2. How are the learning and assessment methods used to foster environmental literacy?
3. What are the issues and future research related to environmental literacy in elementary school?

2. Materials and Methods

Using PRISMA criteria, this study was conducted as a systematic literature analysis (Ardoin et al., 2023). A comprehensive, accurate, and transparent findings report was obtained by utilizing PRISMA, which is based on a checklist with suggestions for every research item. Through an analysis of the body of academic research already conducted, this methodological approach allows for a thorough grasp of the condition of the field today (Husamah et al., 2022). The following subsections detail the databases used, search parameters, inclusion/exclusion terms, validity, dependability, and other factors.

2.1. Sources of data and search methods

The Scopus databases were used to conduct a thorough literature search. These databases were chosen because they are the most well-established and encompass all of the fundamental understanding in the scientific and educational domains. In this way, a few chosen databases satisfy the broad coverage requirement and constitute the ideal database combination. Because it focuses on education-related themes, 'environmental AND literacy' OR ecological AND literacy OR ecology AND literacy OR eco literacy' were the search terms and phrases used. All papers with the search parameters appearing in the title, abstract, or keywords were found using the search. We focused on information retrieval in the publications and conference proceedings published between January 2014 and October 2024, considering both English and Portuguese, due to the dynamic nature of SSI and technical advancements.

2.2. Inclusion and exclusion criteria

Studies that satisfy the following inclusion criteria were taken into consideration based on the search strategy: (i) studies that explain how an educational learning approach affected environmental literacy/eco literacy; (ii) open-access articles that are published in SCOPUS-indexed journals. The exclusion criteria covered the following: (i) conference paper; (ii) the abstract does not contain environmental education or literacy; (iii) the article was a review or in Press; and (iv) the article's samples were positioned at a different educational level.

2.3. Data analysis

Qualitative content analysis was used to assess the data (Longo, 2020; Miles & Huberman, 1994; Taylor et al., 2013). Reading the articles' abstracts was done to select sentences containing pertinent terms for the study. The analytical units were then divided into subcategories, and finally, key categories were connected to classify the subcategories.

The validity and reliability of the analysis process were confirmed using the interrater reliability process, where another researcher repeated the categorizing process.

In accordance with the PRISMA guidelines, a systematic identification and screening process was conducted to select relevant studies. Initially, a total of 3,977 records were identified through database searches. After title and abstract screening, 3,881 records were excluded as they did not focus on pre-primary or elementary school settings. The remaining 96 articles underwent full-text review to assess their eligibility. Of these, 72 were excluded due to reasons such as being conference papers or lacking educational relevance. As a result, 24 studies met all inclusion criteria and were included in the final qualitative synthesis.

3. Results and Discussion

3.1. The summary of environmental literacy research articles in elementary education

To understand the scientific world’s interest in researching the implementation of environmental literacy in elementary schools, three key distributions were analyzed, covering geographic, trend research by year, and journal source characteristics. Table 1 shows the geographical origins of the studies, revealing that most are from the United States, with contributions from other regions, including Asia, Europe, and Latin America. This spread highlights the global importance of environmental literacy, offering insights from varied cultural and educational contexts and enhancing the applicability of findings across regions. The researchers conducted the study in ten countries, with the United States producing six articles, followed by Indonesia and Brazil (3 articles), and then other countries such as Portugal, China, and Iran (2 articles and 1 article, respectively). Out of all the continents in the world, none of the works are from Australia or Africa.

Table 1 Country of origin of the articles.

No.	Country	Continent	N
1	United states	North America	6
2	Indonesia	Asia	3
3	Brazil	South America	3
4	Portugal	Europe	2
5	China	Asia	2
6	Canada	North America	2
7	United Kingdom	Europe	2
8	Iran	Asia	1
9	Israel	Asia	1
10	Costa Rica	North America	1

An upward trend in publications, particularly from 2021 to 2024 (Table 2), suggests a growing research interest in environmental literacy in education, reflecting heightened awareness of global environmental challenges and the role of education in addressing them. A literature review by Ardoin et al. (2020) suggested that the surge of research interest post-2020 is influenced by the rising awareness of the world's environmental deterioration and the need for global-scale restoration action. One of those actions is imparting the importance of environmental literacy in young minds. Moreover, it has not been remiss that although 2024 dominated the number of publications, there is a relatively steady amount of research dissemination from 2014 to 2023 (as shown in Table 2).

Table 2 Publication year distribution of the articles.

No	Year	n
1	2014	1
2	2015	3
3	2018	4
4	2019	2
5	2021	2
6	2022	2
7	2023	5
8	2024	6

The selected articles are published across diverse journals, with *Frontiers in Marine Science* and *Environmental Education Research* leading the list, reflecting the growing interdisciplinary nature of environmental literacy research (see Table 3). This distribution across fields such as marine science, sustainability, educational technology, and social justice indicates that environmental literacy is increasingly recognized as a critical competency for addressing global challenges (Ardoin et al., 2020; Costa et al., 2022). The spread across international and national journals suggests a global scholarly commitment, with contributions emphasizing environmental knowledge and behavioral and civic engagement dimensions (Frensley et al., 2022; Hamilton & Marckini-Polk, 2023). Such diversity enhances the robustness of the systematic review and supports the identification of broad trends and future research needs in promoting environmental stewardship among students. Table 3 below shows the Journal names of the article.



Table 3 Publication names of the articles.

No	Source title	n
1	Frontiers in Marine Science	3
2	Environmental Education Research	2
3	Sustainability (Switzerland)	2
4	Frontiers in Education	1
5	Physical Education and Sport Pedagogy	1
6	Journal of Computer Assisted Learning	1
7	Education and Information Technologies	1
8	Journal of Education and Learning	1
9	Ocean and Coastal Management	1
10	Renewable Energy	1
11	Energy Research and Social Science	1
12	International Journal of Environmental and Science Education	1
13	Chemical Engineering Transactions	1
14	Education, Citizenship, and Social Justice	1
15	Acta Scientiae	1
16	Jurnal Pendidikan IPA Indonesia	1
17	Applied Environmental Education and Communication	1
18	Revista Brasileira de Geografia Fisica	1
19	International Research in Geographical and Environmental Education	1
20	Environment, Development and Sustainability	1
21	Utilities Policy	1
22	International Review of Education	1
23	Edelweiss Applied Science and Technology	1

3.2. Research methods and data collection instruments

Methodological diversity demonstrates the field's commitment to comprehensively assessing environmental literacy through various lenses (see Table 4). Studies utilized qualitative, quantitative, and mixed-methods designs, employing instruments such as interviews, focus groups, open-ended questionnaires, observation sheets, and structured pre- and post-tests (Aurélio et al., 2021; Fisher-Maltese et al., 2018; Wang, 2014). This plurality of methodologies enabled exploring cognitive, affective, and behavioral aspects of environmental literacy, capturing the complexity of students' environmental understanding and engagement (Gal, 2024a; Lovren & Jablanovic, 2023). Notably, the adoption of innovative tools—such as the Web-based Interactive Argumentation System (WIAS) and specialized Environmental Literacy Scales—reflects an ongoing effort to enhance measurement precision and educational relevance (Erdogan, 2015b; Shakirova et al., 2024; Wang, 2014).

Furthermore, the variation in data collection strategies highlights researchers' sensitivity to contextual factors influencing student outcomes. Reflective instruments, including journals and narrative responses, provided nuanced insights into students' emotional and experiential connections with environmental issues (Gal, 2024b; Wallace, 2019). Meanwhile, standardized assessments and structured surveys offered broader generalizability and comparability across settings (Craig & Allen, 2015; Merritt et al., 2024). This integrated methodological framework bolsters the validity of findings and illustrates the interdisciplinary maturation of environmental literacy research, promoting more sophisticated and context-responsive educational interventions.

In elementary education, fostering environmental literacy through varied pedagogical models, for example, storytelling, digital platforms, experiential learning, and citizen science, has proven effective in cultivating students' foundational knowledge, emotional connection, and proactive behaviors toward environmental stewardship. Integrating environmental themes into standard curricula enhances students' cognitive grasp of complex ecological issues and nurtures the critical thinking and motivational capacities necessary for sustainable action. A truly transformative approach to environmental education demands a holistic framework that simultaneously addresses cognitive, affective, and behavioral domains, ensuring the internalization of sustainable values from an early age. Nonetheless, significant challenges remain, notably the insufficient interdisciplinary integration of environmental content and the frequent neglect of the affective dimension, constraining the full potential of eco-literacy development within existing educational systems. Table 4 shows the research methods, data collection, and instrument used.

Table 4 Research methods, data collection, and instruments used.

No.	Methods	Data Collection and Instrument	Authors
1	Qualitative	Interviews and literature review	(Ninsiana et al., 2024)
2		Teacher focus groups and weekly surveys	(Cole et al., 2024)
3		Open-question assessment	(Šedlbauer et al., 2024)
4		1. Focus group interviews 2. Open-ended questions and photographs 3. Children's garden journals and the researcher's journal	(Wallace, 2019)
5		1. Observational data from the Biodiversity4All platform and 2. materials produced collaboratively by students for the final exhibition.	(Boaventura et al., 2021)
6		Open-ended questionnaires (pre-activity) and (post-activity)	(Boesing & Lopes, 2023)
7		Interviews and questionnaires;	(Prasetyo et al., 2024)
8		Categorization based on a holistic framework that integrates cognitive, affective, and behavioral dimensions of learning outcomes in environmental education.	(Lovren & Jablanovic, 2023)
9		Two open-ended questions were aimed at gathering insights from the participants.	(Gal, 2024b)
10		Analyses of drawings, an open-ended questionnaire, and focus group interviews.	(Gal, 2024a)
11		Data collection consisted of observations and field notes from 16 classroom systems lessons, professional development meetings, informal and formal interviews with teachers, and analysis of student work.	(Curwen et al., 2018)
12	Quantitative	Pre- and post-tests to assess the environmental literacy of the pupils on identified topics. Feedback from pupils, teachers, student-teachers, the Institute, and families was also considered to enhance the understanding of the project's impact.	(Andrada et al., 2018)
13		Inductive content analysis to evaluate student responses regarding energy problems and solutions. It involved coding 703 student responses, which were collected from the service-learning (SL) and control groups.	(Merritt et al., 2024)
14		The Environmental Literacy Scale (ELS) consists of four modules: Attitudes, Beliefs, Conservation Knowledge, and Responsible Environmental Behavior. Each module assesses aspects of environmental literacy, with satisfactory reliability indicated by Cronbach's alpha values ranging from 0.79 to 0.88.	(Shakirova et al., 2024)
15		The instruments included the Environmental Knowledge Test, Affective Disposition toward Environment Scale, Children's Responsible Environmental Behavior Questionnaire, and Scientific Process Skill for the Environment Test.	(Erdogan, 2015a)
16		The research employs two assessment tools: the Achievement Test for Environmental Issues (ATEI) and the Environmental Literacy Scale (ELS). The ATEI evaluates students' knowledge on environmental issues, while the ELS measures their environmental literacy across four dimensions: cognition, attitudes, skills, and behaviors.	(Wang, 2014)
17		Observation sheets, interviews, and questionnaires	(Syofyan & Rachmadtullah, 2019)
18		Pre-test and post-test assessments	(Amini, 2015)
19		semi-structured questionnaire on marine environmental topics and collection of biological samples during field classes at local beaches	(Costa et al., 2022)
20	Mixed Methods	Pre-test and post-test assessment, participant observation before and after, in gardening activities.	(Fisher-Maltese et al., 2018)
21		The original questions were designed to measure elementary students' attitudinal and cognitive dimensions regarding their energy efficiency behaviors.	(Craig & Allen, 2015)
22		Survey, observation	(Ribeiro, 2023)
23		Pre and post-instructional questionnaires, project	(Stefanelli-Silva et al., 2019)
24		Pretest-posttest and focus group sessions	(Aurélio et al., 2021)



3.3. Learning and assessment methods used to foster environmental literacy

The learning models used in recent studies include model-based learning, garden-based experiential learning, and citizen science activities (Table 5). These approaches vary widely in methodology but consistently aim to deepen students' understanding of environmental systems and cultivate eco-conscious behaviors. Each model incorporates unique assessment strategies, such as pre- and post-tests, observational data, or reflective group discussions, to evaluate the effectiveness of these interventions in promoting environmental awareness and responsible behaviors.

The enhancement of environmental literacy necessitates a comprehensive and multifaceted strategy that seamlessly integrates various educational methodologies, promotes active community involvement, and capitalizes on the innovative potential of digital media technologies. Within this context, the affective domain of environmental education assumes an indispensable role, as it is instrumental in establishing a profound connection between cognitive knowledge and emotional engagement; this synergy is particularly effective in inspiring pro-environmental behaviors among younger populations, who are increasingly recognized as pivotal agents of change in our society (Paden, 2012). Empirical research, such as that conducted in Turkey, has convincingly demonstrated that the deliberate incorporation of environmental themes into standard educational curricula not only elevates students' literacy levels but also cultivates their reflective problem-solving capabilities, thereby underscoring the critical importance of embedding culturally relevant educational components within the learning process (Erdogan, 2015b). Moreover, the strategic employment of cutting-edge immersive technologies, coupled with innovative problem-solving frameworks, has been shown to enhance environmental literacy significantly; this is achieved by actively engaging students in experiential learning processes that promote critical thinking and informed discussions regarding pressing environmental issues (Arnett et al., 2020; Febriasari & Supriatna, 2017; Shakirova et al., 2024).

The significance of early childhood education cannot be overstated, as the introduction of eco-literacy principles through engaging storytelling, informative videos, and enriching field trips has the potential to foster a deep-seated respect for the natural world and a nuanced understanding of ecological principles that can last a lifetime (Liu et al., 2015). In addition, the effective utilization of digital media platforms, particularly widely accessible channels like YouTube, serves as a powerful tool for raising awareness and deepening understanding of environmental challenges among young children, thereby promoting a sense of empathy and encouraging active participation in community initiatives (Frensey et al., 2022).

Furthermore, fostering eco-literacy at the elementary education level is paramount for cultivating a sustainable community ethos that appreciates the intrinsic value of the environment, ultimately encouraging students to adopt innovative and responsible perspectives on the preservation of natural resources (McClaren, 2019). The preparedness of educators and the establishment of robust capacity-building programs in the realm of environmental education are equally vital, as the efficacy of instructional methods employed can have a profound impact on the enhancement of environmental literacy among students (Kinslow et al., 2019; Suhartini & Haerani, 2024). In summary, an integrative approach that synergistically merges educational reform initiatives, advanced digital technologies, and community-driven programs can substantially enhance environmental literacy, thereby equipping individuals with the essential competencies and insights to confront environmental challenges effectively. Table 5 shows the learning model and assessment used in research.

Table 5 Learning model and assessment/outcome in research.

No.	Authors	Learning Model in The Research	Assessment/Outcomes
1	(Cole et al., 2024)	Model-Based Learning (MBL) is a multi-phase process where students develop, use, evaluate, and revise their models.	Students' causal reasoning abilities remain equivalent across development, with changes reflecting the amount of domain-specific knowledge available to them.
2	(Wallace, 2019)	'Kitchen Garden' is an experiential learning model that integrates various academic disciplines, allowing children to connect their learning to real-world experiences in the garden.	Collaborative discussions and reflections among students are encouraged, facilitating the construction of shared knowledge and progressing towards Eco literacy.
3	(Boaventura et al., 2021)	An inquiry-based educational approach combined with citizen science activities to enhance Ocean Literacy among elementary school students.	The positive impact of these activities on students' understanding of climate change and their ability to identify marine species, as well as their collaborative and communication skills.
4	(Boesing & Lopes, 2023)	Blogs as a pedagogical strategy to enhance learning about household solid waste management.	Pre-activity and post-activity questionnaires to evaluate the effectiveness of the blogs as a learning tool.

5	(Prasetyo et al., 2024)	Digital ethno-pedagogical model framework, which is designed to assist teachers in planning and implementing science learning with a multimodal indigenous science approach in natural sciences for elementary schools	Integrating indigenous science into science learning, which includes content, processes, and products, is meaningful to students.
6	(Gal, 2024a)	'Hackathon' with an active and participatory learning model aimed at promoting environmental citizenship among fifth-grade students.	Enhancing the learning experience through diverse perspectives and expertise, to foster a sense of responsibility and ecological literacy among students
7	(Curwen et al., 2018)	Systems thinking pedagogy that integrates various subjects and encourages students to engage with real-world issues, such as drought.	Cultivate critical thinking skills and environmental awareness among young learners.
8	(Merritt et al., 2024)	The service-learning (SL) model that integrates environmental education, science, and social-emotional learning emphasizes three key principles: academic integrity, apprentice citizenship, and student ownership.	The model aims to foster environmental citizenship and promote pro-environmental behaviors among students.
9	(Shakirova et al., 2024)	Learning approach using augmented reality (AR) technology in a Natural Resource Ecology course.	The AR intervention positively impacted environmental literacy and motivation while reducing cognitive load, but no new learning model was proposed.
10	(Erdogan, 2015a)	Summer Environmental Education Program (SEEP)-grouping students into small teams to enhance responsibility and interdependence, combining theoretical sessions with practical, hands-on activities.	The program aimed to provide first-hand experiences and encourage active involvement in environmental topics, thereby enhancing environmental literacy among participants.
11	(Wang, 2014)	Web-based Interactive Argumentation System (WIAS) for the experiment group and the traditional argumentation instruction (TAI) group for the control group	Enhance students' ability to propose statements, collect evidence, and engage in discussions online, thereby improving their learning outcomes compared to traditional methods, or shortly, improvement in environmental literacy
12	(Syofyan & Rachmadtullah, 2019)	Problem-solving model	A significant increase in students' eco-literacy across these aspects from the first to the second cycle of the research.
13	(Amini, 2015)	Outdoor learning model consisting of three main components: learning plans, implementation of the PLO-based learning model, and evaluation of learning.	The development of caring attitudes and behaviors toward the school environment
14	(Boaventura et al., 2021)	Inquiry-based educational approach combined with citizen science activities	Improve students' knowledge and skills related to climate change and marine biodiversity.

15	(Fisher-Maltese et al., 2018)	Garden-based learning as an informal learning environment	Leveraging students' achievement and environmental awareness
16	(Craig & Allen, 2015)	Curriculum-based experiential learning approach	The increase in student knowledge about energy usage and the impact of the intervention on energy consumption at home and school.
17	(Ribeiro, 2023)	'Minha Hortinha' application as a tool for inclusive education in Environmental Sciences	Advancing learning through interactive content related to gardening, recycling, and sustainability.
18	(Stefanelli-Silva et al., 2019)	Informal education and hands-on activities	Promoting cognitive, socio-emotional, and behavioral learning objectives through interactive lessons and discussions about local marine environments and pollution
19	(Aur�lio et al., 2021)	Storytelling approach	Improvement of knowledge and understanding of environmental awareness

In undertaking a comprehensive and systematic literature review concerning the various pedagogical strategies and evaluative techniques that contribute significantly to the enhancement of environmental literacy, many distinct methodologies arise from the corpus of research articles that have been meticulously analyzed. As shown in Table 5, different educational methods, such as storytelling, digital media, hands-on learning, and citizen science, have effectively built eco-literacy among students. Despite these successes, challenges remain, especially in creating well-rounded learning experiences that connect knowledge with emotions to encourage lasting environmental values. One particularly efficacious approach that has emerged is the seamless incorporation of environmental education into the existing standard curricula. This practice has been empirically validated to enhance not only literacy rates but also the reflective problem-solving capabilities of students, as evidenced by a study conducted with 7th-grade pupils in Turkey (Erdogan, 2015b). In addition, implementing immersive technology courses has been empirically demonstrated to markedly augment environmental literacy, especially in terms of shaping students' attitudes and beliefs regarding ecological issues, as highlighted by research specifically involving high school attendees (Erdogan, 2015b). Moreover, it is imperative to recognize that the affective domain within the realm of environmental education, which encompasses emotional engagement and intrinsic motivation, plays a pivotal role in cultivating a genuine willingness among individuals to engage in proactive measures addressing pressing environmental challenges, thus indicating that educational strategies which effectively weave together emotional and motivational components tend to yield favorable outcomes (Cole et al., 2024).

Furthermore, it is essential to consider that early childhood education programs which utilize storytelling, audiovisual materials, and experiential field trips can significantly nurture eco-literacy by promoting a sense of empathy and fostering community involvement, while also endorsing the 5R framework, which stands for refuse, reduce, reuse, recycle, and rot (Amini, 2015; Aur lio et al., 2021; Gal, 2024a). Numerous evaluation techniques, like pre- and post-assessments, have been diligently utilized to assess the effectiveness of these educational strategies, with evident progress seen in students' awareness of vital domains such as waste management and water conservation methods (Fisher-Maltese et al., 2018). A relevant instance of this is the 'Grinning Built' program, which proved that including environmental education in the early years can lead to a noticeable rise in embracing eco-conscious behaviors in both schools and home environments (Andrada et al., 2018). Furthermore, eco-literacy, which fundamentally emphasizes the comprehension of ecological principles and the ramifications of human activities on the environment, can be effectively nurtured through university-level educational activities that actively promote ecological consciousness and sustainable community values [5]. These diverse pedagogical approaches collectively underscore the imperative nature of integrating environmental education across various educational strata, while simultaneously employing a broad spectrum of instructional and evaluative strategies to cultivate a deep-seated environmental literacy among learners effectively. These results point towards a complete perspective on education that breaks through old-fashioned barriers and encourages a heartfelt engagement with environmental care among individuals of various generations. In light of this, it is critical for both educators and policymakers to identify the synergy of these practices and to execute them as a unified strategy for fostering environmental education in present-day learning scenarios. Numerous evaluation techniques, like pre- and post-assessments, have been diligently utilized to assess the effectiveness of these educational strategies. A network visualization of keywords related to environmental education, literacy, and sustainability is shown in Figure 1.

This visualization demonstrates the multidisciplinary and interconnected nature of environmental education research. It highlights key research themes such as behavioral change, student-centered learning, cultural perspectives, sustainability, and outdoor learning. The presence of diverse clusters suggests an evolving field with a strong emphasis on literacy, inclusivity, and pedagogy. It also pointed out that the trend in environmental literacy research underscores the necessity of integrating knowledge and emotional engagement in educational strategies to cultivate environmentally literate citizens capable of contributing to sustainable development. This holistic approach prepares students to understand and mitigate environmental issues and encourages them to actively participate in creating a sustainable future. The trend in environmental literacy research reflects a growing emphasis on diverse learning models designed to engage students with environmental issues at an early age.

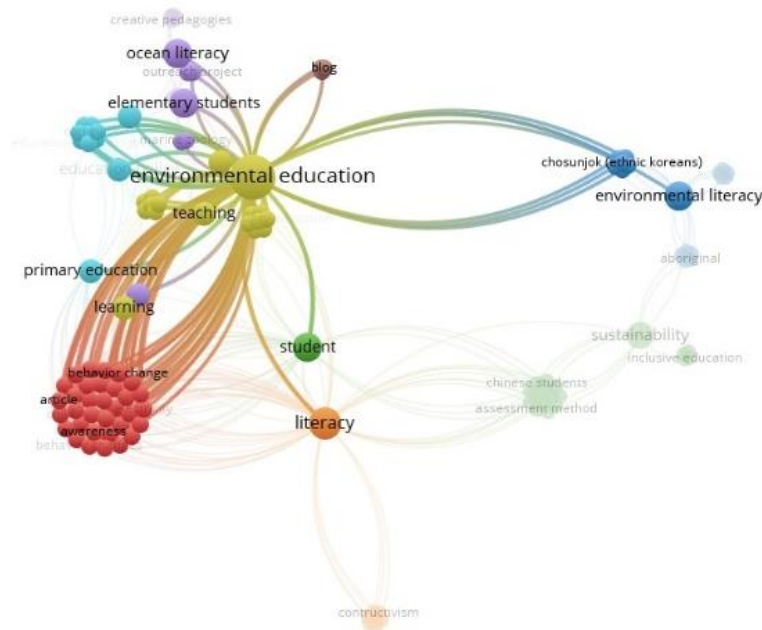


Figure 1 Network visualization of keywords connections in environmental literacy research.

3.4. The challenges and recommendations for future research of environmental literacy

Three main challenges should be addressed regarding environmental literacy (as in Table 6). First, there is a marked absence of longitudinal studies that examine the lasting impact of environmental literacy education from early childhood into adolescence. It calls for exploring the long-term effects of these educational interventions on students' attitudes and behaviors and investigating culturally adaptive methods that make environmental education accessible to diverse student populations. Additionally, assessment tools must evolve to measure immediate learning outcomes and the long-term impact on students' environmental attitudes and behaviors. Second, the field lacks integrative models that seamlessly embed environmental values across standard curricular domains such as mathematics. Future research should develop comprehensive educational frameworks that support a blend of disciplinary learning and hands-on activities, integrating eco-literacy across subjects like science, math, and social studies. Lastly, cultural specificity in designing environmental literacy programs remains an underexplored area.

In exploring the multifaceted issues and prospective trajectories for future research concerning environmental literacy, a plethora of pivotal themes distinctly surface from the existing body of literature. One particularly prominent issue pertains to the increasing detachment of children from vital natural resources, a phenomenon exacerbated by the relentless march of urbanization, which necessitates a concerted effort to incorporate environmental subjects into the standardized curricula, thereby enhancing not only environmental literacy but also equipping students with essential problem-solving competencies (Syofyan & Rachmadtullah, 2019). The affective domain of environmental education, encompassing the critical emotional and motivational dimensions of the learning process, plays a significant role in cultivating a proactive inclination to address environmental challenges; nevertheless, this vital aspect remains insufficiently examined regarding its enduring influence on individual behaviors over time (Frensley et al., 2022).

Furthermore, the influence of digital media platforms, particularly YouTube, in augmenting eco-literacy among the youth represents yet another crucial area warranting deeper scholarly inquiry, especially in terms of understanding how such media can be strategically utilized to nurture empathy and foster community involvement in the realm of environmental conservation (Hudha et al., 2023; Shakirova et al., 2024). In addition, the notion of ecoliteracy, which embodies a comprehensive understanding of ecological systems while simultaneously promoting the creation of sustainable communities, is undeniably essential; however, it frequently suffers from a lack of pragmatic application within educational environments, thereby indicating an urgent need for innovative strategies that seamlessly integrate these fundamental concepts into the fabric of everyday learning experiences (Sumirat et al., 2023). Future scientific endeavors should prioritize the formulation of holistic educational programs that not only disseminate knowledge but also actively cultivate emotional and ethical bonds to the environment, as evidenced by students' heightened engagement in ecological matters, including the dynamics of competition between indigenous and invasive species (Druker-Ibáñez & Cáceres-Jensen, 2022; Garcia & Cobar-Garcia, 2022).

The successful implementation of environmental education (EE) in elementary settings is often obstructed by limited access to structured curricular tools and resource constraints faced by teachers (Ardoin et al., 2020). Addressing these challenges demands a dual approach: first, through the development of adaptable, open-source educational modules aligned with environmental literacy goals; and second, by institutionalizing sustained professional support for teachers. Research by

Costa et al. (2022) underscores the effectiveness of hands-on, inquiry-based activities that do not require sophisticated infrastructure but significantly enhance students' environmental awareness. Modular programs incorporating local contexts, Low-cost materials and community-driven projects can enable widespread EE integration even within under-resourced schools.

Moreover, fostering multi-stakeholder collaboration is essential to bridge curricular and resource gaps. Partnerships between educational institutions, NGOs, governmental bodies, and local communities provide access to expertise, materials, and real-world engagement opportunities (Druker-Ibáñez & Cáceres-Jensen, 2022). Such collaborations have been shown to amplify both teacher efficacy and student engagement. For example, Aurélio et al. (2021) highlight how incorporating community storytelling and local ecological knowledge into classroom activities enriches EE delivery without imposing heavy financial burdens. Additionally, the emergence of digital learning platforms tailored for environmental themes offers scalable solutions; curated repositories of EE materials, interactive modules, and virtual field trips can democratize access for educators across diverse contexts. To realize equitable and effective environmental literacy outcomes, tackling resource and curriculum limitations requires systemic redesign, emphasizing low-cost innovation, networked teacher support, and strategic cross-sector partnerships.

Finally, recent studies predominantly converge on experiential learning models, such as outdoor education and project-based environmental initiatives. Technologies such as gamified apps and virtual simulations have also gained traction. However, adopting technology-enhanced learning remains uneven across geographical contexts, indicating a digital divide in environmental education implementation. There also exists an imperative for more rigorous investigations into the methodologies of teaching eco-literacy through dynamic and participatory frameworks, such as interactive games and immersive field trips, which are instrumental in instilling a profound appreciation for the environment alongside honing critical thinking abilities in learners (Ninsiana et al., 2024). Effectively addressing these pressing issues necessitates an interdisciplinary approach that amalgamates scientific inquiry, cultural understanding, and emotional education, thereby equipping students to confront the intricate environmental dilemmas that lie ahead. In summary, the prevailing literature indicates that although significant strides have been made in comprehending and advocating environmental literacy, a conspicuous chasm remains concerning translating this accumulated knowledge into impactful educational practices capable of engendering sustainable behavioral transformations.

Table 6 Key findings and future research in environmental literacy studies.

No	Authors	Findings	Future Research
1	(Ninsiana et al., 2024)	Eco-literacy through storytelling, digital media, and field trips in early education.	Games, digital media role, and community engagement
2	(Cole et al., 2024)	Improved socio-ecological understanding in green roof studies.	Integrate hydro-social knowledge, and adapt for low rainfall areas
3	(Šedlbauer et al., 2024)	Need for learner-centered methods in energy literacy.	Emphasize energy externalities, assess interventions
4	(Wallace, 2019)	Garden programs enhance eco-literacy and empathy.	Long-term impacts, educator roles, and emotional benefits
5	(Boaventura et al., 2021)	Ocean literacy and climate awareness through citizen science.	Additional ocean principles, climate adaptation
6	(Boesing & De Campos Lopes, 2023)	Blogs improve waste management understanding and digital literacy.	Long-term impacts, use of digital tech in environmental ed.
7	(Prasetyo et al., 2024)	Indigenous science in the curriculum enhances environmental care.	Develop multimodal indigenous learning tools
8	(Lovren & Jablanovic, 2023)	Cognitive dimension dominates environmental ed., undervaluing affective elements.	Integrate the affective domain in education
9	(Gal, 2024b)	Climate education promotes environmental action through hands-on learning.	Long-term impact, fostering activism
10	(Gal, 2024a)	Hackathons enhance environmental citizenship and problem-solving.	Adapt culturally, assess long-term effects
11	(Curwen et al., 2018)	The systems thinking approach improves critical thinking in environmental issues.	Assess long-term and cross-grade impacts
12	(Andrada et al., 2018)	'Grinning Built' project fosters eco-conscious behaviors.	Not specified
13	(Merritt et al., 2024)	Service-learning boosts energy literacy and proactive behaviors.	Assess in diverse contexts, measure long-term impact
14	(Shakirova et al., 2024)	AR-based ecology education increases environmental literacy and motivation.	Explore long-term AR impacts and integrate across subjects



15	(Erdogan, 2015a)	Summer programs improve environmental knowledge and attitudes.	Longer programs, outdoor learning settings
16	(Wang, 2014)	Web-based argumentation supports eco-literacy skills.	Expand topics, develop evaluation rubrics
17	(Syofyan & Rachmadtullah, 2019)	Problem-solving models enhance eco-literacy in waste management education.	Test retention over time, compare urban and rural contexts
18	(Amini, 2015)	Outdoor learning improves eco-literacy attitudes in teacher candidates.	Long-term impact, study effective outdoor components
19	(Boaventura et al., 2021)	Ocean literacy and climate understanding through hands-on, student-led projects.	Earlier integration, playful teaching approaches
20	(Fisher-Maltese et al., 2018)	School gardens increase environmental engagement despite integration challenges.	Explore family impact, scalability to other regions
21	(Craig & Allen, 2015)	Experiential learning reduces household energy consumption.	Long-term impact, scale energy campaigns
22	(Ribeiro, 2023)	The 'Minha horta' app aids in inclusive environmental education.	Test in diverse settings, and integrate family involvement
23	(Stefanelli-Silva et al., 2019)	Informal marine education fosters ocean and coastal literacy.	Adapt for younger children, align language use
24	(Aurélio et al., 2021)	Children's books improve awareness of river conservation.	Test other genres, adapt culturally.

5. Final considerations

This systematic review highlights the essential role of environmental literacy in addressing today’s pressing ecological issues. Environmental literacy is a crucial aspect of education, particularly at the elementary level, as it equips students with the knowledge, skills, and attitudes necessary to make informed decisions about environmental issues (Curdt-Christiansen, 2020). The findings reveal a steady increase in scholarly attention post-2020, reflecting a global urgency to instill sustainability values from an early age. This trend aligns with international agendas such as UNESCO’s Sustainable Development Goals (SDGs), emphasizing the crucial role of education in fostering sustainable societies (García-González et al., 2020). Despite this positive trajectory, there remains a significant geographic imbalance, with most studies concentrated in North America and Europe, while research contributions from the Global South remain scarce.

Nevertheless, diversity is also observed in EE’s learning and assessment models. In elementary education, fostering eco-literacy through diverse learning models, such as storytelling, digital media, experiential activities, and citizen science, effectively builds foundational knowledge, empathy, and proactive behaviors toward environmental stewardship. By integrating environmental subjects into standard curricula, students gain a deeper understanding of complex environmental issues and develop the skills and motivation needed to address them. A holistic approach to environmental literacy that includes cognitive, emotional, and practical dimensions is crucial for instilling lifelong sustainable values in young learners. However, challenges persist, such as the limited interdisciplinary integration of environmental topics and insufficient focus on the affective domain within educational frameworks.

Future research is encouraged to diversify its geographical focus and explore interdisciplinary, culturally sensitive approaches that reflect students’ varied lived experiences. Expanding research contexts and methodologies will ensure that environmental literacy becomes a global and inclusive educational priority. In addition, future research should also focus on developing comprehensive educational frameworks that support a blend of disciplinary learning and hands-on activities, integrating eco-literacy across subjects like science, math, and social studies. There is also a need to explore the long-term effects of these educational interventions on students’ attitudes and behaviors and to investigate culturally adaptive methods that make environmental education accessible to diverse student populations. Additionally, assessment tools must evolve to measure immediate learning outcomes and the long-term impact on students’ environmental attitudes and behaviors. Teachers struggle to implement these methods due to limited resources and a lack of structured curricular tools.

In summary, while significant strides have been made in promoting environmental literacy in elementary education, a more integrated, community-based, and resource-supported approach is needed to prepare future generations for environmental sustainability challenges. By embracing these strategies, educators and policymakers can equip students with the knowledge, attitudes, and skills necessary to make meaningful contributions to a healthier planet.

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Ethical Considerations

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Conflict of Interest

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