

Pedagogical Strategies for Teaching Environmental Literacy in Secondary School Education: A Systematic Review

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Abstract

Environmental literacy is essential for preparing students with the knowledge, skills, and dispositions to address pressing environmental challenges. This systematic literature review examines how pedagogical approaches used in secondary education foster students' environmental literacy. The review enriches the current literature by shifting attention away from the predominant focus on higher education and providing new empirically grounded insights into the effectiveness of classroom practices in enhancing students' environmental literacy at the secondary education level. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, 22 peer-reviewed studies published between 2010 and 2024 were identified through Web of Science, Scopus and ERIC. The analysis is guided by Joyce and Calhoun's taxonomy of teaching models and the conceptualization of environmental literacy developed by the North American Association for Environmental Education (NAAEE). Findings show that strategies grounded in the social family and information-processing models of teaching were most frequently used, reflecting a pedagogical shift toward collaboration, critical thinking, and active engagement, yet a significant gap remains in cultivating environmentally responsible behavior (ERB). The review highlights the need for pedagogical designs that support the integration of every dimension of environmental literacy. It further emphasizes culturally responsive approaches and systematic investment in teacher professional development as critical conditions for pedagogical success.

Keywords: environmental education; environmental literacy; teaching strategies; secondary education; systematic review



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1. Introduction

The intensification of global environmental challenges, ranging from biodiversity loss to climate change, has elevated the strategic importance of environmental education (EE) across all levels of formal education. Since its institutionalization at the 1972 United Nations Conference on the Human Environment, the mandate for EE has evolved, broadening its scope and urgency in response to mounting ecological crises [1,2]. Principle 19 of the Stockholm Declaration articulates the foundational role of education in environmental matters for both youth and adults, emphasizing inclusivity and the need to foster informed public opinion and responsible action [1]. This vision was soon echoed and expanded in subsequent global frameworks, including the Belgrade Charter [3] and the Tbilisi Declaration [4], which established the principles of lifelong and holistic EE, and called for its integration across curricula and societies.

The international policy landscape further underscored EE's foundational role through UN Agenda 21, which positioned education as a cornerstone for sustainable development and called for embedding sustainability within all facets of basic education [5]. In recent decades, ESD has become central to the United Nations Educational, Scientific and Cultural Organization (UNESCO)'s education agenda, with the Global Action Programme (GAP) and Sustainable Development Goal 4.7 reaffirming the imperative to equip learners with the knowledge, skills, values, and attitudes needed for a sustainable future [6,7]. While EE emphasizes ecological systems and environmental protection, ESD extends this foundation by integrating social and economic dimensions, making EE an essential component of ESD. Environmental Literacy, in turn, provides a measurable framework for evaluating the outcomes of EE.

The significance of early educational interventions is well documented. The Attitude-Behavior (A-B) framework highlights the formative influence of basic education on the development of individual's environmental attitudes and subsequent behaviors [8]. Longitudinal research further demonstrates that positive, experiential engagement with the environment during childhood is strongly linked to pro-environmental behavior in adulthood, emphasizing the necessity for sustained and developmentally appropriate pedagogical approaches [9–11]. Recent syntheses also underscore the transformative potential of early interventions, not only for individual behavioral change but for cultivating collective agency and environmental citizenship from an early age [12,13].

A persistent paradox characterizes the current landscape of EE research: the prevailing instrumental orientation, which frames EE primarily as a means of crisis mitigation, has led to a disproportionate focus on higher education. In these settings, EE is frequently integrated with vocational and professional training, aligning closely with labor market demands and sector-specific competencies [14,15]. Acosta et al., in a systematic review, reported that 84% of the analyzed articles were exclusively centered on higher education contexts [16]. This focus risks perpetuating systemic neglect of basic education, thereby widening the gap between the stated theoretical importance of early EE and the relative scarcity of empirical research in these foundational stages.

While numerous scholars underscore the need for humanized, contextualized pedagogical approaches to increase the efficacy and relevance of EE [17,18], such recommendations often remain at the level of theoretical aspiration, insufficiently grounded in concrete, actionable teaching practices. Reviews of the literature recognize the value of pedagogical approaches tailored to learners' lived experiences and local contexts, yet empirical investigations at the secondary level often remain fragmented, with few attempts to identify the common factors underpinning effective pedagogies for fostering students' environmental literacy [19]. As a result, the evidence base is dispersed and inconsistent, offering limited guidance for practitioners seeking to translate principles into everyday teaching.

This gap is compounded by the persistent undervaluation of formal schooling's strategic role in cultivating students' environmental literacy. Despite policy mandates to integrate EE into core curricula [20,21], systematic reviews frequently conflate formal and non-formal educational contexts in EE [8]. This conflation blurs boundaries and contributes to a lack of clear, actionable frameworks for teachers, perpetuating practical inertia—leaving educators uncertain about effective implementation pathways in schools.

To address these challenges, this study focuses specifically on secondary education in school setting. While the body of research in this area is comparatively smaller than in higher education, relevant empirical studies do exist. What is lacking, however, is a systematic synthesis capable of identifying their shared pedagogical characteristics, effectiveness, and practical operability.

By conducting a systematic literature review, this study seeks to address this gap by examining how pedagogical approaches are employed in secondary classrooms, evaluating their effectiveness in fostering students' environmental literacy, and distilling common strategies that can inform evidence-based practice. This research is guided by two research questions:

Research question 1: What pedagogical approaches are employed to deliver EE in secondary school education?

Research question 2: What are the impacts of different pedagogical approaches on students' environmental literacy?

2. Theoretical Framework

2.1. Environmental Education (EE) and Environmental Literacy

Since the adoption of Education for Sustainable Development (ESD) in Agenda 21 [5], the evolving relationship between EE and ESD has remained a central topic in academic discourse. While some scholars regard ESD as an improved version of environmental education due to its integration of economic, environmental, and social dimensions of development [22], others maintain that EE must retain its fundamental emphasis on ecological systems [16]. Amid escalating global environmental challenges, the need to preserve this ecological focus within EE is more critical than ever [23]. Accordingly, this study adopts Pihkala's definition [24], viewing EE as the embodiment of environmental content in both environmental education and education for sustainable development.

The Tbilisi Declaration established that EE should foster the knowledge, skills, attitudes, motivations, and commitment necessary to address environmental challenges [4]. These aims were later conceptualized through the notion of environmental literacy. Originally proposed by Roth in 1968 and further elaborated in 1992 [25], environmental literacy is structured across three levels: nominal (basic knowledge), functional (practical application), and operational (active engagement). This framework has been recognized as a foundational approach for evaluating EE learning outcomes, offering a multidimensional perspective that encompasses cognitive understanding, behavioral change, and civic participation.

Reflecting its growing global significance, environmental literacy has been recognized as a core component of international education assessment. Since 2006, the Programme for International Student Assessment (PISA) has included environmental literacy in its evaluation framework, underscoring the importance of sustainability education for developing global competencies. Notably, the 2025 PISA cycle signals a paradigm shift, with environmental science competencies now formally integrated within the broader science competency domain [26].

The North American Association for Environmental Education (NAAEE), a leading authority in the field, conceptualizes environmental literacy as comprising four interrelated components: knowledge, dispositions, competencies, and environmentally responsible behavior (ERB) [27]. Within this framework, knowledge forms the cognitive foundation, enabling individuals to understand environmental issues; competencies represent the skills required to apply this knowledge in problem-solving contexts; and dispositions encompass the internal attitudes and motivations that drive individual's willingness to act. These three elements are dynamically interrelated, developing through ongoing feedback and reflection, and together they shape ERB across diverse settings lies in its well-defined constructs, which provide operational criteria for assessing the development of students' environmental literacy in EE. Accordingly, the present study adopts the NAAEE framework (see Table 1) as the theoretical lens for assessing and interpreting the impacts

of pedagogical approaches in terms of fostering students' environmental literacy during secondary education.

Table 1. The dimensions of environmental literacy and definitions.

Dimension	Explanation
Knowledge	What you know about: physical and ecological systems; social, cultural and political systems; environmental issues; multiple solutions to environmental issues; citizen participation and action strategies.
Dispositions	How you respond to environmental issues: sensitivity; attitudes, concern, and worldview; personal responsibility; self-efficacy/locus of control; motivation and intentions.
Competencies	What skills and abilities you may call upon and express for specific purposes: identify environmental issues; ask relevant questions; analyze environmental issues; investigate environmental issues; evaluate and make personal judgments about environmental issues; use evidence and knowledge to defend positions and resolve issues; create and evaluate plans to resolve environmental issues.
Environmentally responsible behavior (ERB)	How you act, individually and collectively, to solve and prevent environmental problems: the point at which competencies, knowledge, and dispositions are brought to bear within a particular context.

Note: Adapted from [27] (p. 122).

2.2. Models of Teaching and Pedagogical Approaches

Teaching is inherently a complex and multifaceted practice, in which pedagogical approaches are as critical as curricular content in shaping learning outcomes [28]. Pedagogy, in its broadest sense, encompasses the principles, methods, and approaches that guide the act of teaching, integrating both theoretical orientations and practical techniques. Whereas pedagogical strategies are often adaptive, context-dependent, and open to variation, teaching models are more prescriptive frameworks that provide not only the how of instruction but also the why underlying methodological choices [29] (p. 47). Teaching models are typically derived from established learning theories and are supported by coherent rationales that link instructional methods to expected cognitive, affective, or behavioral learning outcomes.

This conceptualization means that teaching models can be seen as the structured, theory-driven scaffolds within which pedagogical strategies are selected and applied. Joyce and Calhoun's taxonomy—provides a representative and empirically robust classification of pedagogical approaches. There are four well-established categories: information-processing

models of teaching, social family of teaching models, personal family of teaching models, and behavioral family of teaching models [29] (Table 2). This conceptualization demonstrates both strong generalizability in diverse classroom contexts and a balance between theoretical coherence and practical application. This taxonomy is particularly relevant to environmental literacy, as its categories encompass cognitive, collaborative, affective, and behavioral dimensions of learning that align closely with the core components of the NAAEE framework of environmental literacy.

Table 2. Overview of teaching models and descriptions.

Teaching Models	Description	Examples
Information-processing models	Models designed to enhance learners' capacity to acquire, organize, and retrieve information through structured cognitive operations.	Inductive learning Scientific inquiry Concept attainment
The social family of models	Models that utilize social interaction as the primary mechanism for constructing shared understanding and collective knowledge.	Group investigation Cooperative inquiry Role playing
The personal family of models	Models that prioritize the individual's affective development and self-actualization through personalized learning experiences.	Non-directive teaching Inquiry training
The behavioral family of models	Models based on behavior modification principles that shape learning through systematic reinforcement and task analysis.	Explicit teaching of comprehension Mastery learning Direct instruction

Note: Adapted from [29].

By integrating these perspectives, the models of teaching provide a theoretical lens for examining how diverse instructional approaches contribute to knowledge acquisition, skill development, attitudinal change, and ERB. Building on this foundation, this study employs the models of teaching to systematically categorize and analyze the instructional practices identified in the existing literature.

3. Research Methods

3.1. Research Design

This study adheres to the systematic literature review methodology, guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [30]. The PRISMA framework provides a transparent and replicable process for identifying, screening, and selecting relevant studies, thereby enhancing the methodological rigor and credibility of the findings. The review process encompassed three key stages: (1) a comprehensive literature search across multiple academic databases, which initially identified 1186 articles; (2) a structured screening procedure based on predefined inclusion and exclusion criteria, reducing the pool to 310 articles after title screening and

49 after abstract screening; and (3) a detailed full-text analysis, through which 272 studies were ultimately deemed eligible and included in this review (see Figure 1). A thematic analysis approach was employed to extract, categorize, and synthesize the pedagogical strategies reported in the literature, with the aim of directly addressing the research questions outlined above. The protocol for this systematic review was prospectively registered with the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY; Registration No.: [INPLASY202590089]). The PRISMA 2020 Checklist for this review is provided as Supplementary Material, which can be downloaded at: <https://www.mdpi.com/article/doi/s1>.

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only

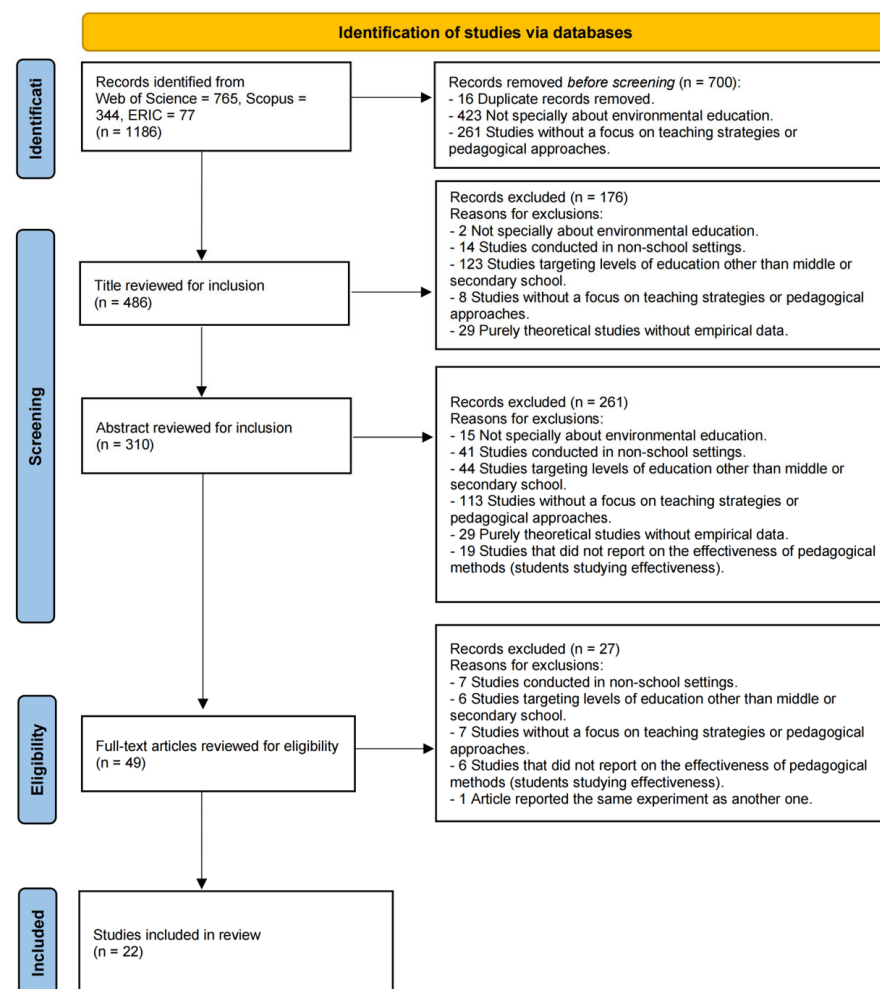


Figure 1. PRISMA flow diagram of systematic review.

3.2. Search Strategy

This study employed a systematic search strategy to identify relevant literature on pedagogical approaches to EE in secondary school contexts. The search query was developed iteratively through preliminary scoping exercises and pilot testing to ensure both breadth and precision. Boolean operators were used to combine the key concepts derived from the research objectives: (“environmental education” OR “sustainability education”) AND (“secondary education” OR “middle school” OR “junior high school” OR “high school”) AND (“teaching strategy” OR “pedagogical approach” OR “instructional method” OR “teaching model”). The search was conducted across three major electronic databases with broad coverage of educational research: Web of Science, Scopus, and ERIC. The query was

further adapted to the indexing structures of each database. These databases were selected to ensure inclusion of both high-impact, peer-reviewed journal literature and specialized educational research outputs.

The search was restricted to English-language articles published in peer-reviewed journals between 2010 and 2024, in order to focus on recent developments in pedagogical practices while maintaining consistency in linguistic analysis. The initial search yielded a total of 1186 records: Web of Science ($n = 765$), Scopus ($n = 344$), and ERIC ($n = 77$).

To ensure the methodological rigor and relevance of the review, inclusion and exclusion criteria were applied. Studies were included if they: (1) were peer-reviewed empirical studies; (2) published in English between 2010–2024; (3) focused on secondary education settings; (4) addressed EE or ESD; (5) examined teaching strategies, pedagogical approaches or instructional models; and (6) reported outcomes related to environmental literacy (see Table 3). Studies were excluded if they: (1) were conducted in non-formal school contexts; (2) did not focused on pedagogy; (3) were purely theoretical papers without empirical data; and (4) reported outcome data unrelated to students' environmental literacy (see Table 4).

Table 3. Inclusion criteria.

Domain	Inclusion Criteria
Publication type	Peer-reviewed empirical studies (qualitative, quantitative, or mixed methods).
Language & Date	Published in English between 2010–2024.
Educational level	Focused on secondary education (lower or/and high secondary education).
Focus of study	Addressed environmental education (EE) or education for sustainable development (ESD).
Intervention	Investigated teaching strategies, pedagogical approaches, or instructional models.
Outcomes	Reported outcomes related to environmental literacy.

Table 4. Exclusion criteria.

Domain	Exclusion Criteria
Educational context	Studies outside formal school contexts (community programs, workshops, corporate training).
Focus of study	Articles not addressing pedagogy (e.g., purely curriculum design without teaching strategies).
Intervention	Theoretical papers with no empirical data.
Outcomes	Studies not reporting outcomes linked to environmental literacy.

The PRISMA screening stage was independently conducted by two reviewers. Inter-coder reliability was assessed through Cohen's kappa values to ensure consistency (See Table 5).

Table 5. Inter-rater reliability (Cohen’s κ).

Screening Stage	Agreement %	Cohen’s κ
Title	88%	0.82
Abstract	88%	0.82
Full-Text	94%	0.91

Note: Interpretation follows Landis and Koch [31]: $\kappa < 0.20$ slight; 0.21–0.40 fair; 0.41–0.60 moderate; 0.61–0.80 substantial; 0.81–1.00 almost perfect agreement.

3.3. Data Analysis

Deductive coding began with two predefined analytical frameworks:

Joyce and Calhoun’s taxonomy of teaching models [29] is used to categorize pedagogical approaches into the four model families (information-processing, social, personal, and behavioral).

NAAEE’s environmental literacy framework [27] is used to code learning outcomes across the four environmental literacy components: knowledge, competencies, dispositions, and ERB.

These frameworks provided the initial “code-book” ensuring conceptual consistency and comparability across studies. Teaching approaches were classified according to Joyce and Calhoun’s taxonomy, while learning outcomes were coded using the NAAEE environmental literacy framework. When a single study employed more than one teaching model (e.g., both social and information-processing), it was coded under multiple categories.

Inductive coding was then applied to the same data-set to identify pedagogical approaches not explicitly covered by the predefined categories. This process enabled us to code hybrid approaches. For example, in one study, inquiry-based learning required students to process information about water pollution while engaging in place-based, collaborative activities. Such a design reflects the information-processing family and the social family of models. To represent this integration, the study was coded under a hybrid category labeled “information-processing + social family”. This approach allowed the analysis to remain sensitive to innovative pedagogical combinations, while still ensuring transparency and replicability through structured coding.

Coding was conducted independently by two reviewers, with inter-coder reliability assessed through Cohen’s kappa values ($\kappa = 0.91$) to ensure consistency. Discrepancies were resolved through discussion to reach consensus.

4. Results

4.1. Characteristics of Studies

In this section, we provided a summary of the core characteristics of the 22 included studies (see Table 6) and followed by a detailed discussion of each characteristic in the subsequent subsections.

Table 6. Distribution of Study Characteristics ($N = 22$ studies).

Category	Subcategory	No. of Studies	Percentage
Region	United States	7	31.8%
	Asia	7	31.8%
	Europe	5	22.7%
	Africa	2	9.1%
	Australia	1	4.5%
Sample Size	<100	13	59.1%
	≥ 100	9	40.9%

Table 6. *Cont.*

Category	Subcategory	No. of Studies	Percentage
Methods	Mixed methods	10	45.5%
	Qualitative	7	31.8%
	Quantitative	5	22.7%
Instruments	Questionnaires	13	59.1%
	Assessments	6	27.3%
	Interviews	6	27.3%
	Student work/products	5	22.7%
	Field notes	3	13.6%
	Participant observation	3	13.6%
	Audio/video recordings	3	13.6%
	Curricular artifacts produced by students	2	9.1%

4.1.1. Geographical Distribution of Studies

This review identified a total of 22 eligible studies (see Table 6). The largest proportion were conducted in the United States ($n = 7$) and in various Asian countries ($n = 7$). These were followed by studies undertaken in Europe ($n = 5$), one of which was a multinational investigation spanning three European countries. The remaining studies were conducted in Africa ($n = 2$) and in Australia ($n = 1$).

4.1.2. Sample Characteristic

Substantial variation was observed in sample sizes across the included studies, ranging from 6 to 906 participants. Of the 22 studies, the majority ($n = 13$) reported sample sizes of fewer than 100 participants, while the remaining studies ($n = 9$) involved cohorts exceeding 100 participants. In terms of target populations, most studies focused on higher secondary school students ($n = 12$), followed by lower secondary school students ($n = 10$). One study targeted students from both lower and higher secondary levels.

4.1.3. Research Methods and Instruments Used

In terms of methodological approach, the most common design among the included studies was mixed methods ($n = 10$), followed by qualitative research designs ($n = 7$). Quantitative approaches were employed in five studies. To address their research objectives, the studies drew upon a variety of data sources. Questionnaires emerged as the most frequently used instrument ($n = 13$), followed by assessments ($n = 6$) and interviews ($n = 6$). Additional sources included student work or products ($n = 5$), field notes ($n = 3$), participant observation ($n = 3$), non-participant observation ($n = 3$), and curricular artifacts produced by students ($n = 2$).

In the following sections, the findings are presented in a structured sequence that reflects the research questions. Section 4.2 examines the pedagogical approaches used to teach EE and describes how each family of teaching models was implemented in classroom settings. Section 4.3 synthesizes students' learning outcomes and their relationship with different pedagogical approaches, with subsections organized around the four dimensions of environmental literacy as defined by the NAAEE framework.

4.2. What Pedagogical Approaches Were Used to Foster Environmental Literacy in Secondary School Settings?

In the majority of the cases, EE courses ($n = 19$) were integrated into science education, while four EE courses ($n = 4$) were embedded within humanities and arts disciplines (see Figure 2).

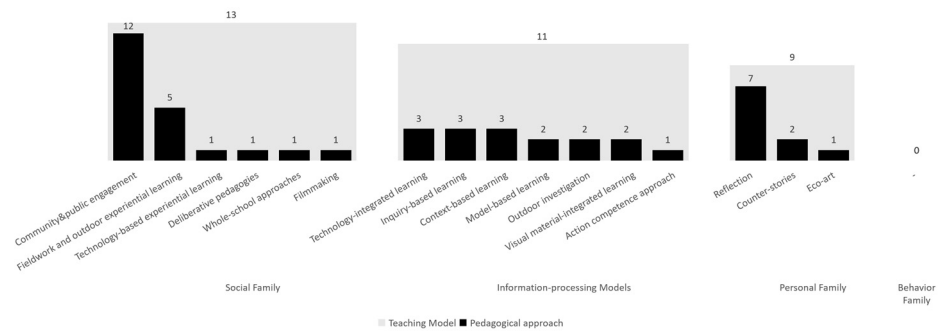


Figure 2. Number of teaching models and pedagogical approaches reported in the articles.

The analysis revealed that instructional practices predominantly fell into three primary families of teaching models: the social family ($n = 13$), the information-processing models ($n = 11$), and the personal family ($n = 9$). Notably, many studies developed their pedagogical approaches by drawing on more than one family of teaching models. For instance, information-processing models were frequently combined with the social or personal family in classroom implementation, while approaches grounded in the personal family often appeared alongside those from the social family (see Figure 3).

			Dispositions				Knowledge				Competencies				ERB					
			sensitivity	attitudes, concern, and worldview	personal responsibility	self-efficacy/locus of control	motivation and intentions	physical and ecological systems;	social, cultural and political systems;	environmental issues;	multiple solutions to environmental issues;	citizen participation and action strategies.	Identify environmental issues	Ask relevant questions		Analyze environmental issues	Investigate environmental issues	Evaluate and make personal judgments about environmental issues	Use evidence and knowledge to defend positions and resolve issues	Create and evaluate plans to resolve environmental issues.
Social Family	Community engagement			+	+	+					+									+
	Deliberative pedagogies			+	+				+	+										
	Public engagement														+		+	+		
	Citizenship PjBL			+	+	+				+										
	In-class discussion													+				+		
	Filmmaking			+	+															
	Whole-school approaches					+	+	+												
	Fieldwork			+	+			+				+								
Information-processing +Social Family	Inquiry-based learning											+	+	+	+					
	Model-based learning													+						
	Storyline	-	+																	
	Place-based PjBL			+	+	+				+	+									
	Station work	+		+	+															
	Progressive environmental action approach			+	+			+			+								+	
	Mathematical modeling-integrated context-based learning		+							+	+	+		+	+	+				
	Media cartoons integrated inquiry learning							+	+	+	+		+	+					+	
Information-processing	Context-based learning			+				+											-	
	AR-integrated documentary-based approach											+	+					+		
	Action competence approach			-	+	+													-	
	GIS based			+				+												
	problem-solving learning																			
	Outdoor investigation	+				+														
	Outdoor teacher-lead questioning							+		+										
	Technology-integrated experimental approach	-				+														
Information-processing +Personal Family	Technology-integrated experimental approach						+				+									
Personal Family	Reflection			+	+			+		+	+									
	Counter-stories				+	+	+										+			
	Student-centered approaches				+	+	+													
	Eco-art		+		+															
Personal Family +Social Family	Culturally responsive approach		+	+				+	+	+		+	+							

Figure 3. The impact of pedagogical approaches and teaching models on environmental literacy. Notes: “+” = positive relationship or enhancement reported; “-” = limited or non-significant relationship reported.

Notably, the review found no evidence of pedagogical approaches aligned with the behavioral family of teaching models being employed to develop students' environmental literacy. This absence indicates that, within the contexts examined, pedagogical strategies are predominantly grounded in social, cognitive, and personal development teaching frameworks. The lack of behaviorist-oriented pedagogical approaches in EE may signal a broader pedagogical shift, with contemporary practice prioritizing active engagement, higher-order thinking, and self-reflection over direct behavior modification.

The following sections present a detailed analysis of how the reported teaching models were implemented within classroom settings, highlighting the instructional practices, contextual factors, and reported learning outcomes associated with each model family.

4.2.1. The Implementation of Social Family of Teaching Models in Classroom

Within the social family of teaching models, community and public engagement emerged as the most frequently adopted approach ($n = 12$) [32–43], followed by fieldwork and outdoor experiential learning ($n = 5$) [32,36,42,44,45] (see Figure 2).

Community and public engagement strategies emphasize direct student participation in civic and community initiatives through various impactful approaches. Students engage in policy-oriented activities by drafting proposals for local governments, contributing directly to governance processes [32–35]. They also spearhead science communication efforts through comprehensive outreach programs, including poster campaigns, public lectures, academic seminars, radio promotions, and social media dissemination to bridge the gap between academia and the public [32,33,36–41]. Furthermore, students collaborate with community organizations through data sharing, joint projects, material donations, and by providing analytical support to strengthen public administration systems [32,36,42,43]. These activities leverage students' roles as active social citizens, fostering both environmental awareness and civic responsibility.

Fieldwork and outdoor experiential learning approaches place a premium on inquiry-based learning in outdoor and natural settings. The teacher often assumes the role of facilitator, providing guidance, answering questions, and supplying relevant resources, while students work predominantly in self-directed groups to explore real-world environmental challenges [32,36,44,45]. In some instances, these experiences are enriched through consultations with subject-matter experts, enabling students to engage in contextually immersive problem-solving tasks that integrate authentic data collection, interdisciplinary analysis, and applied environmental decision-making [36].

Technology-based experiential learning, deliberative pedagogies, whole-school approaches, and film-making were each reported in only one study ($n = 1$), indicating their relatively limited presence in the current evidence base and suggesting that these approaches remain in an emerging stage of practice.

Technology-based experiential learning addresses the limitations of students' inability to physically engage with certain objects or environments by employing interactive online tools that enable real-time remote observation and inquiry into physical phenomena or on-site contexts. Deliberative pedagogies extend community and public engagement by centering curricula on locally relevant issues and structuring scaffolded discussions through strategies such as structured academic controversy and policy deliberation simulations [34]. These approaches encourage students to grapple with conflicting values, adopt multiple perspectives, and collaboratively propose solutions, thereby fostering civic engagement and environmental citizenship. The whole-school approach (WSA) emphasizes campus-wide sustainability projects in which students work with teachers and institutional decision-makers to implement systemic changes such as energy reduction initiatives and sustainable resource use [43]. By incorporating student councils into decision-making,

WSA moves beyond tokenism toward genuine participatory governance. Finally, the filmmaking approach empowers student groups to independently research, produce, and disseminate environmental documentaries, engaging both peers and the wider community in dialogue [40].

The implementation of the social family of teaching models in secondary school environmental education reflects a pronounced emphasis on community integration, experiential engagement, and collaborative inquiry, whose foundations deeply rooted in social constructivism [46,47], which highlight the deepening of knowledge understanding through sociocultural interactions from family, peers, schools and media. While community and public engagement, along with fieldwork and outdoor experiential learning, dominate current practice, the presence of emerging teaching strategies, such as technology-based experiential learning, deliberative pedagogies, filmmaking, alongside broader whole-school approaches, signals a diversification of pedagogical approaches that collectively align with contemporary student-centered and participatory learning paradigms.

4.2.2. The Implementation of Information-Processing Models of Teaching in Classroom

Within the information-processing models of teaching, technology-integrated learning ($n = 3$) [45,48,49], inquiry-based learning ($n = 3$) [37,44,50] and context-based learning ($n = 3$) [38,49,51], emerged as the most frequently reported pedagogical approaches (see Figure 2).

Technology-integrated learning leveraging digital tools such as virtual reality (VR) [48], geographic information systems (GIS) [49], and information and communication technologies (ICT) [45] facilitate data visualization, real-time information sharing and enhanced conceptual understanding of environmental issues.

In contrast, inquiry-based learning centers on engaging students in the full cycle of scientific investigation, from formulating research questions and designing experiments to analyzing data and drawing evidence-based conclusions. Within the various stages of scientific investigation. Experimental approaches can take diverse forms, including but not limited to conventional biochemical assays, specimen observation, field investigation, online observation [44,50].

Context-based learning situates inquiry within students' lived experiences, using locally relevant scenarios to make abstract environmental concepts more accessible. Its effectiveness depends on systematic and meaningful context design, as fragmented or oversimplified examples risk limiting deep learning [38,49,51].

Model-based learning ($n = 2$), outdoor investigation ($n = 2$), visual material-integrated learning ($n = 2$) and the action competence approach ($n = 1$) appeared with moderate frequency.

Model-based learning engages students in iterative processes of constructing and refining ecological or mathematical models, thereby strengthening their information-processing competencies [37,51]. Visual material-integrated learning employs tools such as cartoons, documentaries, or virtual simulations to visualize complex environmental issues, enhancing comprehension and retention when carefully aligned with instructional objectives [48,52]. Finally, the action competence approach leverages behavioral data (e.g., ecological footprints) as cognitive input, enabling students to monitor and regulate their practices while linking individual actions with broader ecological systems [53].

Collectively, the information-processing models tend to conceptualize learning as a linear cognitive process of information input–information processing–information output. Within this framework, different pedagogical approaches align with distinct stages of the cognitive process. For example, visual material-integrated learning primarily operates at the information input stage by enhancing perception through optimized presentation of environmental concepts. Model-based learning emphasizes the processing stage, engaging

students in iterative cycles of representation and refinement that promote higher-order reasoning. In contrast, context-based learning and inquiry-based learning extend across the entire cycle, systematically intervening from information acquisition to application in order to support comprehensive cognitive development. These variations illustrate the differentiated roles and mechanisms of pedagogical strategies within the information-processing models, highlighting both their complementarity and capacity to scaffold multiple levels of cognitive engagement in EE.

4.2.3. The Implementation of Personal Family of Teaching Models in Classroom

The personal family of teaching models underscores the importance of self-reflective and narrative-based methods in fostering students' environmental literacy. Reflection was the most frequently observed strategy ($n = 8$) [32,36,39,41,42,48,51], while counter-stories ($n = 2$) [33,54] and eco-art ($n = 1$) [41] appeared less commonly.

Reflection in EE typically takes two forms: verbal and written expression [36,41]. Verbal reflection, often embedded in classroom discussions, helps students connect hands-on experiences with environmental awareness, while written reflection through reports, worksheets, or role-playing exercises supports more systematic analysis and formative assessment. Counter-storytelling engages students in drawing upon personal experiences to articulate ecological perspectives, a practice shown to be particularly effective in empowering marginalized communities and fostering stronger ecological identities [33,54]. Eco-art, by contrast, emphasizes creative visual expression through artworks addressing themes such as climate change or water conservation, offering students an alternative medium for individual meaning-making and promoting environmental empathy when shared in school-wide exhibitions [41].

These findings suggest that while personal family of teaching models, though less frequently applied, holds considerable potential in supporting individual meaning-making, creativity, and student agency, which are key elements in the development of environmental literacy, significant challenges still remain in achieving their broader and more systematic integration into contemporary classroom practice. Factors such as curricular constraints, assessment limitations, and the dominance of content-driven instruction may inhibit the effectiveness and widespread adoption of these teaching methods, despite their potential for developing deep, transformative learning in EE.

4.3. How Did Different Pedagogical Approaches Contribute to the Development of Students' Environmental Literacy?

The majority of the reviewed studies reported outcomes spanning multiple dimensions of environmental literacy (see Figure 3). Disposition emerged as the most frequently assessed dimension ($n = 20$), reflecting a strong research emphasis on fostering pro-environmental attitudes, values, and motivations. This was followed by competencies ($n = 11$), which capture students' skills in applying environmental knowledge to problem-solving and knowledge ($n = 10$), representing conceptual understanding of environmental systems and issues. In contrast, only five studies explicitly examined students' development of ERB, indicating a relative underrepresentation of this dimension in the current evidence base. Even when ERB was stated as a learning objective [43], studies often failed to assess actual behavioral outcomes in their evaluations. This observation aligns with the NAAEE's documented challenge: "Measures of behavior tend, for obvious reasons, to rely heavily on self-reports, which many researchers consider less reliable than other assessment methods" [27] (p. 4). The imbalance aforementioned suggests that while pedagogical approaches in EE often target affective and cognitive domains, fewer systematically evaluate or prioritize the translation of these learning gains into sustained pro-environmental action.

4.3.1. Pedagogical Approaches and the Knowledge Dimension of Environmental Literacy

Knowledge forms the foundational dimension of environmental literacy, providing the cognitive basis upon which dispositions, competencies, and behaviors are built.

However, its development in classroom practice is often accompanied by notable pedagogical tensions. For example, Bergman's study reveals a paradox: while 90% of students could recall environmental project-related topics, demonstrating surface-level knowledge retention, only 5% identified "knowledge acquisition" as a preferred learning activity [36]. This disconnect suggests that, although knowledge is essential, it is frequently perceived by students as less engaging, which may help explain the absence of significant environmental knowledge gains between experimental and control groups in her study.

This paper's analysis demonstrates that engagement-driven pedagogical approaches consistently yield stronger knowledge outcomes in EE contexts. These approaches can be situated within different instructional model families depending on their defining characteristics: strategies emphasizing collaboration align with the social family of models, while those prioritizing cognitive processing correspond to the information-processing models. Notably, many pedagogical designs integrate features of both. A central principle across these approaches is the embedding of learning within authentic environmental contexts, such as place-based, project-based learning (e.g., addressing local water pollution or regional energy controversies) [35] or outdoor investigations [45]. Such contextual anchoring lowers the cognitive threshold for engaging with complex ecological systems, thereby facilitating the integration of theoretical knowledge with real-world environmental phenomena, while simultaneously enhancing student engagement.

The innovative application of digital tools further broadens these pedagogical possibilities. For example, King and Ginns employed Flip cameras to enable students to document and revisit field experiences [42]. This process not only facilitated reflection, a defining feature of the personal family of models, but also functioned as a cognitive scaffold, reinforcing connections between theoretical constructs and situated environmental contexts. Similarly, the use of visual materials as instructional scaffolds within information-processing models has demonstrated substantial efficacy. Studies show that media-based resources such as educational cartoons can advance conceptual development [52], while videos, infographics, and other visualizations are strongly preferred by learners. El Youssfi et al. reported that 91% of participants perceived improved comprehension of environmental issues when visual aids were integrated into instruction, with 83% exhibiting long-term retention of key concepts [41]. Collectively, these findings highlight the importance of multimodal, contextually embedded strategies in strengthening students' conceptual understanding of environmental systems.

Importantly, the effectiveness of these pedagogical approaches depends largely on teacher expertise. For instance, inquiry-based facilitation in field settings depends on the teacher's ability to provide spontaneous scaffolding through dialogic questioning, deepening students' conceptual understanding of physical and ecological systems and environmental issues [42]. Likewise, designing effective visual scaffolds demands training for teachers in terms of selecting scientifically accurate visual materials and embedding metacognitive prompts that guide students' reflection [52]. Without such expertise, the intended benefits of these innovative practices may not be fully achieved, thereby limiting their impact on students' environmental knowledge development.

4.3.2. Pedagogical Approaches and the Dispositional Dimension of Environmental Literacy

Environmental dispositions represent a core prerequisite for predicting students' future ERB, fundamentally shaping their potential as effective sustainability practitioners.

Within this dimension, environmental sensitivity serves as the foundational element, defined as a spontaneous affective response to natural settings (e.g., situational emotional reactions) [44]. Empirical evidence demonstrates that its development is strongly dependent on direct outdoor experiences. For instance, in the social family of models, field work activities such as hands-on pollinator contact reported enhanced well-being and reduced boredom compared to peers engaged in remote learning [44]. However, this dependency also reveals its limitations: in the absence of direct nature exposure, interventions often fail to produce significant gains in environmental comfort [37]. Moreover, when fieldwork incorporates highly structured inquiry activities like station work, which blend characteristics of information-processing models, it may, in some cases, provoked aversion responses such as negative perceptions of the Wadden Sea environment [50]. This suggests that poorly designed experiences may hinder rather than enhance environmental dispositions.

Within the dispositional dimension of environmental literacy, deeper layers such as attitudes, concern, worldview, personal responsibility, self-efficacy, motivation, and intentions extend beyond mere sensitivity. Given the limitations of outdoor-based interventions discussed earlier, sensitivity is often not the primary focus of pedagogical research. However, since the dispositional dimension is non-linear in its development [37], even when sensitivity cultivation proves ineffective, deeper attitudes and values can still be fostered through alternative pedagogical pathways.

Context-embedded learning represents a promising pedagogical pathway for cultivating environmental dispositions, particularly within the social family and information-processing models of teaching. Context-based learning, characteristic of the social family, anchors instruction in locally relevant environmental issues, thereby strengthening students' sense of agency and responsibility [38]. Within the information-processing models, GIS-based inquiry engages learners in spatial data analysis, transforming abstract ecological challenges into tangible insights that foster pro-environmental attitudes [49]. Similarly, mathematical modelling situated in authentic contexts, such as plastic waste or sustainable architecture, bridges analytical reasoning with environmental concern by preventing the disconnect of decontextualized abstraction [51].

Equally important, the Information-processing models of teaching can also catalyze students' dispositional growth by equipping them with scientific tools for problem-solving. Participation in authentic practices, such as water quality testing or carbon footprint measurement, not only develops technical competence but also reshapes students' self-perception from passive learners to active agents of change [35,53]. For example, Basche et al. observed that students who conducted water analyses and advocated for pipeline reforms began to view science as accessible and participatory [35]. Similarly, iterative cycles of footprint analysis fostered methodological self-efficacy and reinforced the belief that science can change the environment [53]. These findings suggest that dispositional transformation emerges not only from contextual engagement but also from the intrinsic empowerment derived from mastery of scientific practices. By positioning science as both methodological and agentic, information-processing models foster enduring dispositions that extend beyond isolated pedagogical interventions.

Dispositional growth also benefits from integration with sociocultural feedback mechanisms—the cornerstone of the social family of models. Environmental socialization processes strengthen agency and responsibility when students perceive validation from policymakers [33]. Similarly, structured classroom dialogue facilitates the reconstruction of attitudes through cycles of critical reflection [41], while the public dissemination of student outputs—such as environmental films—amplifies self-efficacy via social recognition [40]. Collectively, these mechanisms operate as agency cultivation levers, reinforcing students'

belief in their capacity to effect meaningful environmental change and embedding these dispositions within a supportive social and cultural framework.

Teacher expertise remains an indispensable precondition for operationalizing these pedagogical approaches. Torsdottir et al. caution that within whole-school approaches, the absence of timely and meaningful teacher feedback on learning outcomes can undermine student self-efficacy by fostering perceptions of ineffectiveness of such approaches [43]. Moreover, teachers' dual expertise, encompassing both content mastery and pedagogical design, is essential for translating "learning by doing" into students' sustainable dispositional gains.

4.3.3. Pedagogical Approaches in Fostering Students' Competencies Dimensions of Environmental Literacy

Analysis revealed that inquiry- and experiential-based learning anchored in real-world environmental problems constitutes a highly effective paradigm for fostering students' environmental competencies. This paradigm systematically integrates teaching frameworks from both the social family and information-processing models, following a progressive cycle of problem identification, scientific explanation, and practical resolution that aligns precisely with the core dimensions of environmental literacy (see Figure 3). Specifically, problem identification corresponds to the ability to "identify environmental issues and ask relevant questions"; scientific explanation maps onto the capacities to "analyze environmental issues" and "investigate environmental issues"; and practical resolution encompasses decision-making competencies, including the ability to "evaluate and make personal judgments about environmental issues," "use evidence and knowledge to defend positions and resolve issues," and "create and evaluate plans to resolve environmental issues" [45,48,52].

In practical implementation, several effectiveness-enhancing teaching strategies can amplify the impact of this paradigm. First, visual materials can be employed to render environmental problems more tangible and accessible [41], while modeling tools facilitate systematic analysis by enabling students to deconstruct complex ecological relationships [45]. Second, aligning learning design with students' cultural identities and lived experiences is essential for engagement and inclusivity. For instance, Cermak redesigned EE curricula using black hip-hop music as a pedagogical medium, fostering a "decolonizing pedagogy" that significantly enhanced African American students' abilities in environmental issue identification and problem-posing [54].

Finally, establishing diverse expression mechanisms is crucial for strengthening the transfer and application of environmental competencies. First, personal narrative expression through counter-stories (approach from personal family of models) integrates environmental science knowledge (e.g., principles of lead pollution) with individual experiences, effectively demonstrating environmental knowledge application capabilities [33]. Second, representative expression (activity from personal family of models) engages students in deliberative pedagogies and public engagement approaches, where they role-play various stakeholders to articulate perspectives in both simulated and authentic deliberative contexts [34,35]. These distinct yet complementary pathways reinforce environmental competencies at both personal and societal levels, ensuring literacy development resonates individually ("I can act") and collectively ("We must act").

4.3.4. Pedagogical Approaches in Fostering Students' ERB

Although the measurement of ERB in EE program evaluations remains relatively limited in the literature, this does not diminish its pedagogical significance. On the contrary, as the ultimate intended outcome of EE, ERB is rooted in the coordinated development of knowledge, competencies, and dispositions. Existing research suggests that attitudinal change often precedes behavioral change [38,55]. However, fostering ERB does not solely result from students' dispositional development; rather, it requires the integrated devel-

opment of multiple dimensions of environmental literacy and their transformation into contextually grounded, actionable practices within real-life settings.

Deliberative pedagogy, a core approach within the social family of teaching models, illustrates a promising pathway for fostering ERB. As demonstrated in Chan's wetland curriculum intervention, its efficacy lies in the alignment with the social family's focus on collaborative interaction, public issue inquiry, and democratic skill-building [34]. Within this framework, ERB development follows a spiral reinforcement mechanism consisting of three iterative stages: reflection, action, and re-reflection. Crucially, behavioral practice serves as the pivotal link, consolidating ERB through authentic public engagement. When students communicate environmental concepts to local residents, deliberate solutions with peers, or present policy recommendations to decision-makers, classroom-acquired skills are translated into civic participation. In this way, deliberative pedagogy elevates ERB from a temporary instructional outcome to a sustained habit embedded in real social contexts, exemplifying the transformative potential of social family of models.

While deliberative pedagogy highlights the role of structured public engagement, research also underscores the importance of immediate, context-based application. Yucel and Ozkan found that seventh-grade students who engaged in practical activities such as water and soil testing reported improved environmental attitudes compared to peers in conventional instruction [38]. However, despite performing process-oriented tasks (e.g., proposing solutions, reflecting on ecosystem interdependencies), these students did not demonstrate sustained ERB. A key limitation was the absence of structured opportunities for public participation, such as disseminating findings to stakeholders or engaging in community-based initiatives. Without these extensions beyond the classroom, the translation of attitudes and knowledge into durable behavioral practices remained incomplete.

Taken together, these findings affirm the essential role of social family of models in fostering ERB but also emphasize that pedagogical strategies alone are insufficient without temporal depth. Gottlieb et al. observed no significant short-term behavioral improvements, highlighting the need for sustained and coherent interventions [53]. Effective ERB development thus requires longitudinally structured educational commitments in which behavioral practice outcomes continually inform renewed cognitive engagement, producing an iterative cycle of attitudinal refinement and skill consolidation. Ultimately, the cultivation of enduring ERB depends not only on the choice of pedagogical model but on the systemic integration of long-term, practice-oriented EE [36,50].

5. Discussion

This systematic review provides a comprehensive synthesis of pedagogical approaches employed to foster environmental literacy in secondary education, highlighting geographical distribution, methodological trends, and the differential impact of instructional models across the knowledge, dispositional, competency, and behavioral dimensions of students' environmental literacy. The findings reveal both continuities with established literature and novel insights that contribute to advancing theory–practice alignment in environmental education.

The dominance of studies from the United States, Asia, and Europe reflects a geographical imbalance, with Africa, Oceania, and Latin America underrepresented. This echoes recent critiques of environmental and sustainability education research, which continues to marginalize perspectives from the Global South [56,57]. This imbalance risks narrowing the knowledge base of EE, as locally embedded pedagogies from ecologically vulnerable regions remain under-explored. It further constrains the cultural and contextual generalizability of current findings, since pedagogical approaches validated in high-resource settings may not be directly applicable to Global South classrooms. Several structural factors contribute to this gap, including limited funding for pedagogical reform and research,

language barriers, and competing policy priorities that often sideline EE in lower-resource education systems [58]. In addition, this review is limited by its focus on English-language publications indexed in major international databases. While this choice ensured methodological transparency and replicability, it may have excluded non-English and regionally indexed studies—particularly those representing Global South perspectives. Addressing these gaps in future research is critical, not only to advance epistemic justice but also to foster pedagogical innovation informed by diverse ecological contexts and cultural realities.

Methodologically, the prevalence of mixed-methods research aligns with a broader shift toward methodological pluralism in EE [59]. However, the over-reliance on questionnaires in the reviewed studies indicates a tendency to capture perceptions rather than observable or long-term behavioral outcomes in EE. This limitation echoes Wals, who argued that measuring transformation in sustainability education requires longitudinal, participatory, and behaviorally grounded methodologies [60]. Accordingly, there is a need in future research to triangulate more diverse research methods—such as performance-based assessments, longitudinal designs, and participatory approaches—to more effectively capture changes in students' environmental literacy.

Although the number of included studies is relatively small, this in itself is a significant finding as it reflects the scarcity of research on pedagogical approaches for environmental literacy at the secondary education level. The value of this review does not lie in broad statistical generalization but in providing an evidence-informed synthesis of existing practices and outcomes. By systematically analyzing current studies, the review highlights tendencies in the use of teaching models for EE in secondary education and identifies critical gaps in fostering students' environmental literacy. In doing so, the study establishes a foundation for future research, offering direction for innovation in pedagogical design in EE.

5.1. Pedagogical Orientation in Teaching EE During Secondary Education

The results of this review demonstrate a strong alignment with constructivist pedagogy, as most pedagogical approaches used in EE fell within the social, information-processing, or personal families of teaching models. The absence of behavioral family teaching models in the reviewed educational research is, to some extent, revealing. While early EE often relied on behaviorist strategies such as conditioning routines (e.g., recycling drills or pro-environmental pledges) [61,62], contemporary approaches have shifted toward pedagogies that emphasize active engagement, critical and higher-order thinking, and the development of student agency.

Nevertheless, this paradigmatic transition is not without tension. While the shift away from behaviorism prevents superficial compliance-based learning, the relative neglect of environmentally responsible behavior in the reviewed studies ($n = 5$) suggests a risk of disconnecting dispositions and competencies from concrete action when fostering students' environmental literacy. Scholars caution that without sustained opportunities for praxis, EE risks developing “scaring but passive” students who hold strong attitudes but lack the experience and efficacy to translate them into real-world behaviors [13,63]. In addition, at the institutional level, many schools face structural constraints, such as limited curricular time and lack of administrative support for action-based projects, which further restrict opportunities to design and evaluate ERB-focused interventions [64].

The limited representation of ERB in the reviewed literature can also be partly attributed to methodological limitation. While dispositions and attitudes are often easier to measure through standardized questionnaires, whereas documenting sustained behavioral change requires long-term, resource-intensive interventions. There is a need for future studies to develop appropriate methodologies capable of capturing students' development in ERB.

5.2. Contributions of Different Pedagogical Models to Students' Environmental Literacy

The findings confirm that environmental literacy is multidimensional—spanning knowledge, dispositions, competencies, and behaviors—yet current pedagogical emphases are unevenly distributed.

For knowledge dimension of environmental literacy, engagement-driven and multi-modal teaching strategies, including outdoor experiential learning, ICT-supported inquiry learning, and visual scaffolds, significantly enhance conceptual retention and integration of environmental knowledge. These findings converge with recent work by Frisk and Larson [65], who demonstrate that immersive and multi-modal EE pedagogical approaches improve students' systems thinking and conceptual depth regarding environmental issues. However, the motivational paradox identified in Shepardson et al.'s study—where students can recall fragmented knowledge but they tend to undervalue knowledge acquisition as an important learning goal—points to a persistent disjunction between teacher intention of fostering students' systems thinking and students' lack of motivation to learn deeper [66]. Effective pedagogy must therefore situate content knowledge within personally relevant, participatory experiences, creating meaningful opportunities for learners to connect ecological concepts with their own lives and communities. In doing so, educators can reconcile cognitive gains in environmental literacy with the motivational engagement needed for sustained pro-environmental action.

In terms of disposition dimension of environmental literacy, outdoor experiences and contextualized learning remain essential for fostering affective connections between students and nature, yet they also risk negative or ambivalent learning outcomes when instructions are poorly designed [67]. Recent research emphasizes that dispositions are not merely “outputs” of students' learning experiences. Instead, dispositions evolve through iterative cycles of reflection, dialogue, and social validation [68]. This aligns with the reviewed evidence on sociocultural feedback systems (e.g., public dissemination of student work) as critical levers for the development of students' sense of agency. Pedagogical design that aims to foster students' positive disposition in EE are suggested to move beyond “nature exposure” toward structured reflective and dialogic instruction that deepen students' dispositional transformation.

This review highlights that inquiry- and problem-based pedagogies are particularly effective in fostering students' environmental competencies. By engaging learners in cycles of identifying environmental problems, developing scientific explanations, and exploring practical solutions, these pedagogical approaches strengthen students' critical skills such as decision-making, evidence-based argumentation, and collaborative problem-solving. Moreover, culturally sustaining teaching practices—such as integrating local cultural expressions and justice-oriented perspectives in EE (e.g., [54])—demonstrate how environmental competencies can be developed in ways that broaden students' participation, affirm diverse identities, and advance equity within environmental education.

The review found little pedagogical interventions that have direct impacts on students' behaviors compare to knowledge, competence or disposition dimensions of environmental literacy. This may imply that sustainable behavioral change emerges not from isolated behaviorist strategies but from integrated, praxis-oriented learning pathways which also draw upon knowledge, competencies and dispositions dimensions of the environmental literacy. To sustain ERB, students must be given repeated opportunities to practice pro-environmental actions in real contexts, supported by feedback loops that reinforce efficacy and collective responsibility.

6. Recommendation

Based on the synthesis of this review and alignment with recent literature, three key recommendations emerge for advancing the pedagogy of environmental education in secondary schools. First, environmental literacy is most effectively conceptualized as an integrated construct rather than a set of discrete or sequentially developed components. Pedagogical strategies should therefore avoid privileging knowledge or dispositions in isolation, and instead foster the coordinated development of cognitive, affective, and behavioral dimensions, thereby facilitating progression from conceptual understanding to meaningful action. For instance, inquiry-based projects demonstrate the greatest potential when extended to student-led community interventions that connect content knowledge with the practice of competencies and the enactment of environmentally responsible behaviors. Second, the evidence highlights the value of participatory, dialogic, and justice-oriented pedagogical approaches. These approaches require a shift from transmissive models of instruction toward pedagogies that incorporate deliberative dialogue, culturally sustaining practices, and whole-school initiatives, thereby positioning students not merely as recipients of knowledge but as co-constructors of learning and contributors to community change. Finally, the review underscores the pivotal role of teacher expertise as a systemic determinant of effectiveness across pedagogical models. Student outcomes are contingent upon teachers' capacity to facilitate inquiry, scaffold reflection, and design inclusive and technologically mediated learning experiences. As such, sustained investment in teacher professional development and institutional support is essential if innovative pedagogies are to be consistently implemented and achieve impact at scale.

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Abbreviations

The following abbreviations are used in this manuscript:

A-B	Attitude-Behavior
ESD	Education for Sustainable Development
EE	Environmental education
ERB	Environmentally responsible behavior
GIS	Geographic information systems
GAP	Global Action Programme
ICT	Information and communication technologies
NAAEE	North American Association for Environmental Education
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PISA	Programme for International Student Assessment

UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual reality
WSA	Whole-school approach

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