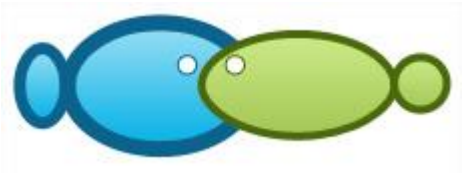

Pedagogical approaches in ocean literacy education: innovations and effectiveness (2020-2025)

[1]Ahmad Satibi, [1]Agus Setiawan, [1]Iwa Kuntadi, [1]Isma Widiaty, [1]Dwi Fitria A. Husaeni, [1]Purnomo Sidiq, [2]Daniel J. Tarigan

[1] Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Bandung, Indonesia; [2] Marine and Fisheries Study Program, Universitas Pendidikan Indonesia, Bandung, Indonesia. Corresponding author: A. Setiawan, agus_setiawan@upi.edu

Abstract. Ocean literacy represents a critical educational priority as global societies face unprecedented marine environmental challenges. This systematic literature review examines pedagogical strategies in ocean literacy education between 2020-2025, identifying effective teaching methods, learning outcomes, and implementation challenges. Following PRISMA guidelines, we searched Scopus database, yielding 19 peer-reviewed English articles with explicit pedagogical focus. Thematic analysis revealed four dominant pedagogical clusters: game-based and experiential learning (n = 6), technology-enhanced education including AR/VR (n = 5), place-based and contextual learning (n = 4), and interdisciplinary systems thinking (n = 4). Significant innovations include augmented reality board games, citizen science applications, and community co-creation models. Effectiveness indicators emphasized knowledge acquisition and attitude formation over behavioral change. Contemporary pedagogy shifts from teacher-centered lectures toward immersive, participatory, technology-enhanced approaches. However, critical gaps persist in longitudinal assessment, cultural adaptation, and formal curriculum integration, particularly in developing regions. This review provides evidence-based directions for advancing ocean literacy education toward greater effectiveness and equity.

Keywords: educational technology, marine environmental education, marine literacy, pedagogical innovations, technical and vocational education and training (TVET).

Introduction. The world's oceans cover over 70% of Earth's surface and provide more than 50% of atmospheric oxygen, yet fewer than 20% of the global population adequately understands ocean-human relationships (Santoro et al 2021). This literacy gap becomes increasingly critical as marine ecosystem degradation accelerates: approximately 8 million tons of plastic enter oceans annually, and 30% of global fish stocks are overexploited (FAO 2022). Ocean literacy defined as understanding the ocean's influence on humans and human influence on the ocean (Cava et al 2005; Schoedinger et al 2005) has consequently emerged as essential for sustainable development, directly supporting SDG 14 (Life Below Water), SDG 13 (Climate Action), and SDG 4 (Quality Education).

The UN Ocean Decade (2021-2030) positions ocean literacy as central to transforming humanity's relationship with the ocean (United Nations 2017), emphasizing the urgent need for effective pedagogical approaches that transcend traditional knowledge transmission. This global initiative recognizes that protecting marine ecosystems requires not merely scientific understanding, but fundamental shifts in how societies perceive, value, and interact with ocean environments (Visbeck 2018; McKinley et al 2023). The accelerating climate crisis and its profound ocean impacts including warming, acidification, and sea-level rise compound the urgency for widespread ocean literacy as a foundation for informed decision-making and collective action (IPCC 2019). Marine ecosystem services, valued at trillions of dollars annually, underpin global food security, climate regulation, and economic prosperity, yet face unprecedented cumulative

human impacts requiring urgent educational responses (Costanza et al 2014; Halpern et al 2015).

Despite its global significance, ocean literacy education faces considerable pedagogical challenges that constrain its effectiveness and reach. First, integration across sociocultural contexts remains limited, with programs often remaining localized without standardized, transferable models that respect cultural diversity while maintaining educational rigor (Mogias et al 2019; Koulouri et al 2022). Second, while digital technology offers transformative potential, its integration remains uneven potentially exacerbating educational inequalities rather than democratizing access to marine knowledge (Mokos et al 2020; Ahmad-Kamil et al 2022). Third, the inherent complexity of marine ecosystems and uncertainty in environmental data complicate impact evaluation, with most assessments focusing on immediate knowledge gains rather than sustained pro-ocean behaviors (Ashley et al 2019; Stoll-Kleemann 2019). The persistent knowledge-behavior gap further complicates educational design, as research demonstrates that increased environmental knowledge does not automatically translate into pro-environmental action (Kollmuss & Agyeman 2002; Stern 2000). This gap is mediated by complex factors including values, social norms, perceived self-efficacy, and structural constraints (Ajzen 1991), requiring pedagogical approaches that address cognitive, affective, behavioral, and systemic dimensions simultaneously (McKinley et al 2023).

However, significant opportunities exist within this challenging landscape. Cross-disciplinary collaboration between marine scientists, educators, social scientists, and indigenous knowledge holders can generate more holistic, culturally grounded approaches (Brennan & Ashley 2020). Community-based education models show promise for contextualizing ocean literacy within local cultures, livelihoods, and traditional ecological knowledge systems (Guest et al 2015; Lotze et al 2018). Participatory and co-creation approaches that position learners as active knowledge producers rather than passive recipients offer pathways toward more meaningful engagement (Ballantyne et al 2009; Jacobson et al 2015). Place-based pedagogies connecting abstract ocean concepts to learners' immediate environments demonstrate enhanced relevance and motivation (Gruenewald 2003; Sobel 2004). Additionally, emerging technologies including open data platforms, citizen science applications, augmented and virtual reality, and artificial intelligence offer unprecedented potential for creating immersive, personalized learning experiences that transcend geographical constraints (Dede 2009; Merchant et al 2014).

Ocean literacy has attracted growing scholarly attention over the past two decades. Foundational work established core principles and frameworks defining what it means to be ocean literate (Cava et al 2005; Schoedinger et al 2010; Steel et al 2005). Subsequent research examined ocean literacy's role in formal education systems (Schoedinger et al 2010; Freitas et al 2022), community engagement strategies (Guest et al 2015; O'Brien et al 2023), and connections to broader sustainability and environmental citizenship frameworks (Brennan et al 2019; McKinley & Fletcher 2012). Recent systematic reviews have examined ocean literacy frameworks and measurement instruments (Fauville et al 2019; Santoro et al 2017), public perceptions of marine threats and conservation (Lotze et al 2018; McKinley & Fletcher 2012), behavior change mechanisms (Stoll-Kleemann 2019), and the overall evidence base for ocean literacy interventions (Shellock et al 2024).

However, critical gaps persist in understanding how ocean literacy is most effectively taught and learned. While various pedagogical approaches have been documented - including experiential learning (Kolb 1984), technology-enhanced instruction, place-based education (Sobel 2004), game-based learning (Prensky 2001; Squire 2006), and interdisciplinary curricula - systematic synthesis comparing effectiveness across contexts remains limited. Few studies systematically examine which specific pedagogical strategies produce which learning outcomes (cognitive, affective, behavioral), or how these relationships vary across age groups, cultural contexts, and educational settings (Ashley et al 2019; Shellock et al 2024; Asikin et al 2025). The field lacks consistent frameworks for measuring educational effectiveness beyond immediate knowledge acquisition, with limited attention to attitude formation, skill development,

and particularly behavioral change (Stoll-Kleemann 2019). Moreover, while technology-enhanced learning receives considerable attention, empirical evidence regarding how digital tools (augmented reality, virtual reality, online platforms, and mobile applications) specifically contribute to ocean literacy development remains scattered and poorly synthesized (Chappell & Hetherington 2024; Leitão et al 2025). Questions persist about whether technology serves primarily as an engagement tool, a visualization aid, or fundamentally transforms learning processes in ocean education contexts.

Geographic concentration of ocean literacy research in Global North contexts represents another critical gap (Paredes-Coral et al 2021; Cavas et al 2023). Coastal communities in developing regions, Small Island Developing States, and indigenous territories areas where ocean dependence is highest and climate vulnerability most acute remain dramatically underrepresented in research literature. This imbalance raises concerns about the cultural appropriateness and transferability of predominantly Western-developed pedagogical models to diverse global contexts (Christie & Cárcamo-Ulloa 2023; Pazoto et al 2023a). Recent studies from Brazil (Ghilardi-Lopes et al 2023; Pazoto et al 2023b), Chile (Christie & Cárcamo-Ulloa 2023), Turkey (Cavas et al 2023), and Mediterranean regions (Koulouri et al 2022; Mioni 2022) begin addressing this gap but require broader synthesis. Additionally, curriculum integration challenges persist, with ocean content often remaining marginalized in national curricula rather than being treated as core knowledge (Ahmad-Kamil et al 2022; Freitas et al 2022). Understanding teacher preparedness, professional development needs, and how ocean literacy can be systematically integrated across subject areas while respecting disciplinary integrity requires attention (Freitas et al 2025; Ghilardi-Lopes et al 2023).

This systematic literature review addresses these gaps through comprehensive synthesis of pedagogical approaches in ocean literacy education published between 2020 and 2025. This timeframe captures the post-UN Ocean Decade launch period (2021 onwards), encompasses COVID-19-driven digital transformations that fundamentally reshaped educational delivery, and reflects renewed global commitment to ocean sustainability and blue economy development. By systematically examining peer-reviewed empirical studies and reviews, this research provides evidence-based mapping of dominant pedagogical approaches employed across diverse learning contexts, investigates how different teaching methods are evaluated for effectiveness, analyzes technology's role in ocean literacy development, identifies implementation challenges across varied geographical and cultural settings, and illuminates promising future directions for advancing ocean literacy education.

This synthesis serves multiple audiences and purposes. For researchers, it identifies productive directions for future investigation, highlights methodological needs, and reveals theoretical gaps requiring attention. For practitioners (teachers, informal educators, curriculum developers, program designers) it provides evidence-based guidance for selecting and adapting pedagogical approaches appropriate to their specific contexts and goals. For policymakers and educational administrators, it offers data-driven insights to inform curriculum development, professional development initiatives, and resource allocation decisions. Throughout this analysis, the review attends to issues of educational equity, cultural responsiveness, and scalability recognizing that effective ocean literacy education must be simultaneously scientifically rigorous, culturally relevant, pedagogically sound, accessible across resource contexts, and socially just. Only through such comprehensive, contextualized approaches can ocean literacy fulfill its transformative potential as a foundation for sustainable ocean governance, climate action, and global environmental citizenship in the UN Ocean Decade and beyond.

Material and Method

Methodological section. Ocean literacy research during 2020-2025 demonstrates a significant pedagogical transformation from teacher-centered lectures toward learner-centered, immersive, and participatory approaches. Key innovations include game-based learning pedagogy utilizing augmented reality board games that effectively enhance knowledge acquisition, attitude formation, and activism engagement simultaneously,

alongside the integration of AR/VR technologies and digital platforms that facilitate visualization of complex oceanic processes such as ocean acidification and circulation patterns while democratizing educational access for landlocked populations. Citizen science mobile applications have emerged as powerful tools developing dual competencies in ocean and data literacy through community co-creation models. However, more focused research is critically needed in several areas: developing standardized multidimensional assessment frameworks for consistent evaluation across cognitive, affective, and behavioral dimensions, implementing digital divide mitigation strategies to ensure equitable technology access, conducting longitudinal behavioral impact measurements beyond immediate post-intervention outcomes, culturally adapting pedagogical approaches for non-Western contexts, and exploring the transformative potential of artificial intelligence technologies and open data platforms for achieving scalable and equitable global marine education.

This systematic literature review followed seven sequential stages as illustrated in Figure 1. The methodological workflow proceeded through: (1) protocol establishment following PRISMA 2020 guidelines (Page et al 2021); (2) eligibility criteria definition using the SPIDER framework (Cooke et al 2012); (3) comprehensive search strategy in Scopus database with structured Boolean queries; (4) two-stage selection process from title-abstract to full-text screening; (5) standardized data extraction encompassing study characteristics, pedagogical approaches, learning outcomes, and implementation challenges; (6) integrated data synthesis combining thematic narrative analysis (Miglani et al 2026; Popay et al 2006) with quantitative descriptive summaries; and (7) quality assessment using adapted Critical Appraisal Skills Programme criteria (Long et al 2020). This systematic process ensured transparent, rigorous, and replicable evidence synthesis of pedagogical approaches in ocean literacy education during 2020-2025.

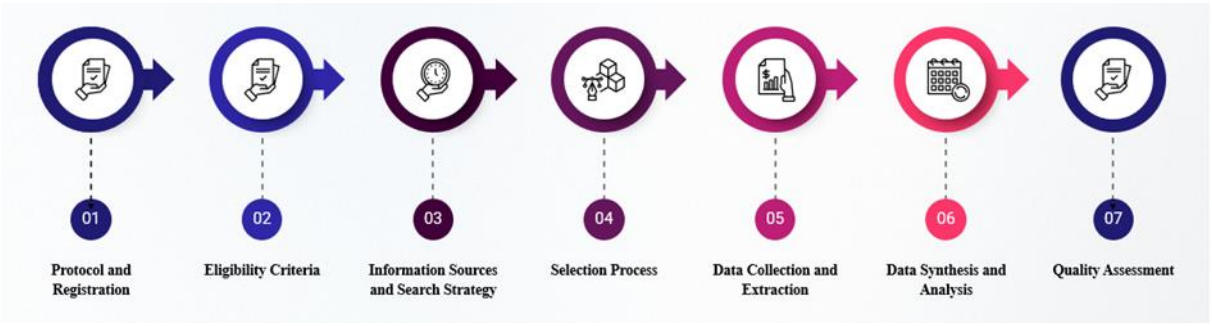

Figure 1. Research procedure of systematic literature network analysis (SLNA).

Protocol and registration. This systematic literature review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al 2021). The review protocol was not prospectively registered given the educational and non-clinical nature of the study. All methodological procedures were systematically documented to ensure transparency and reproducibility.

Eligibility criteria. Study selection followed the SPIDER framework (Sample, Phenomenon of Interest, Design, Evaluation, Research type) (Cooke et al 2012) to ensure systematic and transparent eligibility assessment. Inclusion criteria comprised: (1) peer-reviewed articles or reviews published between January 2020 and December 2025; (2) English language publications; (3) explicit ocean or marine literacy focus within educational contexts; (4) discussion of pedagogical approaches or learning interventions; (5) empirical data or systematic analysis; and (6) full-text accessibility. The 2020-2025 timeframe captured contemporary innovations following the UN Ocean Decade launch (2021) and post-pandemic digital transformations in education.

Exclusion criteria eliminated: (1) purely theoretical papers without pedagogical applications; (2) marine biology studies lacking literacy education components; (3) non-English publications; (4) non-peer-reviewed materials including conference papers, book chapters, and proceedings; and (5) inaccessible full-texts. The complete selection process

from initial database search through final inclusion is detailed in Figure 2, which presents the PRISMA 2020 flow diagram (Page et al 2021) illustrating systematic filtering stages and exclusion rationale at each decision point.

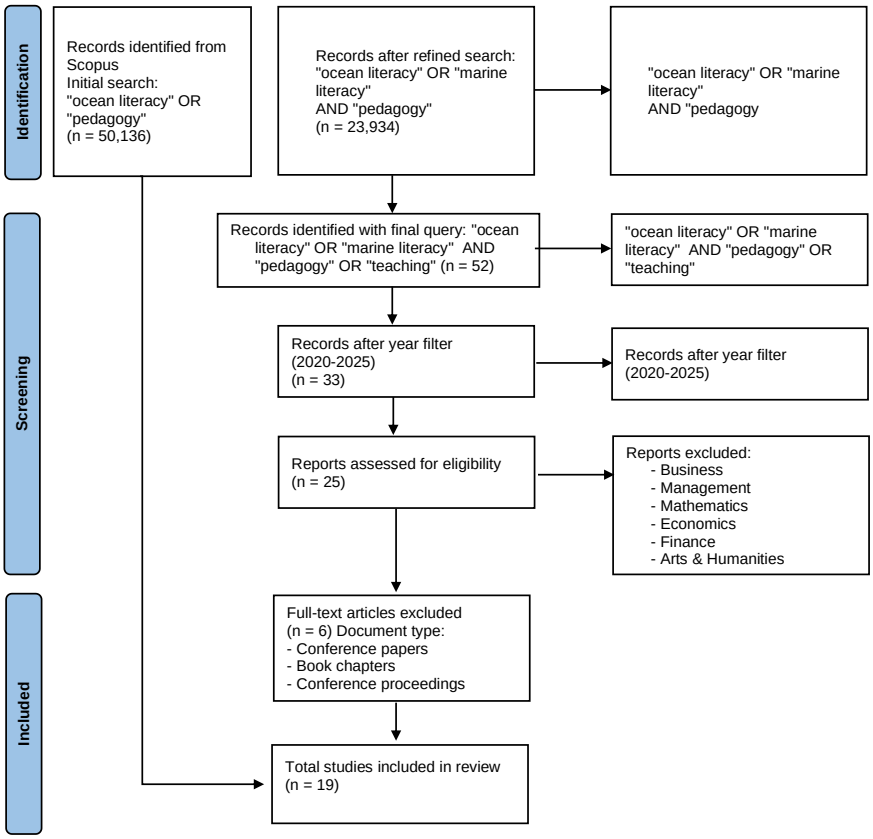

Figure 2. PRISMA diagram.

Information sources and search strategy. A comprehensive literature search was conducted using the Scopus database on October 19, 2025, selected for its extensive interdisciplinary coverage, consistent metadata quality, comprehensive international indexing, and robust citation tracking capabilities. The Boolean search query employed was: (TITLE-ABS-KEY(ocean) AND TITLE-ABS-KEY(literacy) AND (TITLE-ABS-KEY(pedagogy) OR TITLE-ABS-KEY(education) OR TITLE-ABS-KEY(teaching) OR TITLE-ABS-KEY(learning))). This search strategy ensured that all retrieved articles contained both "ocean" and "literacy" in combination with pedagogical terminology, effectively capturing diverse disciplinary vocabularies while systematically excluding purely scientific oceanographic research without educational components. Applied filters included: publication year range 2020-2025; document types restricted to articles and reviews; and English language publications. Notably, no geographical or subject area filters were imposed during the initial search phase to avoid inadvertent exclusion of valuable interdisciplinary contributions. The search yielded 52 initial records, which after applying year restrictions (2020-2025) resulted in 33 documents. Following systematic screening based on subject relevance and document type criteria as detailed in Figure 2, a final corpus of 19 documents proceeded to comprehensive analysis.

The bibliometric characteristics of the 19 selected studies are presented in Table 1. The corpus spans 14 distinct journals, demonstrating the interdisciplinary nature of ocean literacy education research. An annual growth rate of 31.95% indicates rapidly expanding research interest following the UN Ocean Decade launch (2021) and post-pandemic digital transformations. With a document average age of 2 years and 7.684 citations per document, the studies reflect current pedagogical innovations and emerging scholarly impact. The document type distribution comprises 18 research articles and 1 review paper. Notably, the complete absence of single-authored documents and an

average of 7.37 co-authors per document underscore the highly collaborative nature of ocean literacy research, while international co-authorship at 15.79% reflects global knowledge exchange in marine education initiatives.

Table 1

Main data information

Description	*Results*
Timespan	2020-2025
Sources (journals, books, etc.)	14
Documents	19
Annual growth rate (%)	31.95
Document average age	2
Average citations per doc	7.684
References	153
Document contents	
Keywords plus (ID)	72
Author's keywords (DE)	80
Authors	
Authors	90
Authors of single-authored docs	0
Authors collaboration	
Single-authored docs	0
Co-authors per doc	7.37
International co-authorships (%)	15.79
Document types	
Article	18
Review	1

Selection process. Two-stage screening followed PRISMA guidelines. First stage: title/abstract screening of 19 articles using structured decision matrix with documented rationale. Given highly targeted Boolean construction combining three mandatory concepts, all 19 demonstrated sufficient relevance for full-text examination. This 100% retention reflects search precision rather than lax standards. Second stage: full-text screening assessed pedagogical depth, outcome measurement clarity, and methodological transparency. All 19 met inclusion criteria, explicitly addressing instructional approaches with empirical/systematic evidence. Articles were categorized by pedagogical approach, target population, and study design. While dual independent screening represents best practice, resource constraints limited review to single-reviewer screening with structured documentation enabling transparency. No exclusions during full-text assessment; 19 studies proceeded to extraction, documented in PRISMA flow diagram.

Data collection and extraction. Data extraction used a standardized framework capturing: (1) bibliographic information; (2) study characteristics (design, setting, location, duration); (3) population details (sample size, demographics); (4) pedagogical approaches (methods, frameworks, strategies); (5) intervention description (delivery, frequency, materials); (6) learning outcomes (knowledge, attitudes, behaviors, skills, engagement); (7) assessment instruments; (8) results summary; (9) implementation challenges; (10) technology integration; and (11) author recommendations. Multiple pedagogical approaches within single studies were coded comprehensively.

Data synthesis and analysis. Data synthesis combined thematic narrative analysis with descriptive quantitative summaries. Thematic analysis proceeded inductively, identifying patterns across studies. Initial coding generated pedagogical method labels that were refined into four clusters: (1) game-based and experiential learning; (2) technology-enhanced education; (3) place-based and contextual learning; and (4) interdisciplinary and systems thinking approaches. Quantitative descriptive analysis documented temporal

trends, geographical distribution, study methodologies, and outcome measurement prevalence.

Quality assessment. Quality assessment employed adapted CASP (Critical Appraisal Skills Programme) criteria across six dimensions: research aims clarity, design appropriateness, data collection rigor, outcome measurement validity, analysis transparency, and limitations acknowledgment. Studies received narrative quality assessment rather than numerical scores given design heterogeneity. Common strengths: validated instruments, appropriate statistical analyses, rich qualitative description. Limitations: small samples, lacking controls, short-term follow-up, limited fidelity discussion. No studies excluded based on quality; all met peer-reviewed standards. Quality considerations informed confidence in findings, with patterns across higher-quality studies weighted more heavily than isolated findings from methodologically limited studies

Results and Discussion. Keyword co-occurrence network analysis reveals the conceptual structure and thematic relationships within ocean literacy pedagogy research, as illustrated in Table 2. Network analysis identifies "literacy" and "teaching" as the most central concepts, each demonstrating identical betweenness centrality (24.600), closeness centrality (0.053), and PageRank scores (0.085), underscoring the field's dual focus on literacy development and pedagogical implementation. Secondary hub concepts include "education" (betweenness: 8.000), "learning" (betweenness: 5.400), and "student" (betweenness: 5.400), forming an interconnected pedagogical cluster reflecting learner-centered orientation.

Table 2

Co-occurrence in Network Cluster 1

Node	*Cluster*	*Betweenness*	*Closeness*	*PageRank*
Literacy	1	24.600	0.053	0.065
Teaching	1	24.600	0.053	0.065
Education	1	8.000	0.045	0.068
Learning	1	5.400	0.045	0.066
Student	1	5.400	0.049	0.066
Sustainable development	1	0.000	0.029	0.025
Environmental education	1	0.000	0.030	0.025
Integrated approach	1	0.000	0.020	0.024
Knowledge	1	0.000	0.020	0.024
Marine environment	1	0.000	0.024	0.018

Thematic analysis reveals three distinct conceptual clusters. The first cluster centers on pedagogical processes encompassing "teaching", "learning", "education", and "student", reflecting the field's instructional core. The second cluster emphasizes sustainability dimensions, linking "sustainable development", "environmental education", and "marine environment", indicating integration within broader environmental education frameworks aligned with SDG 14 and SDG 13. The third cluster represents methodological themes including "integrated approach" and "knowledge", suggesting recognition of interdisciplinary strategies and knowledge co-production processes.

Network topology analysis reveals balanced centrality distribution with all keywords belonging to a single cluster, indicating strong thematic coherence without fragmentation into distinct research silos. The PageRank algorithm confirms "literacy" and "teaching" as most influential concepts (0.085 each), validating the field's focus on pedagogical effectiveness rather than purely scientific content transmission. However, relatively modest centrality of "sustainable development" and "environmental education" suggests potential underutilization of established environmental education frameworks, representing an opportunity for enhanced theoretical integration in future research.

Network cluster analysis reveals a secondary thematic cluster (Cluster 2) representing implementation and methodological dimensions of ocean literacy research, as detailed in Table 3. This cluster demonstrates remarkable homogeneity with all nodes exhibiting identical closeness centrality (0.042) and betweenness centrality (0.000), alongside nearly uniform PageRank scores (0.053-0.054), indicating a tightly integrated thematic unit focused on practical implementation rather than bridging disparate research domains.

Table 3

Co-occurrence in Network Cluster 2

Node	*Cluster*	*Betweenness*	*Closeness*	*PageRank*
Curriculum	2	0.000	0.042	0.053
Ocean literacy	2	0.000	0.042	0.054
Students	2	0.000	0.042	0.053
Article	2	0.000	0.042	0.053
Curricula	2	0.000	0.042	0.053
Human	2	0.000	0.042	0.053
Human experiment	2	0.000	0.042	0.053
Oceanography	2	0.000	0.042	0.053
Questionnaire	2	0.000	0.042	0.053
Sea	2	0.000	0.042	0.053

Cluster 2 encompasses three primary thematic subgroups. The curriculum integration subgroup comprises "curriculum" and "curricula" (PageRank: 0.053), reflecting sustained attention to formal education system integration, a critical implementation challenge. The target population subgroup includes "students", "human", and "human experiment" (PageRank: 0.053-0.054), indicating methodological focus on learner-centered pedagogical evaluation. The methodological subgroup encompasses "questionnaire", "article", "oceanography" and "sea" (PageRank: 0.053), revealing quantitative survey methodology dominance and disciplinary connections between marine science content and educational pedagogy.

Cluster differentiation between Cluster 1 (pedagogical processes with higher centrality scores) and Cluster 2 (implementation and methodology with tighter internal integration) reveals conceptual specialization within the field. Zero betweenness centrality across all Cluster 2 nodes indicates these concepts do not bridge to other thematic areas, functioning instead as a coherent implementation-focused subdomain. The relatively balanced PageRank distribution (0.014-0.085) across both clusters indicates that while Cluster 1 maintains greater network connectivity, Cluster 2 represents equally important research addressing translation from pedagogical theory into educational practice.

The keyword co-occurrence network visualization in Figure 3 provides a spatial representation of thematic relationships and conceptual clusters within ocean literacy pedagogy research. The network employs force-directed layout where node size reflects keyword frequency, edge thickness indicates co-occurrence strength, and color differentiation distinguishes thematic clusters. Two distinct yet interconnected clusters emerge, revealing the field's dual focus on pedagogical theory (Cluster 1, red/coral tones) and practical implementation (Cluster 2, blue tones).

Cluster 1 (pedagogical processes) occupies the upper-right quadrant, characterized by densely interconnected hub nodes including "teaching" and "literacy" as the most prominent vertices. These core concepts demonstrate extensive connections to "education", "learning", and "student", creating a tightly integrated semantic network representing the field's foundational pedagogical discourse. Secondary concepts include "sustainable development", "marine environment", "knowledge", "environmental education", and "integrated approach", positioned at moderate distances from the core hub. The dense web of interconnecting edges visualizes how contemporary ocean literacy research integrates sustainability frameworks, environmental education theory, and knowledge systems perspectives into core pedagogical practice.

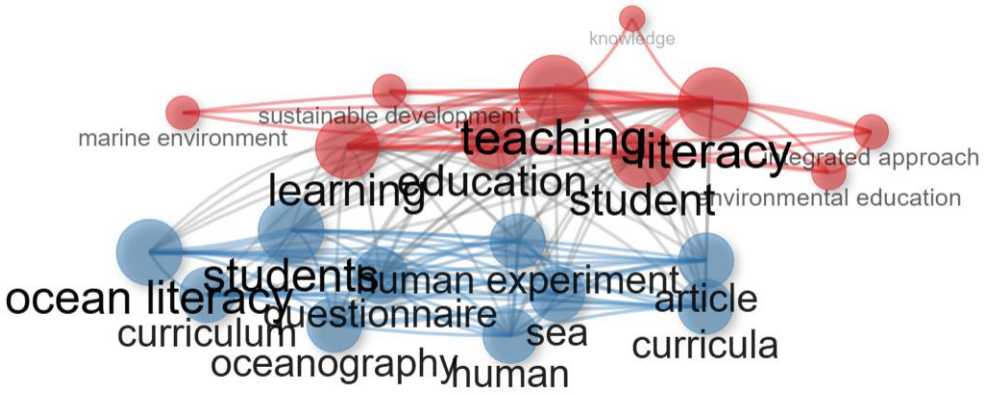

Figure 3. Co-occurrence network.

Cluster 2 (implementation and methodology) occupies the lower-left quadrant, distinguished by blue coloration. The most prominent node is "ocean literacy" itself, functioning as the primary anchor point for implementation-focused research. Surrounding nodes include "students", "curriculum", "curricula", "questionnaire", "article", "oceanography," and "sea", forming a constellation of concepts related to formal education implementation, research subjects, and methodological approaches. The spatial separation between clusters, while maintaining bridging connections, suggests conceptual distinctiveness between theoretical frameworks and practical concerns.

Network topology reveals several critical features. First, inter-cluster connections, though less dense than intra-cluster ties, demonstrate field coherence despite thematic specialization. Second, positioning "ocean literacy" as the largest node in Cluster 2 rather than Cluster 1 suggests that while pedagogical processes dominate theoretical discourse, ocean literacy frameworks are more strongly associated with practical implementation and curriculum design. Third, the balanced distribution of node sizes indicates a maturing field with multiple established research themes rather than dominance by a single paradigm. Overall, the network topology illustrates ocean literacy pedagogy as a coherent yet internally diverse field, balancing pedagogical innovation with implementation pragmatism.

Temporal analysis of the 19 included studies reveals dynamic publication patterns and citation trajectories across 2020-2025, as detailed in Table 4. Annual scientific production fluctuated from 1 article in 2020 to a peak of 5 articles in 2023, before stabilizing at 3-4 articles in 2024-2025, reflecting rapid expansion following the UN Ocean Decade launch in 2021. Citation analysis demonstrates complex relationships between publication timing and scholarly impact. The 2020 publication achieved highest mean citations per article (29.00) and annual citation rate (4.83), indicating foundational influence. The 2022 cohort demonstrated strong sustained impact (MeanTCperArt: 16.50 across 4 articles; MeanTCperYear: 4.12), while recent publications show predictably lower citation rates due to limited windows: 2023 (1.73 citations/year), 2024 (1.33), and 2025 (0.75). The CitableYears metric reveals that 68% of studies (n = 13) were published in 2023-2025 with only 1-3 citable years, potentially underrepresenting their ultimate impact. The corpus has accumulated 146 total citations, yielding an overall average of 7.68 citations per article, comparable to typical educational research citation rates. The publication surge in 2023 coincides with heightened attention following the 2022 UN Ocean Conference, with sustained productivity in 2024-2025 indicating evolution toward established research programs contributing to evidence-based ocean education policy.

The thematic map reveals distinct conceptual clusters within ocean literacy pedagogy research, reflecting the field's intellectual structure and thematic priorities (Figure 4). The Formal Education Cluster dominates the thematic landscape, characterized by dense interconnections among curriculum, education, literacy, students, sustainable development, and environmental education. This cluster's high centrality signals a fundamental shift: ocean literacy is transitioning from peripheral enrichment activities toward core curricular integration (Freitas et al 2022; Ahmad-Kamil et al 2022). The tight coupling between education for sustainable development, integrated

approaches, and coastal zone management suggests contemporary scholarship increasingly frames ocean literacy as essential to holistic sustainability education rather than isolated marine content (Brennan et al 2019; McKinley et al 2023).

Table 4

Average citation per years

Year	*Mean TC per art*	*N (number of articles)*	*Mean TC per year*	*Citable years*
2020	29.00	1	4.83	6
2021	7.00	2	1.40	5
2022	16.50	4	4.12	4
2023	5.20	5	1.73	3
2024	2.67	3	1.33	2
2025	0.75	4	0.75	1

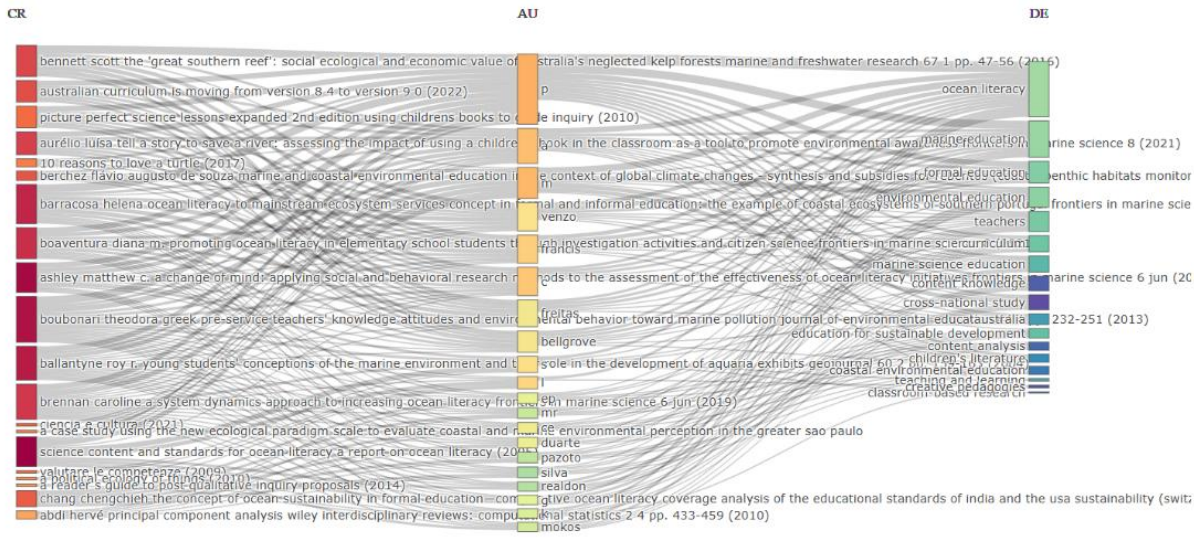

Figure 4. Three-field plot analysis.

The Marine Context Cluster emphasizes place-based and scientific elements application systems, marine environment, reefs, oceans and seas, with geographic specificity. The moderate density but strong bridging connections to the central 'ocean literacy' node indicate that while marine science content remains foundational, it increasingly serves as context for broader educational objectives (Gruenewald 2003; Sobel 2004). The inclusion of application systems reflects growing integration of technological tools for marine environment exploration and learning (Dede 2009; Merchant et al 2014). The Biodiversity and Scientific Literacy Cluster occupies a peripheral position, centering on biodiversity, genomic data, and advanced scientific concepts. This cluster's separation from the dominant education cluster reveals a persistent gap between cutting-edge marine science and pedagogical practice (Munandar et al 2025). Weak connections between scientific frontiers and formal education suggest ongoing challenges in translating complex marine science into accessible educational content.

The Research Infrastructure Cluster, positioned peripherally, includes literature review, knowledge, and research development. This meta-level cluster's distance from the pedagogical core suggests methodological and theoretical discussions remain somewhat disconnected from practical implementation (Shellock et al 2024; Asikin et al 2025). Notably absent from prominent positions are terms related to behavioral outcomes, long-term impact assessment, equity, and cultural adaptation gaps that warrant critical attention (Stoll-Kleemann 2019; Ashley et al 2019).

Geographic analysis reveals striking concentration in ocean literacy pedagogy research, raising critical questions about knowledge equity and global representativeness (Figure 4). Research demonstrates substantial imbalance favoring Global North contexts, particularly Australia, Mediterranean regions, and North America (Paredes-Coral et al

2021; Cavas et al 2023). This geographic concentration leaves critical gaps regarding pedagogical effectiveness in Global South coastal communities where ocean dependence is highest yet research representation remains lowest (Christie & Cárcamo-Ulloa 2023; Pazoto et al 2023a). Recent studies from Brazil (Ghilardi-Lopes et al 2023; Pazoto et al 2023b), Chile (Christie & Cárcamo-Ulloa 2023), and Mediterranean regions (Koulouri et al 2022; Mioni 2022) begin addressing this gap, yet systematic comparison across diverse cultural and economic contexts remains limited. This imbalance raises concerns about cultural appropriateness and transferability of predominantly Western-developed pedagogical models to diverse global contexts, highlighting the urgent need for decentralized, culturally-responsive ocean literacy research that respects local knowledge systems and contextual realities (Lotze et al 2018).

Australia leads in research productivity, with multiple collaborative teams focusing on curriculum integration, teacher professional development, and institutionalization within formal schooling (Freitas et al 2022; O'Brien et al 2023; Freitas et al 2025), reflecting a policy environment where ocean literacy has achieved recognition in national educational frameworks. Brazil represents the second major cluster, with researchers emphasizing coastal environmental education, participatory approaches, and place-based learning responsive to local community needs (Ghilardi-Lopes et al 2023; Pazoto et al 2023a, b), aligning with socio-ecological contexts where coastal populations maintain direct marine resource dependencies. Mediterranean region contributions demonstrate thematic concentration in cross-national comparative studies, assessment development, and marine pollution education (Koulouri et al 2022; Mioni 2022), addressing shared regional conservation priorities around Mediterranean Sea health. This geographic concentration reveals a concerning pattern: research is dominated by countries with extensive coastlines, established marine science infrastructure, and well-resourced educational systems (Paredes-Coral et al 2021; Cavas et al 2023). Critically underrepresented are Small Island Developing States (SIDS), landlocked nations, and coastal communities in Africa and Asia precisely the regions where ocean dependency is highest and vulnerability to marine changes most acute, yet research representation remains dramatically insufficient (Shellock et al 2024). This knowledge asymmetry risks perpetuating pedagogical approaches that may not adequately address the diverse cultural, economic, and ecological contexts of global ocean literacy needs, highlighting the urgent necessity for geographically diversified research collaborations and South-South knowledge exchange (Lotze et al 2018; McKinley et al 2023).

The thematic map (Figure 5) reveals how geographic location substantially shapes pedagogical priorities, demonstrating three distinct research orientations with fundamentally different philosophical approaches. Australian research demonstrates strong institutional orientation, prioritizing formal curriculum integration, teacher capacity building, and alignment with national standards (Freitas et al 2022; O'Brien et al 2023; Freitas et al 2025). While this approach facilitates systemic embedding of ocean literacy, it may overemphasize top-down institutional mechanisms at the expense of informal, community-based educational initiatives that often reach marginalized populations (Jacobson et al 2015). Brazilian scholarship emphasizes environmental awareness, coastal management, community participation, and place-based pedagogy, demonstrating cultural responsiveness by connecting learning to immediate livelihood concerns (Gruenewald 2003; Ghilardi-Lopes et al 2023; Pazoto et al 2023a, b). However, its strength in local contextualization may limit transferability, and the focus on awareness-raising may insufficiently address action competence and behavioral change (Stoll-Kleemann 2019). Mediterranean contributions prioritize cross-cultural evaluation, marine pollution education, and knowledge measurement (Koulouri et al 2022; Mioni 2022), advancing ocean literacy assessment capabilities but potentially undervaluing affective and behavioral dimensions (Ashley et al 2019).

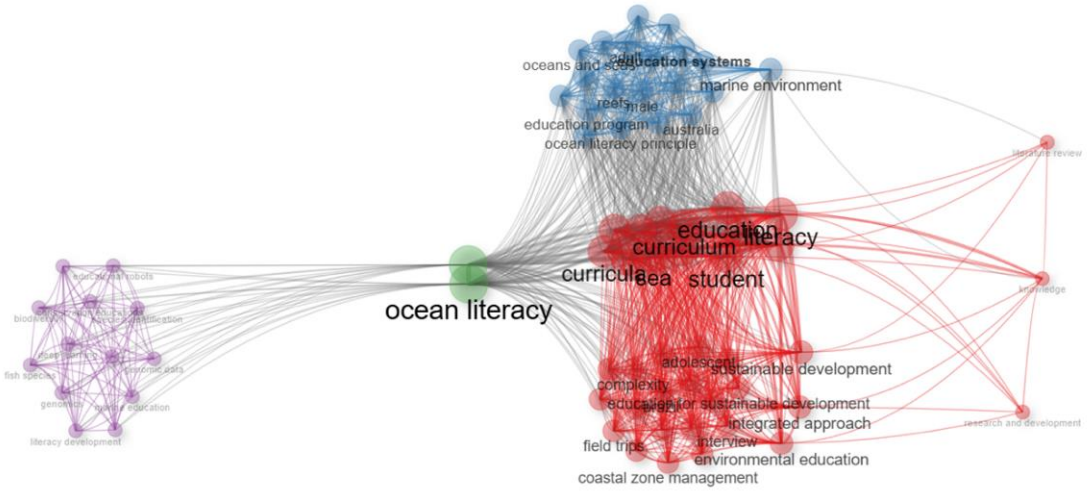

Figure 5. Thematic map.

These models reflect fundamentally different pedagogical philosophies: Australian research prioritizes systemic sustainability through institutional integration; Brazilian approaches emphasize contextual relevance through community participation; Mediterranean research advances methodological rigor through standardized assessment. Each offers valuable contributions yet reveals limitations no single model adequately integrates institutional capacity, community engagement, and comprehensive evaluation, suggesting need for hybrid approaches (McKinley et al 2023; Shellock et al 2024).

The documented geographic imbalance perpetuates three problematic patterns. First, current research reflects concerns of relatively affluent coastal nations rather than frontline communities facing most severe ocean challenges (Paredes-Coral et al 2021). SIDS confronting existential sea-level rise threats, West African communities experiencing overfishing, and Southeast Asian populations managing marine plastic pollution remain largely absent from scholarly discourse, meaning pedagogical innovations may inadequately address most urgent global ocean literacy needs (Lotze et al 2018). Second, documented pedagogical approaches predominantly reflect Western educational paradigms which may misalign with collectivist learning cultures, oral knowledge transmission traditions, and resource-constrained contexts prevalent in Global South settings (Sobel 2004; Mogias et al 2019). This risks pedagogical imperialism where culturally-specific approaches are universalized without adequate adaptation. Third, international co-authorship remains low (15.79%), restricting knowledge exchange, capacity development, and co-creation of culturally responsive approaches (Cavas et al 2023). North-South collaborations could integrate diverse epistemologies indigenous marine stewardship, traditional ecological knowledge, and locally-evolved pedagogical practices, enriching global ocean literacy while respecting knowledge pluralism (Guest et al 2015; Brennan et al 2019).

Geographic concentration fundamentally limits research generalizability. Interventions demonstrating effectiveness in Australian primary schools or Brazilian coastal communities may not transfer to landlocked African nations, Arctic Indigenous communities, densely populated Asian coastal megacities, or SIDS where entire cultural identities center on ocean dependencies (Christie & Cárcamo-Ulloa 2023; Shellock et al 2024). Without representative geographic diversity, the field cannot develop universally applicable pedagogical frameworks or inform globally relevant policy. Current research provides valuable context-specific insights but limited guidance for addressing diverse global ocean literacy needs in culturally responsive, equitable, and scalable ways (McKinley et al 2023).

As a step in our in-depth analysis, we synthesized the 19 articles used in the bibliometric analysis method described above. The synthesis of findings on pedagogical approaches to marine literacy education, summarized in Table 5, demonstrates that marine literacy education is evolving through diverse pedagogical approaches and increasingly complex technology integration across various educational contexts

Table 5

Synthesis analysis of pedagogical approaches in ocean literacy education

No	*Research direction*	*Methods*	*Conclusions*	*Recommendations*	*References*
1	Development of game-based learning with AR technology to improve marine literacy through formal and informal education	The co-design approach with students uses the Design, Play and Experience (DPE) framework; intervention with a pre/post assessment design to evaluate six dimensions of marine literacy	AR games have significant potential to improve various dimensions of marine literacy including knowledge acquisition, awareness enhancement, communication skills, attitude formation, activism involvement, and behavior change compared to traditional lecture methods	Development of more engaging environmental education tools by integrating game-based activities into formal and informal environments; Increased knowledge can have a positive impact on awareness, communication, attitudes, activism and behavior	Leitão et al (2025)
2	Teacher professional development for the integration of marine literacy in formal education in primary schools	Teacher training program with the provision of marine learning materials; evaluation of teachers' responses to the program and their experience in incorporating marine literacy into lessons	Teachers showed a positive response to the training program and successfully incorporated marine literacy in various learning areas; absence of curriculum, lack of teacher knowledge, and limited educational resources are the main obstacles	Design marine education programs that take into account the local context, culture, and environment of the individual school; importance of teacher training in marine literacy as a model	Freitas et al (2025)
3	Integration of deep learning technology genomics databases in project-based marine literacy education	Quantitative approach with 36 biology students; activities include analysis of marine issues, identification of fish species through the Fishiden platform, phylogenetic tree construction, and advocacy through social media; pretest-posttest evaluation and Likert scale questionnaire	Significant improvement in posttest scores with average improvement from 58.11 to 71.88 and moderate N-Gain of 0.30; students with positive responses achieve higher gains; strong correlation between engagement and learning outcomes	Integration of innovative technologies in marine literacy education; improving accuracy of deep learning models; bridging technology, pedagogy, and ocean conservation for sustainability	Munandar et al (2025)

4	A systematic review of the integration of curriculum, teaching methods, learning technologies, and assessment instruments for marine literacy	Systematic literature review (SLR) using Scopus database (2012-2022); PRISMA model generated 43 of the 357 articles analyzed	The principles of marine literacy have been incorporated into the educational curriculum in many countries; effective project-based, problem-based, and inquiry-based learning methods; game-based learning and virtual reality technologies provide an interactive learning experience	Teaching the concept of marine literacy through integration of curriculum, innovative methods, technology-based media, and appropriate assessment instruments at all levels of education to support global sustainability and marine conservation efforts	Asikin et al (2025)
5	Creative pedagogy with the integration of digital technology (AR/VR) in STEAM education and marine literacy	The diffractive approach is inspired by the new materialist theory; data analysis from six projects at schools in Denmark, Spain, and the UK; development of four material-dialogical assemblages	The interaction between theory, practice, nature, culture, digital, and human allows for emergent perspectives on changing power dynamics in education and related activism	The development of new pedagogies and activism as well as theoretical development for the combined educational principles of creative pedagogy and digital technology in STEAM education	Chappe II & Hefterington (2024)
6	Place-based education with digital storytelling to build emotional connections and attachment of places to the marine environment	Place-based education framework with 5E model for project design and evaluation; digital storytelling; project pre-post questionnaires; qualitative assessment of short films	Visual storytelling has transformative potential in creating an emotional and cultural connection with the ocean; digital media is effective in cultivating marine literacy and citizenship	Use of digital media to promote marine education and civic engagement; harnessing the power of imagery and imagination to enrich the relationship with the marine world	Stocco & Rocca (2024)
7	Semantic and conceptual analysis of marine literacy terms in the context of Brazilian formal education	Bibliographic review; semantic analysis of the terms 'literacy' and 'culture' in the context of Brazilian science education	The term 'Ocean Culture' translates Ocean Literacy and has the greatest semantic relevance for inclusion of marine topics in formal teaching; however, few are associated with formal curriculum and school contexts	Standardization of terminology in marine literacy education; increased integration of marine topics in formal curriculum and school contexts	de Toni et al (2024)
8	Curriculum analysis for the integration of	Curriculum content analysis; documentary	Biology and geography have the highest	The results provide valuable support for managers to	Pazoto et al (2023)

	marine literacy in formal education and participatory coastal management	analysis of PCN and RC-RJ; Mann-Whitney U test; major component analysis (PCA)	number of marine literacy concepts in both PCN and RC-RJ; there is no significant difference between PCN and RC-RJ; PCA discriminates documents based on subject regardless of origin	promote effective coastal zone management practices and public compliance	
9	Integrated interventions in the school curriculum to promote marine literacy with local contexts	A one-year project with 235 students (ages 8-15) from a public school in Rio de Janeiro; theory lessons, laboratory experiments, field trips, and reading circles; evaluation through questionnaires and focus group interviews	Findings reveal learning and attitude change, increased student engagement, and revitalization of the school environment; projects can be adapted for other regions and audiences	Development of marine education activities that are integrated with the school curriculum based on the local context of students	Pazoto et al (2023)
10	Evaluation of informal marine education programs in filling the gap in formal education related to marine literacy	Mixed methods: semi-structured surveys and interviews with informal education providers	89.4% of participants were familiar with the principles of marine literacy; 51% of informal providers incorporate these principles; lack of a formal education system that facilitates marine literacy	Formal and informal education programs that work together can enhance school curricula and promote greater marine literacy; overcoming barriers to teaching and learning marine concepts	O'Brien et al (2023)
11	Analysis of marine representations in elementary school textbooks and curricula	Analysis of textual and pictorial material content; review of the Science Curriculum Learning Objectives; recording the number and types of fauna species in the picture	Only three Learning Objectives explicitly define ocean-related content; a little more than 20% of the total animal images are marine fauna; most marine animals displayed are native but rarely labeled	Improvement of marine content in school textbooks; additional species name labels to images; only three principles of marine literacy covered in the science curriculum need to be expanded	Christie & Cárcamo-Ulloa (2023)
12	Interdisciplinary integration by integration of marine themes in Brazil's primary	Documentary analysis; identification of the presence and frequency of the relationship between the specific	The relationship between all the Principles and SC is identified, facilitating aspects of interdisciplinarity, scientific work,	The use of the ocean as an integrative theme; need for educational processes for educators and pedagogical proposals; the	Ghilardi i-Lopes et al (2023)

	education national curriculum	competency (SC) of BNCC SMA and the principles of marine literacy based on the content of natural sciences	social dimension and complexity	potential of the ocean as a unifying theme across subjects	
13	Mapping of marine science teaching practices and teachers' professional development needs in primary education	Online survey of Australian primary school teachers (Foundation-Grade 6); case study of the Australian public school system	Although teachers appreciate the importance of marine education from an early age, most rarely or only occasionally discuss marine science topics; increasing knowledge and availability of educational resources	Importance of formal marine science education in basic education; need for professional development opportunities for teachers; increasing availability of marine education resources connected to the school curriculum	Freitas et al (2022)
14	Review of teacher content knowledge for effective marine literacy education	Scoping review; search of Web of Science, Scopus, and ERIC databases (2015–2021); content analysis of 14 peer-reviewed articles	Topics related to marine debris are often discussed; topics about teaching environmental education/ education for sustainable development are discussed the least; benthic marine debris, solutions, and new types of marine debris need to be discussed	Teachers need to increase their knowledge of benthic marine debris, solutions to marine debris, and new types of marine debris; content knowledge lists are useful for improving the effectiveness of marine litter education in schools	Ahmad-Kamil et al (2022)
15	Cross-national evaluation of marine literacy of junior high school students in the Mediterranean region	Cross-national study with 2,533 junior high school students from 8 Mediterranean countries (Croatia, Cyprus, Egypt, Greece, Italy, Malta, Spain, Turkey); survey of knowledge, attitudes, behaviors, and background elements	Students from all countries have a moderate level of marine science knowledge; they exhibit a satisfactory pro-environmental attitude and behavior	The findings serve as a baseline for the design, implementation and launch of specifically targeted programs, educational activities, teaching resources, curriculum and school textbooks through close collaboration between schools, universities, research institutes and the Ministry of Education	Koulouri et al (2022)
16	Integration of marine literacy and marine citizen science in the school curriculum	Long-term projects (since 2011) with a network of schools, institutions and residents;	The project aligns existing education plans with the UN SDGs 2030 and improves STEM teaching;	Vertical and incremental approaches from kindergarten to university for marine literacy; integration of citizen	Mioni (2022)

	vertically and incrementally in the long term	partnerships with research centers; gradual implementation of scientific literacy in marine biology from kindergarten to university	students' active involvement in the introduction of marine flora and fauna increases interest in STEM disciplines and marine science	science with school curriculum; collaboration between the school and the research center	
17	The use of comic and multimodality medium in marine literacy education for elementary school students	Classroom-based research; development of students' visual meaning-making skills through activities focusing on visual arts and design elements as well as conventions of the comic medium; visual and descriptive analysis of students' comics including interviews	The development of students' knowledge of visual arts and design elements and the conventions of the comic medium can inform and deepen students' understanding, interpretation, and design of science comics	Integration of science comic making in marine literacy curriculum; development of meaning-making visual skills and critical thinking about multimodal ensembles	Pantaleo (2021)
18	Analysis of children's literature (picture books) as a marine education medium.	Analysis of 100 ocean-themed picture books on marine science concepts and Australian Science Understanding Curriculum streams.	81% and 91% of the 100 books related to marine science and the Australian Science Understanding Curriculum; dominant biological concepts; Chemistry and Physics are underrepresented.	This study provides examples of books that can be used for the teaching of marine education in Australian primary schools; further research is needed on marine science literature for children.	Francis et al (2021)
19	Evaluation of the effectiveness of non-formal marine education in improving marine literacy of elementary school students.	Pre-post evaluation of non-formal education interventions with different themes; measurement of information retention three weeks after the activity.	Non-formal educational activities resulted in a significant increase in knowledge levels three weeks after being carried out, indicating information retention; transfer of knowledge from graduate to elementary level significantly increases knowledge and exposes learning misconceptions.	An integrated approach in marine literacy teaching starts from the beginning of the classroom by combining teacher professional development, strengthening marine topics in the school curriculum, and promotion of non-formal educational activities.	Mokos et al (2020)

Overall, the studies in this synthesis demonstrate a paradigm shift from traditional pedagogies to more interactive, participatory, and contextual learning models. Technology-based approaches such as game-based learning, augmented reality (AR), virtual reality (VR), and immersive learning (Chappell & Hetherington 2024; Leitão et al 2025; Munandar et al 2025) have been shown to increase student engagement, understanding of scientific concepts, and environmental communication skills, underscoring the importance of digital innovation in marine education.

Beyond technological aspects, strengthening teacher capacity and professional development play a crucial role in ensuring the sustainability of marine literacy practices in primary and secondary schools. Studies such as Freitas et al (2022) and Freitas et al (2025) emphasize that teachers perceive marine literacy as an important topic but still face curriculum constraints and resource constraints. This aligns with findings from curriculum analyses (Christie & Cárcamo-Ullo 2023; Ghilardi-Lopes et al 2023; Pazoto et al 2023), which indicate that the representation of marine topics in curriculum documents is often disproportionate, despite their significant potential to support cross-disciplinary integration.

Context and culture-based approaches such as place-based education and digital storytelling (Stocco & Rocca 2024) have demonstrated significant impact in building students' emotional connections and ecological identities toward the marine environment. Meanwhile, informal education programs, non-formal activities, and citizen science (Mokos et al 2020; Minna 2022; O'Brien et al 2023) enrich learning experiences by providing practical spaces not available in formal education. These findings reinforce the notion that effective marine literacy requires a connected learning ecosystem between schools, communities, researchers, and informal institutions.

Thus, this synthesis of 19 articles confirms that the success of marine literacy education depends on the integration of innovative pedagogies, strengthening teacher capacity, adequate curriculum representation, the application of cutting-edge technologies, and the provision of authentic learning experiences through context-based approaches and citizen science. Recommendations emerging from various studies also indicate that a layered educational model that combines formal, non-formal, and informal education is the most promising approach to enhancing pro-environmental understanding, attitudes, and actions among young people.

Conclusions. This systematic review of 19 peer-reviewed studies reveals that ocean literacy pedagogy is undergoing fundamental transformation from traditional lecture-based instruction toward learner-centered, experiential, and technology-enhanced approaches. Four dominant pedagogical clusters emerged: game-based and experiential learning, technology-enhanced education utilizing AR/VR platforms, place-based and contextual learning, and interdisciplinary systems thinking approaches. While these innovations demonstrate enhanced engagement and knowledge acquisition, critical gaps persist in behavioral impact assessment, geographic representation beyond Global North contexts, and formal curriculum integration. The field disproportionately measures cognitive outcomes while neglecting long-term behavioral change, concentrates research in affluent coastal nations while underrepresenting Global South communities most vulnerable to marine challenges, and struggles to embed ocean literacy as core rather than supplementary educational content. Future progress requires developing standardized multidimensional assessment frameworks, expanding geographic diversity through South-South collaborations, conducting longitudinal studies tracking sustained impacts, investigating cultural adaptation mechanisms, addressing technology equity concerns, and supporting educator capacity building. Realizing ocean literacy's transformative potential for sustainable ocean governance demands evidence-based, culturally responsive, and equitable pedagogical approaches supported by robust assessment frameworks, adequate resources, and cross-disciplinary, cross-sectoral, cross-geographical collaboration, building ocean literacy education that is simultaneously scientifically sound, culturally relevant, pedagogically effective, and socially just for fostering global environmental citizenship capable of addressing unprecedented marine challenges.

Acknowledgements. The authors extend their gratitude to Universitas Pendidikan Indonesia for their support in conducting this study.

Authors Contributions. Conceptualization and methodology: AS, ASw, IK, IW; data collection and analysis: AS, ASw, IK, IW, PS, DFAH, DJT; writing - original draft preparation; AS, ASw, IK, IW; writing - review and editing: AS, ASw, IK, IW, PS, DFAH DJT.

Conflicts of Interest. The authors declare that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Funding. This work was supported by the Operational Assistance Program for State Universities (BOPTN) under the Advanced Multiyear Research Grant Scheme, as stipulated in Decree Number 108/C3/DT.05.00/2026 dated March 9, 2026.

References

Ahmad-Kamil E. I., Syed Zakaria S. Z. S., Othman M., 2022 What teachers should know for effective marine litter education: a scoping review. Sustainability 14(7):4308.

Ajzen I., 1991 The theory of planned behavior. Organizational Behavior and Human Decision Processes 50(2):179-211.

Ashley M., Pahl S., Glegg G., Fletcher S., 2019 A change of mind: applying social and behavioral research methods to the assessment of the effectiveness of ocean literacy initiatives. Frontiers in Marine Science 6:288.

Asikin N., Suwono H., Sumitro S. B., Dharmawan A., 2025 Teaching ocean literacy in science education: a systematic review. Environmental Education Research 32(3): 812-837.

Ballantyne R., Packer J., Hughes K., 2009 Tourists' support for conservation messages and sustainable management practices in wildlife tourism experiences. Tourism Management 30(5):658-664.

Brennan C., Ashley M., Molloy O, 2019 A system dynamics approach to increasing ocean literacy. Frontiers in Marine Science 6:360.

Cava F., Schoedinger S., Strang C., Tuddenham P., 2005 Science content and standards for ocean literacy: a report on ocean literacy. College of Exploration, 50 pp.

Cavas B., Acık S., Koc S., Kolac M., 2023 Research trends and content analysis of ocean literacy studies between 2017 and 2021. Frontiers in Marine Science 10:1200181.

Chappell K., Hetherington L., 2024 Creative pedagogies in digital STEAM practices: natural, technological and cultural entanglements for powerful learning and activism. Cultural Studies of Science Education 19(1):77-116.

Christie C., Cárcamo-Ulloa L., 2023 How is the ocean represented in school textbooks in Chile? An analysis of curricular content and images of marine fauna. Ocean and Coastal Research 71:e23016.

Cooke A., Smith D., Booth A., 2012 Beyond PICO: the SPIDER tool for qualitative evidence synthesis. Qualitative Health Research 22(10):1435-1443.

Costanza R., de Groot R., Sutton P., van der Ploeg S., Anderson S. J., Kubiszewski I., Farber S., Turner R. K., 2014 Changes in the global value of ecosystem services. Global Environmental Change 26:152-158.

de Toni K. R., Fonseca A. L., Cremer M. J., 2024 The semantics of ocean literacy: several definitions in only one ocean. Desenvolvimento e Meio Ambiente 63:1-22.

Dede C., 2009 Immersive interfaces for engagement and learning. Science 323(5910): 66-69.

Fauville G., Strang C., Cannady M. A., Chen Y. F., 2019 Development of the international ocean literacy survey: measuring knowledge and attitudes about the ocean. Environmental Education Research 25(2):238-263.

FAO, 2022 The state of world fisheries and aquaculture 2022: towards blue transformation. FAO, Rome, 266 pp.
Francis P., Venzo P., Bellgrove A., 2021 Reading over and under the waves: a study of ocean picture books for children. Australian Journal of Environmental Education 37(3):167-186.
Freitas C., Bellgrove A., Venzo P., Francis P., 2022 Towards a 2025 national ocean literacy strategy: current status and future needs in primary education. Frontiers in Marine Science 9:883524.
Freitas C., Venzo P., Bellgrove A., Francis P., 2025 Diving into a sea of knowledge: empowering teachers to enhance ocean literacy in primary schools through an ocean education training program. Environmental Education Research 31(2):262-283.
Ghilardi-Lopes N. P., Motokane M., Barradas J. I., Xavier L. Y., van Sluys Menck E., Franco A. C. G., Turra A., 2023 Ocean as an interdisciplinary theme in Brazilian basic education. Ambiente e Sociedade 26:e0134.
Gruenewald D. A., 2003 The best of both worlds: a critical pedagogy of place. Educational Researcher 32(4):3-12.
Guest H., Lotze H. K., Wallace D., 2015 Youth and the sea: ocean literacy in Nova Scotia, Canada. Marine Policy 58:98-107.
Halpern B. S., Frazier M., Potapenko J., Casey K. S., Koenig K., Longo C., Lowndes J. S., Rockwood R. C., Selig E. R., Selkoe K. A., Walbridge S., 2015 Spatial and temporal changes in cumulative human impacts on the world's ocean. Nature Communications 6:7615.
Intergovernmental Panel on Climate Change (IPCC), 2019 The ocean and cryosphere in a changing climate. A special report of the Intergovernmental Panel on Climate Change. IPCC, 755 pp.
Jacobson S. K., McDuff M. D., Monroe M. C., 2015 Conservation education and outreach techniques. 2nd edition. Oxford University Press, 428 pp.
Kolb D. A., 1984 Experiential learning: experience as the source of learning and development. Prentice Hall, 256 pp.
Kollmuss A., Agyeman J., 2002 Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research 8(3):239-260.
Koulouri P., Mogias A., Mokos M., Cheimonopoulou M., Realdon G., Boubonari T., Previati M., Formoso A. T., Kideys A. E., Hassaan M. A., Patti P., Korfiatis K., Fabris S., Juan X., 2022 Ocean literacy across the Mediterranean Sea basin: evaluating middle school students' knowledge, attitudes, and behaviour towards ocean sciences issues. Mediterranean Marine Science 23(2):289-301.
Leitão R., Yao S., Guimarães L., 2025 An augmented reality board game to work ocean literacy dimensions. Education and Information Technologies 30(13):19245-19268.
Long H. A., French D. P., Brooks J. M., 2020 Optimising the value of the critical appraisal skills programme (CASP) tool for quality appraisal in qualitative evidence synthesis. Research Methods in Medicine and Health Sciences 1(1):31-42.
Lotze H. K., Guest H., O'Leary J., Tuda A., Wallace D., 2018 Public perceptions of marine threats and protection from around the world. Ocean and Coastal Management 152: 14-22.
McKinley E., Fletcher S., 2012 Improving marine environmental health through marine citizenship: a call for debate. Marine Policy 36(3):839-843.
McKinley E., Burdon D., Shellock R. J., 2023 The evolution of ocean literacy: a new framework for the United Nations Ocean Decade and beyond. Marine Pollution Bulletin 186:114467.
Merchant Z., Goetz E. T., Cifuentes L., Keeney-Kennicutt W., Davis T. J., 2014 Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: a meta-analysis. Computers and Education 70:29-40.
Miglani S., Verma V., Agrawal M., Singh J., Patel J., 2026 Competency-based learning as a framework for holistic development of 21st century learners in school education. Discover Education 5:324.

Minna M., Minna M., Heidi H. L., 2022 Difficult but valuable! Learning in student-centered assessment feedback practices in higher education. Journal of Education, Society and Behavioural Science 35(11):20-37.
Mioni E., 2022 "Percorsi nel Blu" ("Blue Paths"): a long-lasting project to integrate ocean literacy and marine citizen science into school curricula. Mediterranean Marine Science 23(2):405-416.
Mogias A., Boubonari T., Realdon G., Previati M., Mokos M., Koulouri P., Cheimonopoulou M., 2019 Evaluating ocean literacy of elementary school students: preliminary results of a cross-cultural study in the Mediterranean region. Frontiers in Marine Science 6:396.
Mokos M., Realdon G., Zubak Čižmek I. Z., 2020 How to increase ocean literacy for future ocean sustainability? The influence of non-formal marine science education. Sustainability 12(24):10647.
Munandar R. R., Hidayat T., Sanjaya Y., Riza L. S., 2025 Deep learning and genomic strategies for ocean literacy development. AIMS Environmental Science 12(3):461-477.
O'Brien M., Freitas C., Venzo P., Francis P., 2023 Fostering ocean literacy through informal marine education programs. Marine Pollution Bulletin 193:115208.
Page M. J., McKenzie J. E., Bossuyt P. M., Boutron I., Hoffmann T. C., Mulrow C. D., Shamseer L., et al., 2021 The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71.
Pantaleo S., 2021 The designing of ocean threat comics by elementary students. Multimodal Communication 10(3):229-243.
Paredes-Coral M., Ferreira J., Carvalho L. G., Santoro F., 2021 Mapping global research on ocean literacy: implications for science, policy, and the blue economy. Frontiers in Marine Science 8:648492.
Pazoto C. E., Duarte M. R., Silva E. P., 2023a Ocean literacy in Brazilian formal education: a tool for participative coastal management. Australian Journal of Environmental Education 39(4):507-521.
Pazoto C. E., Duarte M. R., Silva E. P., 2023b Promoting ocean literacy among students in Brazilian schools. Marine Pollution Bulletin 197:115690.
Popay J., Roberts H. M., Sowden A., Petticrew M., Arai L., Rodgers M., Britten N., Roen K., Duffy S., 2006 Guidance on the conduct of narrative synthesis in systematic reviews. A product from the ESRC Methods Programme. 92 pp.
Prensky M., 2001 Digital game-based learning. McGraw-Hill, New York, 442 pp.
Santoro F., Santin S., Scowcroft G., Fauville G., Tuddenham P., 2017 Ocean literacy for all: a toolkit. UNESCO, IOC Manuals and Guides, 136 pp.
Schoedinger S., Cava F., Strang C., Tuddenham P., 2005 Ocean literacy through science standards. In: Proceedings of OCEANS 2005 MTS/IEEE, vol. 1, pp. 736-740.
Schoedinger S., Tran L. U., Whitley L., 2010 From the principles to the scope and sequence: a brief history of the ocean literacy campaign. NMEA Special Report 3:3-7.
Shellock R. J., Fullbrook L., McKinley E., Cvitanovic C., Kelly R., Martin V., 2024 The nature and use of ocean literacy in achieving sustainable ocean futures: a systematic map. Ocean and Coastal Management 257:107325.
Sobel D., 2004 Place-based education: connecting classrooms and communities. Orion Society, 109 pp.
Squire K., 2006 From content to context: videogames as designed experience. Educational Researcher 35(8):19-29.
Steel B. S., Smith C., Opsommer L., Curiel S., Warner-Steel R., 2005 Public ocean literacy in the United States. Ocean and Coastal Management 48(2):97-114.
Stern P. C., 2000 New environmental theories: toward a coherent theory of environmentally significant behavior. Journal of Social Issues 56(3):407-424.
Stocco S., Rocca L., 2024 Place-based education for ocean literacy: fostering ocean literacy and place attachment through short film. J-Reading 2:151-166.
Stoll-Kleemann S., 2019 Feasible options for behavior change toward more effective ocean literacy: a systematic review. Frontiers in Marine Science 6:273.

United Nations, 2017 Resolution adopted by the General Assembly on 6 July 2017: our ocean, our future: call for action (A/RES/71/312). United Nations, 6 pp.
Visbeck M., 2018 Ocean science research is key for a sustainable future. Nature Communications 9:690.

Received: 23 March 2026. Accepted: 30 April 2026. Published online: 28 June 2026.
Authors:
Ahmad Satibi (AS), Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: ahmadsatibi@upi.edu
Agus Setiawan (ASw), Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: agus_setiawan@upi.edu
Iwa Kuntadi (IK), Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: iwa_kuntadi@upi.edu
Isma Widiaty (IW), Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: isma@upi.edu
Dwi Fitria A. Husaeni (DFAH), Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: dwifitriaalhusaeni@upi.edu
Purnomo Sidiq (PS), Technical and Vocational Education Postgraduate, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: purnomosidiq@upi.edu
Daniel Julianto Tarigan (DJT), Marine and Fisheries Education Study Program, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: danieljulianto@upi.edu

How to cite this article:
Satibi A., Setiawan A., Kuntadi I., Widiaty I., Husaeni D. F. A., Sidiq P., Tarigan D. J., 2026 Pedagogical approaches in ocean literacy education: innovations and effectiveness (2020-2025). AACL Bioflux 19(3):1425-1446.