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Integration of Digital Technologies in Environmental Education: A Systematic Review of Trends, Impacts, and Future Directions

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ABSTRACT

The integration of digital technologies in environmental education (EE) has emerged as an important research area. However, a comprehensive synthesis of international research remains scarce. This systematic literature review (SLR), adhering to the PRISMA guidelines, aims to fill this gap by synthesizing peer-reviewed articles published in the past decade, specifically from the Scopus database. While the Scopus database was prioritized due to its comprehensive collection of high-quality, peer-reviewed journals in the field, future research should consider incorporating studies from other databases to ensure broader coverage of the topic. The primary objectives of this review are to analyze: (1) the predominant research approaches and instruments used in digital technology research in EE; (2) key findings regarding the application of digital technologies in EE; (3) thematic categories that explain the role of digital tools in environmental learning; and (4) the impact of digital technologies on promoting pro-environmental behavior through pedagogical integration. This review synthesizes current research practices and outlines how technologies such as augmented reality (AR), virtual reality (VR), and mobile applications enhance student engagement, environmental knowledge, and pro-environmental behavior. Additionally, the review explores the potential risks associated with the adoption of digital technologies, including the phenomenon of "techno-solutionism." It emphasizes the importance of culturally and ethically responsive pedagogies to mitigate these risks. Methodologically, the review adopts a critical approach, evaluating how different studies have addressed these challenges and suggesting strategies for responsible and context-aware implementation of digital tools in EE. The findings of this review underscore the need for critical thinking in the use of digital technologies in EE. The future of digital EE research should focus on long-term impact assessments and the integration of indigenous knowledge into digital pedagogies, ensuring a more inclusive and effective approach to environmental education.

Keywords: digital technology, environmental education, virtual reality, augmented reality, pro-environmental behavior

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INTRODUCTION

The ever-growing rate of digital technology has transformed various domains of education, including the field of environmental education (EE) (Bahroun et al., 2023; O'Neil et al., 2020; Peterson et al., 2019). Since educators seek alternative approaches to address intricate environmental issues, digital technologies such as augmented reality (AR), virtual reality (VR), mobile apps, and web

platforms have emerged as important resources that offer new ways of engaging students, simulating environmental interactions, and encouraging pro-environmental behavior (Alalawi & Omar, 2024; Dwivedi et al., 2022; Georgiou et al., 2021; Kellberg et al., 2023; Liu & Green, 2024; Xiong et al., 2024; Zhao et al., 2024). This convergence of digital innovation and ecological literacy/environmental literacy is especially important within the context of global environmental problems and the increasing need for education systems to foster ecological awareness and action-oriented dispositions (Ardoin et al., 2023; Sari et al., 2024).

Recent research suggests that new digital technologies have the potential to significantly transform pedagogical methods in EE (Huang et al., 2024; Lowan-Trudeau, 2023). These technologies facilitate experiential learning, which allows learners to engage with real-world environmental challenges through interactive and immersive experiences. For example, AR and VR tools offer opportunities for students to explore ecosystems, climate change, and sustainability issues in dynamic and engaging ways (Cao & Jian, 2024; Negi, 2024). This kind of learning enables students to deeply interact with the environment, providing a hands-on approach to understanding environmental processes and systems.

In addition, digital technologies contribute to personalizing content delivery in EE. Adaptive learning platforms, for instance, can tailor educational experiences to individual needs, adjusting the complexity and style of content based on a student's learning pace and preferences. This personalization helps address diverse learning needs and improves student outcomes by ensuring that educational materials are relevant and engaging for each learner (Chalkiadakis et al., 2024; Filiz et al., 2025; Mariyono & Nur Alif Hd, 2025; Sposato, 2025).

Furthermore, these technologies promote engagement with both local and global environmental challenges. Digital tools, such as mobile applications and online platforms, allow learners to connect with environmental issues not only within their local communities but also globally (Hajj-Hassan et al., 2024; Haraty & Bitar, 2019; Mhlongo et al., 2023). For example, online collaborative platforms enable students to participate in global environmental campaigns, exchange knowledge with peers from different regions, and engage in joint projects focused on addressing pressing environmental problems, such as deforestation and biodiversity loss (Dwivedi et al., 2022).

It is important to note that these findings are drawn from a systematic literature review (SLR) that synthesizes multiple studies on the integration of digital technologies in EE, including research by Buchanan et al. (2019) and Jukes & Lynch (2024), which specifically examine how these technologies enhance pedagogical practices. Previous systematic reviews have primarily focused on the technical aspects of these tools rather than their pedagogical implications or broader educational outcomes. However, scholars have also raised concerns regarding the risks of techno-solutionism—the belief that

technological interventions alone can solve environmental problems—without considering contextual, cultural, and ethical implications (Greenwood & Hougham, 2015; Perkins, 2024).

Despite the growing body of literature, there is still a lack of comprehensive syntheses that map research methodologies, thematic trends, and conceptual frameworks in this interdisciplinary field. Existing reviews often focus on the technical efficacy of tools rather than their pedagogical implications or behavioral outcomes (Gunnars, 2021; Ma & Ismail, 2025; Pedagogy & Outcomes, 2023). Moreover, very few studies have systematically explored how digital technologies have been evaluated in terms of their long-term impact on ecological understanding and environmental citizenship. This review uniquely addresses this gap by not only aggregating studies but by critically analyzing the methodologies, findings, and the pedagogical impacts of these technologies in EE (Hajj-Hassan et al., 2024; Lopera-Perez et al., 2021; Merritt et al., 2022; Syahri & Salahudin, 2024). Therefore, this study fills a critical gap in the literature by providing an in-depth analysis of the pedagogical effects of digital technologies, an area that has not yet been thoroughly examined in previous reviews.

The rationale for focusing on the Scopus database exclusively stems from its comprehensive and curated collection of high-quality, peer-reviewed articles in the field of EE and digital technology integration. Although there are other databases available, Scopus was chosen for its broad global representation and authoritative sources, which are critical for ensuring the validity and relevance of the included studies. Future research should, however, explore the integration of other databases to broaden the scope of findings.

This SLR aims to address this gap by analyzing peer-reviewed articles published within the past decade, retrieved exclusively from the Scopus database. The purpose is to investigate: (1) the dominant research methodologies and instruments used; (2) the key findings related to the integration of digital technology in EE; (3) the thematic domains characterizing the role of digital tools in environmental learning; and (4) the extent to which digital technologies promote pro-environmental behavior through pedagogical integration. The significance of this study lies in its ability to provide a synthesized understanding of current research practices, offering insights into how digital technologies can be ethically integrated into EE to foster lasting environmental change. The review contributes to the field by identifying future directions for culturally responsive and context-aware digital EE pedagogies.

METHOD

Research Question (RQ)

This SLR is guided by four key research questions that explore the landscape of digital technology in environmental education. RQ1: What research methodologies and instruments are predominantly used in studies on digital technology in environmental education? RQ2: What are the key findings of digital technology in environmental education? RQ3: What are the main thematic domains of digital technology's role in environmental education as identified in recent literature? RQ4: How does

the integration of digital technologies within pedagogical frameworks promote pro-environmental behavior among learners?

Research Framework

This SLR adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, replicability, and academic rigor (Page et al., 2021; Selcuk, 2019; Sohrabi et al., 2021). The steps undertaken include (see Figure 1): (1) Identification: A focused search was conducted exclusively through the Scopus database due to its comprehensive indexing of high-impact peer-reviewed journals. Search terms included combinations of using "digital technology" AND "environmental education", search within article title, abstract and keyword. The search was limited to journal and proceeding articles published until 2025. While limiting to Scopus and open-access articles ensures accessibility and relevance, future reviews may benefit from including additional databases to mitigate potential selection bias and enhance the breadth of the findings. (2) Screening: The initial search yielded 59 articles. After removing Book chapter, book, review, and note, 48 articles remained. The selected articles are focused on original articles and conference papers. (3) Eligibility: English and open access screening was performed on 48 articles. We excluded Croatian, Portuguese, Russian and Turkish (remaining 45 articles), and then excluded gold, hybrid gold, green, and bronze (remaining 23 articles). The exclusion of certain languages was based on the availability of English language resources and the ability to assess open-access status. However, this exclusion may introduce potential linguistic bias, and future research may consider including studies in other languages if feasible. (4) Inclusion: From this process, we excluded irrelevant keywords and finally 21 articles met all eligibility criteria and were included in the final review for analysis.

This search history is as follows: TITLE-ABS-KEY ("digital technology" AND "environmental education") AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (OA, "all")) AND (EXCLUDE (EXACTKEYWORD, "Scopus") OR EXCLUDE (EXACTKEYWORD, "Romania") OR EXCLUDE (EXACTKEYWORD, "Iceland") OR EXCLUDE (EXACTKEYWORD, "Greece") OR EXCLUDE (EXACTKEYWORD, "Europe") OR EXCLUDE (EXACTKEYWORD, "Cyprus")). Based on the subject area (Figure 2), the documents obtained are dominated by social sciences (44.4%), followed by environmental sciences (13.9%), and health professions (8.3%). Other subject areas with low percentages are computer sciences, earth and planet, energy, agricultural and biological sciences, art and humanities, mathematics, and psychology, which shows that this theme can be approached with a variety of subject area backgrounds.

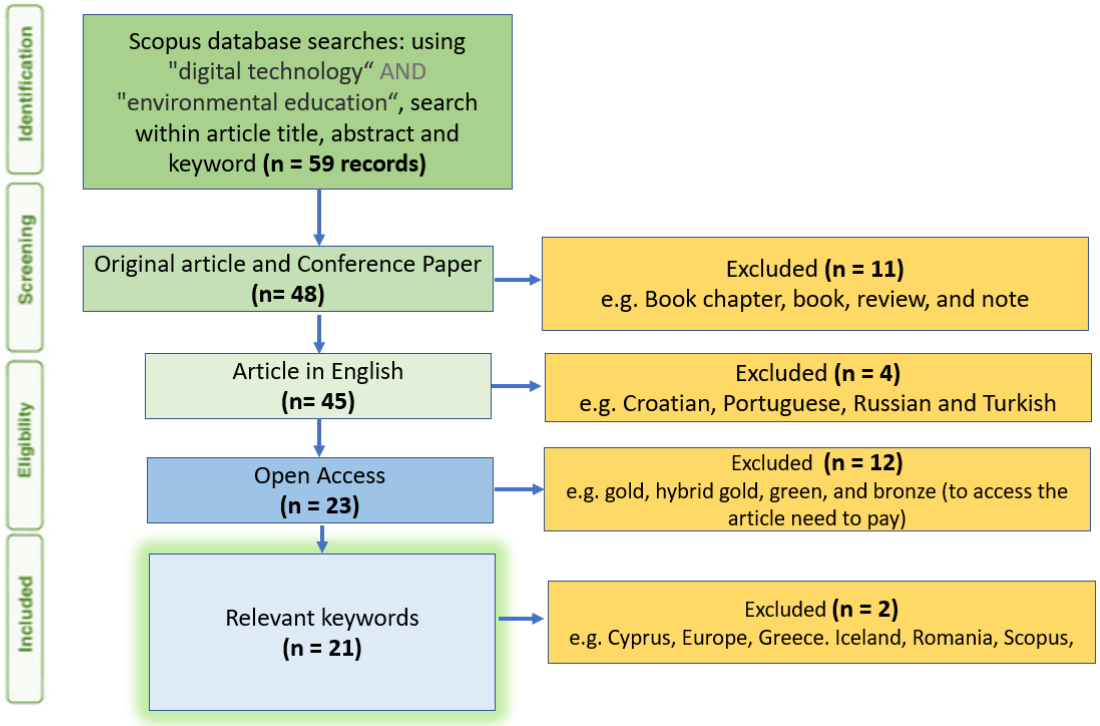

Figure 1. PRISMA flow diagram

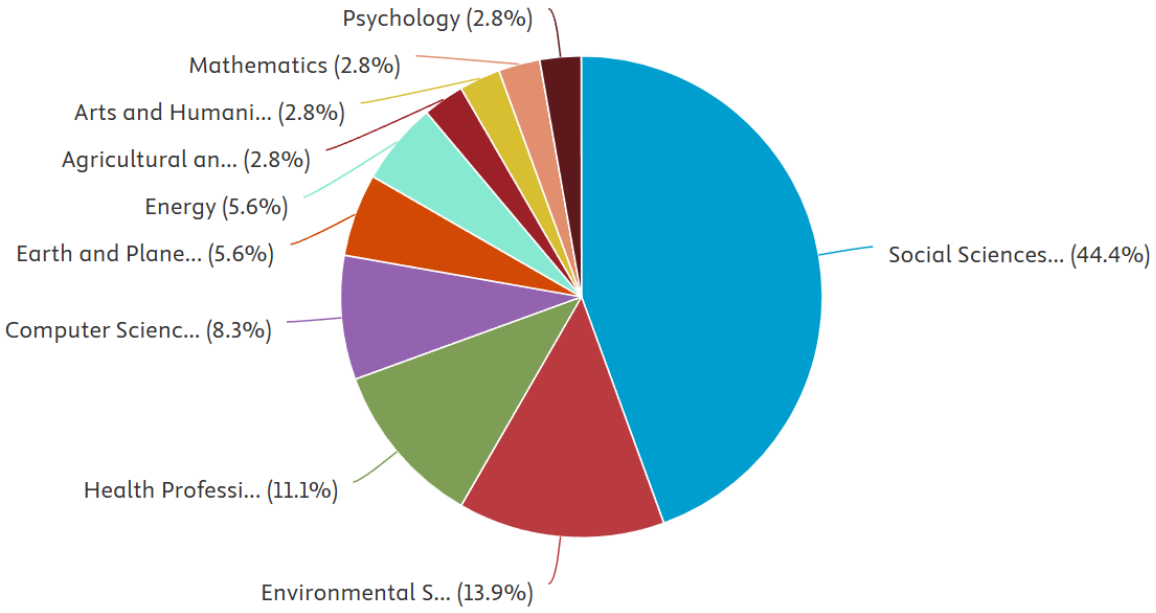

Figure 2. Documents by subject area

Data Extraction and Synthesis

Key data were extracted from each study, including research approach, instruments/tools used, sample/participants, and major findings. The data were organized into a comparative matrix and

analyzed thematically. The findings were categorized in relation to the four research questions that guide this review. This methodical approach ensures a rigorous synthesis of global research trends on digital technology in environmental education, drawing exclusively from the Scopus database to maintain consistency and relevance in scope. Additionally, a quality assessment of the studies included in the final review was performed to evaluate their methodological rigor, relevance, and contribution to the field. This assessment ensures the validity and reliability of the synthesized findings.

RESULTS & DISCUSSION

Result

Research Methodologies and Key Findings

The Table 1 summarizes the research methods and key findings of the selected studies on incorporating digital technology in environmental education. It provides an overall summary of different research approaches, instruments, sample respondents, and key findings of the different studies. Quantitative synthesis of the results, such as effect sizes or statistical analysis, was not conducted due to the heterogeneous nature of the studies included, though future research could benefit from such an approach to enhance the depth of understanding.

Table 1. Summary of Research Methodologies and Key Findings

No.	Reference	Research Approach	Instruments / Tools	Sample / Participants	Key Findings
1	(Greenwood & Hougham, 2015)	Theoretical	Conceptual analysis	N/A	Advocates for place-conscious approaches in integrating digital technologies.
2	(Buchanan et al., 2019)	Mixed Methods	Digital tools, assessments	Primary school students	Digital technologies effectively enhance environmental learning among young students.
3	(Chang et al., 2019)	Experimental	AR navigation system, assessments	Students	AR systems enhance cultural and environmental learning experiences.
4	(Zakharova et al., 2020)	Quantitative	Surveys	University students	Digital engagement influences students' social health and environmental behaviors.
5	(Konovalova & Denisenkova, 2020)	Descriptive	Program evaluations	Museum visitors	Zoological museums play a vital role in public environmental education.
6	(Adanali, 2021)	Mixed Methods	Geogames, questionnaires	Geography students	Geogames enhance engagement and spatial thinking in geographical education.

No.	Reference	Research Approach	Instruments / Tools	Sample / Participants	Key Findings
7	(Dudar et al., 2022)	Case Study	Remote sensing, GIS analysis	Landscapes in Novgorod-Siverskyi Polissia	Human activities significantly alter landscapes; education programs need to address these dynamics.
8	(Park, 2022)	Philosophical Analysis	Theoretical frameworks	N/A	Contrasting philosophical views offer insights into technological literacy education.
9	(Nakamura et al., 2023)	Design-Based Research	Web application, observations	Elementary school students	Web applications support climate-related learning through phenology observations.
10	(de Souza et al., 2023)	Case Study	Online modules, feedback surveys	University students and community members	Digital outreach programs effectively promote energy efficiency and climate awareness.
11	(Jukes et al., 2024)	Qualitative	Observations, interviews	Outdoor education participants	Combining technology and movement fosters deeper environmental connections.
12	(Lin & Ardoin, 2023)	Qualitative	Interviews, content analysis	Families	Digital media supports environmental learning within family settings.
13	(Jukes & Lynch, 2024)	Qualitative; New Materialism	Case studies, reflective narratives	Tertiary outdoor education students	Digital technologies are deeply embedded in outdoor education, influencing pedagogical practices and learner experiences.
14	(Mospan, 2024)	Descriptive	Surveys, interviews	University educators and students	The pandemic accelerated digital integration in sustainability education.
15	(Aslanova et al., 2024)	Literature Review	Document analysis	N/A	IT applications enhance environmental education and support sustainable development goals.
16	(North & Ratima, 2024)	Qualitative	Interviews, thematic analysis	Educators and community members	Integrating Indigenous perspectives enriches environmental education practices.
17	(Perkins, 2024)	Critical Review	Literature analysis	N/A	Emphasizes the need for critical engagement with digital technologies in environmental education.
18	(Shuai et al., 2024)	Experimental	Digital platforms, pre/post-tests	Teenagers	Digital tools improve environmental literacy among adolescents.
19	(Millward et al., 2024)	Survey Research	Questionnaires	K-12 teachers	Teachers recognize the potential of technology but need support for effective integration.
20	(Kurpayanidi et al., 2024)	Analytical Review	Literature synthesis	N/A	Calls for a balanced approach to digital transformation in environmental education.

No.	Reference	Research Approach	Instruments / Tools	Sample / Participants	Key Findings
21	(Ditrich & Lachmair, 2025)	Experimental	Virtual Reality simulations, surveys	University students	Immersive technologies increase empathy and pro-environmental intentions.

Key and important findings from each article

The Table 2 summarizes the key findings and important themes identified across 21 articles on environmental education. It highlights the various areas where digital technologies have been integrated into environmental learning and the significant contributions made in each domain.

Table 2. Summary of 21 Environmental Education Articles

No	Main findings	Important findings	Reference
1	Digital Technologies in Environmental Education	Digital technologies can enrich outdoor learning experiences by connecting digital and natural spaces. The use of technologies such as AR and web applications increases student engagement in environmental learning.	(Buchanan et al., 2019; Jukes et al., 2024; Jukes & Lynch, 2024)
2	Challenges in Environmental Education	Landscape changes due to human activities require adaptation in environmental education. The COVID-19 pandemic has demonstrated the need for technology integration in sustainability education.	(Dudar et al., 2022; Mospan, 2024)
3	Critical Perspectives on Technology in Education	Critique of the view that technology is always the solution; the need for a more reflective and critical approach. Understanding the philosophy of technology can deepen technological literacy in education.	(Park, 2022; Perkins, 2024).
4	Cultural Integration and Local Approach	Local and indigenous cultural approaches can enrich environmental pedagogy. Digital media can be used to strengthen families' connections with nature at home.	(Lin & Ardoin, 2023; North & Ratima, 2024).
5	Impact Evaluation and Measurement	Immersive technologies such as VR can increase empathy and pro-environmental behavior. AR navigation systems are effective in increasing cultural and environmental understanding.	(Chang et al., 2019; Ditrich & Lachmair, 2025).
6	Technology for Environmental Education	Information technology drives continuing education through digital approaches in the classroom	(Aslanova et al., 2024)
7	Technology in Geography Education	Technology-based games support more engaging and active geographical learning.	(Adanali, 2021)
8	Digital Student Environmental Behavior	High digital exposure affects students' social behavior and environmental awareness	(Zakharova et al., 2020)
9	The Role of Museums in Environmental Education	Museums as an important tool in strengthening local environmental awareness and education.	(Konovalova & Denisenkova, 2020)
10	Web-Based Climate Applications	Web applications help observe climate change and natural phenomena in elementary schools.	(Nakamura et al., 2023)
11	Environmental Literacy in Adolescents	Digital technology improves environmental literacy among adolescents.	(Shuai et al., 2024)

No	Main findings	Important findings	Reference
12	Critical Perspectives on Technology	The importance of contextual and place-based approaches in the use of technology for environmental education.	(Greenwood & Hougham, 2015)
13	Teachers' Views on Technology	Teachers suggest special training to maximize technology in environmental learning."	(Millward et al., 2024)
14	Energy and Climate Outreach	Digital outreach raises awareness of energy and climate change amidst the pandemic	(de Souza et al., 2023)
15	Digital Transformation of Environmental Education	A balanced approach between technology and environmental education values is needed	(Kurpayanidi et al., 2024)

Thematic framework of Digital Technology in Environmental Education

Figure 3 presents a thematic framework that categorizes the various roles and impacts of digital technology in environmental education. This framework highlights the key themes identified across the studies and provides a visual representation of how digital tools contribute to different aspects of environmental education. However, the explanation of Figure 3 could be expanded further in the discussion to ensure its interpretative value is fully realized.

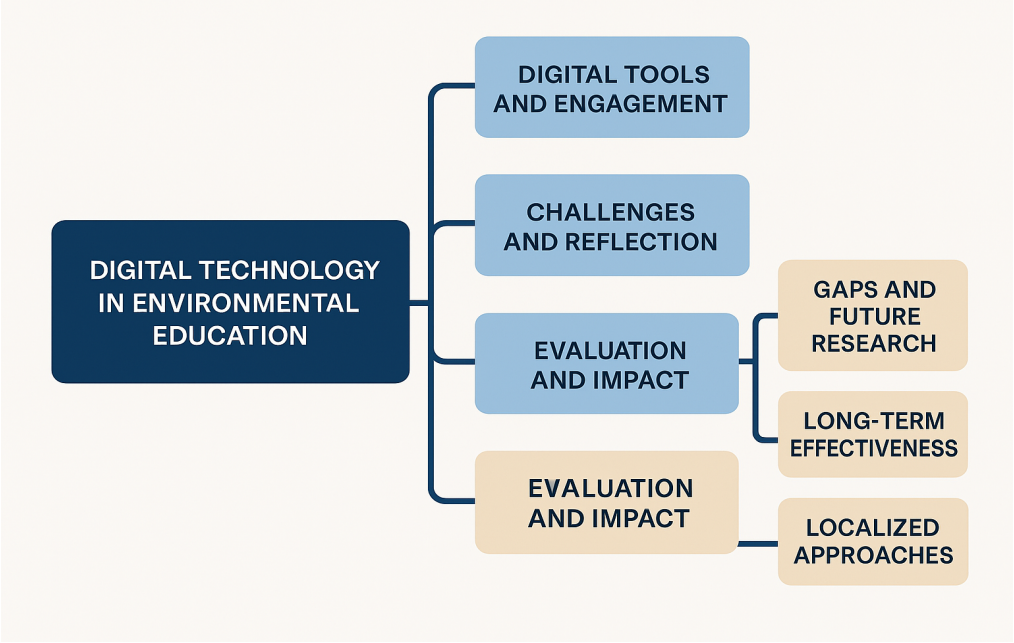

Figure 3. Thematic framework of Digital Technology in Environmental Education

Visual Model of Technology Integration in Environmental Education

Figure 4 illustrates the relationship between digital technologies, pedagogical approaches, and learning outcomes in environmental education. It would be beneficial to include a more detailed explanation of this model to ensure that its implications are clearly understood and provide actionable insights for future pedagogical practices.

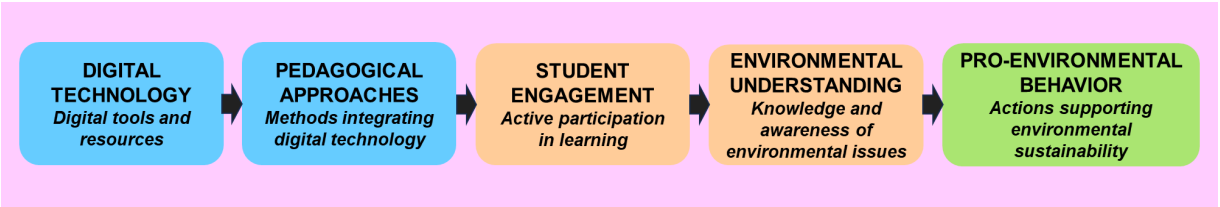

Figure 4. Visual Model of Technology Integration in Environmental Education

Discussion

Referring to the 21 scientific articles reviewed, it appears that qualitative and mixed methods approach dominate research on the relationship between digital technologies and environmental education. Many studies use case study designs, controlled experiments, and descriptive approaches to capture technology-based environmental learning transformations. The most commonly used instruments and techniques are surveys, interviews, observations, digital applications (such as AR/VR), and narrative and reflective analysis. Several studies stand out methodologically with their use of immersive technology (VR), augmented reality navigation systems, and web-based phenology apps, demonstrating strong innovation in the application of digital tools to enhance environmental understanding and awareness.

However, the results also show conflicting findings regarding the impact of certain technologies on student engagement and behavioral change. Some studies, such as those by Perkins (2024) and Greenwood and Hougham (2015), argue that the over-reliance on technology could lead to a techno-solutionist approach that fails to address the deeper cultural, contextual, and ethical issues surrounding EE. This study contributes to the existing body of knowledge by critically examining these contrasting findings and offering insights into the conditions under which digital technologies can be effectively integrated into environmental education to foster pro-environmental behavior. Future research should critically examine these contrasting outcomes and investigate the conditions under which digital technologies can be truly effective in fostering pro-environmental behavior.

The rapid progress made in digital technology has greatly influenced environmental education through all education levels. The synergy among approaches, means, and participant interaction when examining the capacities of digital technology to promote environmental awareness and pro-environmental action is exemplary in summarizing 21 articles published and reviewed within the past ten years. The outcome emphasizes not only the pedagogic use of technology but its revolutionary power in constructing ecological thought and action. In addition, this review provides new insights into the integration of immersive technologies, such as AR and VR, into environmental education, which has not been widely explored in previous studies.

While the use of immersive technologies like VR and AR has been shown to engage students emotionally and foster empathy, it is crucial to also consider the limitations of these technologies in

promoting long-term behavior change. More research is needed to assess the long-term impact of these technologies on environmental literacy and sustainable behavior. A key gap in the current literature is the lack of longitudinal studies that track the long-term effects of digital interventions on ecological understanding and behavioral change. This gap highlights the need for more comprehensive evaluations of the sustainability of these technological applications in environmental education.

First, *Major Research Methodologies*. Qualitative and mixed methods are predominant in the literature, and this is reflective of environmental education's strong focus on experience, context and making meaning in online spaces. Reflective narratives and interviews are used in the work of (Jukes & Lynch, 2024), and by (North & Ratima, 2024), to uncover ways in which online spaces make outdoor and Indigenous pedagogies possible. (Adanali, 2021) and (Buchanan et al., 2019) utilize mixed methods to balance the richness of qualitative findings and quantitative outcome measures. Quantitative work (Zakharova et al., 2020) supplements these with systematic evidence on learner behavior and environmental attitudes.

Second, *Tools and Equipment: Surveys to Virtual Reality*. Traditional tools like questionnaires, interviews, and observation are still the best. Tool innovation is particularly impressive, however. Immersion tools like Virtual Reality (Ditrich & Lachmair, 2025), Augmented Reality (Chang et al., 2019), and online climate apps (Nakamura et al., 2023) are not only used to acquire learning material, but are being used experimentally in and of themselves. They not only expose individuals to material, but recreate environmental experiences on which emotive engagement and empathic involvement with nature are made possible.

Diversity within the Sample The populations examined in the literature are school children (Buchanan et al., 2019), and adolescents (Shuai et al., 2024), university students (Ditrich & Lachmair, 2025), and family members (Lin & Ardoin, 2023). Some examined teachers' attitudes and needs (Millward et al., 2024), evoking the importance of teachers being prepared to embrace digital methods. The variety serves to emphasize the suitability of environmental education through digital methods to all learning environments and age groups.

Third, *Analysis of Key Trends*. In the process, digital technology is harnessed to promote student engagement, deepen environmental learning, and enable the development of pro-environmental behavior. Digital tools applied to pedagogical frameworks—from pedagogy to more-than-human pedagogy—enable inclusive, individualized, and context-bound learning experiences. (Buchanan et al., 2019) found that young learners showed more environmental literacy when given access to interactive digital imagery. Similarly, VR experiences, aided by (Ditrich & Lachmair, 2025), were found to trigger affective responses that foster ecological empathy.

Forth, *Future Implications*. This experiment attests to the capacity of digital technologies to revolutionize environmental education. However, for this transformation to be truly effective, digital

technologies must be integrated within a pedagogical framework that emphasizes critical thinking, cultural sensitivity, and long-term impact evaluation. As (Perkins, 2024) and (Greenwood & Hougham, 2015) caution, uncritical adoption of digital tools could lead to techno-solutionism. Future studies should focus on evaluating the long-term sustainability and behavioral consequences of these interventions, examining how digital tools can be integrated into a more culturally sensitive and reflective pedagogical approach.

Outcomes from 15 main thematic themes substantiate that environmental learning is facilitated through digital technologies. Studies by (Jukes et al., 2024) and (Buchanan et al., 2019) identify AR, VR, and mobile/web apps as effective tools to bridge the difference between ecological and virtual worlds in the improvement of outdoor and place-based learning. Learning aspects like empathy and behavioral intention are greatly affected by immersive tools, as evidenced by (Ditrich & Lachmair, 2025).

However, the review does register warning critical voices and scholars like Park (2022) and Perkins (2024), who propose risks in adopting technology generally as the solution and instead emphasize the need for reflective, critical, and culture-centered pedagogical planning. Culturally situated and place-based pedagogies—such as pedagogies that are centered on Indigenous worldviews (North & Ratima, 2024)—are more attuned to the environment if incorporated with digital technologies.

Also evident is the scalability and adaptability of digital environmental education to the variety of participant groups. Student, family, and teacher studies point to increased calls for participatory and community-focused methods (Lin & Ardoin, 2023; Millward et al., 2024). The COVID-19 pandemic (de Souza et al., 2023; Mospan, 2024) actually hastened digital outreach and underscored the value of digital resilience to sustain climate and energy education.

Based on these findings, one can see that environmental education needs to go beyond access and novelty with the integration of technology. As Greenwood and Hougham (2015) and Kurpayanidi et al. (2024) argue, successful transformation in the digital age requires ethical, place-sensitive and pedagogically informed strategies. Digital technologies, when accompanied by local knowledge, empathic designing and critical pedagogy, can support an active role in remaking environmental citizenship in the digital age. The significance of these findings in the current body of knowledge on environmental education lies in the synthesis of existing research, identification of gaps, and the proposal for further studies that will evaluate long-term behavioral outcomes and the sustainability of digital technologies in this field.

The Figure 3 presents a thematic structure of Digital Technology in Environmental Education, mapping out its multifaceted roles and influences. It begins with three overarching domains—Digital Tools and Engagement, Challenges and Reflection, and Evaluation and Impact—each covering a large realm explored by research discussion. Further elaboration of these themes in the discussion will

strengthen the framework and provide deeper insights into how these roles interact with pedagogical strategies and environmental outcomes.

The diagram captures the evolving framework of digital technology in environmental education, emphasizing not only its instructional potential but also the critical need for reflection, contextual relevance, and long-term assessment. Digital tools such as augmented reality, virtual reality, and geo-games have been shown to increase learner engagement and environmental awareness (Adanali, 2021; Jukes & Lynch, 2024). However, scholars warn against techno-solutionism, urging educators to remain critically reflective and context-sensitive in their pedagogical approaches (Greenwood & Hougham, 2015; Perkins, 2024). The inclusion of localized approaches is particularly important, as environmental education must resonate with learners' cultural and ecological realities to foster meaningful behavioral change (North & Ratima, 2024). Moreover, despite the rapid adoption of technology, longitudinal evaluations of its impact remain scarce—underscoring an urgent research gap in understanding the sustainability of these interventions (Ditrich & Lachmair, 2025). This synthesis underscores that the integration of digital technology in environmental education is not a one-size-fits-all solution, but a dynamic process that must be continually adapted, assessed, and grounded in diverse learner experiences.

The Figure 4 shows a linear model of how digital technology can generate pro-environmental behavior through five interconnected stages: Digital Technology, Pedagogical Approaches, Student Engagement, Environmental Understanding, and Pro-Environmental Behavior. It begins with the use of digital tools such as augmented and virtual reality, mobile applications, and online portals which are integrated into the learning environment through reflective pedagogical interventions. These strategies operate to actively engage students, encouraging them to take part in meaningful learning experiences. The more actively engaged students are, the more aware and knowledgeable they become about environmental issues, which ultimately leads to behavior that supports environmental sustainability. This is in line with (Buchanan et al., 2019) who demonstrated that digital technologies can enhance environmental awareness among young learners. Besides, (Ditrich & Lachmair, 2025) point out that immersive technologies significantly increase empathy for environmental concerns, a key element in motivating sustainable behavior. The diagram emphasizes the importance of linking technological innovation with pedagogical design in creating not just knowledge, but action-oriented ecological consciousness. Pro-Environmental Behavior illustrating a shift where well-educated learners adopt ecologically friendly practices in daily life. This model highlights the importance of successful integration of digital innovations in pedagogy to create ecological awareness and behavioral change. This model shows that digital technologies, when integrated with effective pedagogical approaches, can increase student engagement, which then deepens their awareness of the environment and leads to more pro-environmental behavior.

CONCLUSION

Based on the analysis of 21 peer-reviewed articles in this systematic literature review, it can be concluded that qualitative and mixed-method approaches are the most prevalent in studies exploring the relationship between digital technology and environmental education. The most used instruments include surveys, interviews, observations, and innovative tools such as augmented reality (AR), virtual reality (VR), and web-based climate applications. The findings consistently show that the integration of digital technology within pedagogical frameworks enhances student engagement, deepens environmental understanding, and encourages the development of pro-environmental behaviors. Moreover, the reviewed literature underscores the importance of critical reflection, place-based approaches, and balancing local values with technological innovation. Thematically, digital technology in environmental education spans three key domains: digital tools and engagement, challenges and reflective practice, and evaluation and impact—forming a conceptual framework that informs meaningful and sustainable technology integration.

Future research should prioritize longitudinal evaluations to assess the sustained impact of digital technologies on environmental literacy and behavioral change. Future research should focus on refining pedagogical frameworks that integrate digital tools in a way that supports long-term, sustainable environmental behavior and education. Additionally, greater attention must be paid to incorporating cultural and local contexts into pedagogical designs to avoid uncritical techno-centric solutions. Professional development for teachers is essential to equip them with the skills and critical mindset needed for effective integration of digital tools into context-sensitive environmental education. Further studies should also explore hybrid learning models that combine immersive digital experiences with direct interaction with nature, especially in light of the proven emotional and cognitive benefits of technologies such as VR and AR. Finally, expanding the research scope to include families and communities is crucial, as environmental learning is a collective and lifelong process. The digital transformation of environmental education, therefore, must be approached not just as a technical innovation but as an ethical and pedagogical commitment to cultivating ecological citizenship in the digital age.

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