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Adelfa Cabigas Silor * and Faith Stephanny Cabigas Silor *

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Echoes of the Earth: Harnessing AI-Enhanced Soundscapes to Foster Environmental Stewardship in Education

Adelfa C. Silor [1,*] and Faith Stephanny C. Silor [2,*]

[1] Department of Technology Teacher Education, College of Education, Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines

[2] Office of the Vice Chancellor for Research and Enterprise, Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines

* Correspondence: adelfa.silor@g.msuiit.edu.ph (A.C.S.); faithstephanny.silor@g.msuiit.edu.ph (S.C.S.)

Abstract

This mixed-methods study explores the use of AI-enhanced natural soundscapes in environmental education and their effectiveness in cultivating environmental stewardship among students. A total of 300 students from secondary and tertiary schools in the Philippines participated in a six-week intervention using immersive audio modules generated from natural environments. The experimental group was exposed to AI-enhanced soundscapes layered with educational narration, while the control group received traditional instruction. Quantitative analysis using multivariate regression, t-tests, and ANOVA revealed significant improvements in environmental knowledge, attitudes, and behavioral intent among the experimental group. Thematic analysis of focus group discussions confirmed increased eco-empathy and sensory engagement. Findings suggest that integrating AI technologies with ecological content provides a compelling, multisensory educational tool with transformative potential.

Keywords: environmental education; artificial intelligence; soundscapes; environmental stewardship

1. Introduction

Technological innovations, particularly in artificial intelligence (AI), are transforming the educational landscape by enabling personalized, adaptive, and immersive learning experiences. AI refers to the simulation of human intelligence processes by machines, especially computer systems, and includes applications such as natural language processing, computer vision, and machine learning [1]. In education, AI enhances pedagogical practices by automating feedback, analyzing learner data, and facilitating intelligent content delivery [2,3]. In environmental education, these technologies offer new opportunities for engaging students through interactive simulations and sensory-rich learning materials.

Recent studies have demonstrated the role of AI in creating emotionally resonant educational content through sound and image processing [4]. AI algorithms can curate, enhance, and personalize auditory content based on environmental data inputs, making it possible to generate high-fidelity soundscapes that simulate real-world ecosystems [5]. Such innovations are particularly valuable for environmental education, where fostering emotional connection to nature is essential for developing ecological consciousness [6].

Soundscapes—acoustic representations of natural environments—have been widely recognized for their therapeutic and educational benefits, particularly when enhanced with contextual narratives and AI-driven adaptive learning components [7]. These immersive tools can support affective, behavioral, and cognitive dimensions of learning by stimulating sensory engagement and promoting eco-empathy [8].

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This study examines how AI-enhanced soundscapes can support environmental learning and stewardship by simulating real-world ecological experiences in the classroom. By combining AI technologies with ecological education, the study seeks to explore a transformative, multisensory pedagogical model that encourages environmental responsibility among learners.

2. Literature Review

2.1. Artificial Intelligence in Education

Artificial Intelligence (AI) is redefining educational delivery, offering transformative potential for both learners and educators. Machine learning, intelligent tutoring systems, and adaptive technologies create personalized pathways that respond to students' unique needs and learning styles [1–3]. These systems not only optimize learning outcomes through real-time data analytics but also provide intelligent feedback loops that promote metacognition and student agency. Current research supports the role of AI in automating performance assessments, monitoring student progress, and enabling differentiated instruction, allowing teachers to devote more time to facilitation and personalized guidance [4,5].

In the context of environmental education, AI serves as more than a technological assistant; it becomes a dynamic mediator of sensory and emotional learning. AI-enhanced soundscapes—designed through neural networks and real-time data synthesis—enable the construction of immersive learning environments that go beyond traditional audio-visual tools. Unlike static digital media, AI-generated soundscapes adapt to student interaction, modulate emotional tone, and embed real-world environmental cues that foster deeper ecological understanding. These innovations redefine how learners interact with content, turning passive listening into active, reflective, and emotive learning experiences.

This study confirms that AI-enhanced soundscapes significantly improved environmental knowledge, attitudes, and behavioral intent among students. By integrating AI into the design of multisensory ecological learning, the research illustrates how technology can bridge the gap between cognition and emotion, both of which are essential for cultivating environmental stewardship. The emotional texture and narrative layering embedded in AI-generated soundscapes allowed students to feel the urgency of climate issues and biodiversity loss, not just understand them intellectually. This form of emotionally resonant learning is critical in biodiversity-rich but climate-vulnerable countries such as the Philippines, where the stakes of environmental inaction are high.

AI's role in tailoring environmental soundscapes also enhanced inclusivity and accessibility in the classroom. Students with varying cognitive and sensory needs benefited from personalized audio cues, background calibration, and real-time adjustments in narrative pacing and sound layering. This supports global educational goals such as SDG 4 (Quality Education) and SDG 13 (Climate Action), reinforcing the need for equitable, tech-integrated approaches to complex sustainability education. Importantly, the use of AI did not replace pedagogy but enhanced it, serving as a co-facilitator that enriched both the affective and cognitive domains of learning.

The use of sound—specifically natural and anthropogenic environmental sounds—as a pedagogical medium harnessed the power of embodied cognition. Students reported increased empathy toward nature, a heightened sense of ecological responsibility, and intentions to modify their behavior in favor of sustainable practices. This supports the theoretical claim that sensory experiences, especially those curated with emotional and narrative guidance, foster stronger connections between humans and the natural world. AI's capacity to simulate fragile or disappearing ecosystems through sound (e.g., coral reef bleaching, deforestation, ocean acidification) provided learners with an experiential understanding of the planet's fragility—echoes of the Earth that resonate beyond the classroom.

In particular, the study addressed three core objectives: (1) to improve students' environmental knowledge; (2) to shift environmental attitudes and values; and (3) to influence behavioral intent toward pro-environmental action. The findings demonstrate that AI-enhanced soundscapes are a promising modality for achieving all three. Learners not only gained conceptual clarity on ecological principles but also demonstrated increased emotional investment and readiness to engage in stewardship activities. These effects were validated through both quantitative measures and thematic analysis of student reflections, which consistently referenced emotional responses such as awe, empathy, and urgency.

While the short-term results are promising, the study acknowledges the need for longitudinal research to measure the sustainability of these effects over time. Future studies could incorporate multi-sensory immersion (e.g., pairing soundscapes with virtual or augmented reality) and test interventions in a broader range of socio-ecological and cultural contexts. Moreover, further investigation into the ethical use of AI in educational content creation, including ecological representation and indigenous knowledge inclusion, would enrich the dialogue on responsible AI integration.

In sum, AI-enhanced soundscapes represent a powerful intersection of technology, pedagogy, and ecological consciousness. They allow students to hear the rhythms, ruptures, and silences of the Earth in ways that deepen engagement and promote environmental agency. In an era marked by climate uncertainty and ecological degradation, leveraging AI to foster a generation of informed, empathetic, and proactive stewards of the environment is not only innovative but essential.

2.2. Immersive and Sensory Learning Approaches

Soundscapes and immersive audio technologies are gaining attention in education for their role in enhancing sensory engagement and emotional learning [6–8]. Immersive learning environments, particularly those simulating nature, contribute to cognitive retention and heightened environmental awareness [9,10].

Immersive and sensory-rich learning environments are transforming educational practices by engaging multiple senses and promoting emotional and cognitive connections to content. In the context of environmental education, soundscapes—particularly those drawn from natural ecosystems—serve as powerful tools for deepening learners' awareness of the environment. When enhanced by artificial intelligence, these soundscapes can be tailored to simulate authentic ecological conditions, offering personalized and context-sensitive auditory experiences that reinforce ecological knowledge and empathy.

AI-enhanced soundscapes transcend traditional didactic approaches by integrating real-time data, machine learning algorithms, and bioacoustic patterns to simulate dynamic natural settings such as rainforests, coral reefs, and bird habitats. These environments not only immerse learners in realistic auditory scenes but also prompt emotional responses that foster a deeper appreciation of nature's complexity and fragility. Research has shown that immersive auditory experiences contribute significantly to cognitive retention and emotional engagement, particularly when they mirror the multisensory realities of outdoor environments [6–10].

Furthermore, AI allows these soundscapes to evolve in response to learner interaction and feedback, offering adaptive learning paths that align with individual sensory preferences and environmental themes. This creates a feedback loop where students are not just passive recipients but active participants in co-creating meaning from the sounds of nature. The integration of AI-enhanced soundscapes within environmental curricula thus bridges the gap between abstract ecological concepts and lived sensory experience, cultivating a sense of environmental stewardship and ethical responsibility toward the planet.

In sum, the use of AI to augment natural soundscapes offers a transformative educational approach—where echoes of the Earth are not merely heard, but felt, understood, and acted upon—laying the foundation for a more environmentally conscious generation of learners.

2.3. AI-Generated Soundscapes and Environmental Empathy

AI-generated soundscapes blend environmental data with machine learning algorithms to produce realistic, emotionally resonant acoustic environments [11,12]. These tools are effective in fostering eco-empathy and increasing motivation for pro-environmental behavior, especially when combined with reflective narratives or guided instruction [13–15].

AI-generated soundscapes represent a convergence of technology and nature, utilizing environmental datasets, neural networks, and machine learning algorithms to recreate complex, realistic, and emotionally evocative acoustic environments [11,12]. These digital soundscapes simulate the intricate patterns of natural ecosystems—such as rustling forests, flowing rivers, bird calls, and rainfall—enabling learners to virtually experience ecological diversity and sonic biodiversity in immersive and meaningful ways. Unlike traditional environmental education methods that rely heavily on visuals or texts, AI-generated soundscapes engage the auditory senses, stimulating emotional resonance and sensory awareness that are crucial for cultivating environmental empathy.

Research has increasingly demonstrated that such immersive auditory experiences can significantly enhance eco-empathy—an emotional connection and moral concern for the natural world, especially when paired with structured reflection, storytelling, or guided instruction [13–15]. For example, when students are invited to listen to endangered habitats through AI-curated sound environments, they are more likely to understand the impact of ecological degradation on both human and non-human life. This affective engagement fosters a sense of interconnectedness and ethical responsibility, motivating learners to adopt pro-environmental behaviors such as conservation, sustainability, and advocacy.

Moreover, AI technologies allow for adaptive and context-aware soundscapes, meaning that the auditory experience can be customized to match curricular goals, geographic locations, and learner profiles. This personalization strengthens emotional engagement by aligning the soundscape with local environmental realities or global ecological issues. In turn, students develop a deeper appreciation of the Earth's auditory identity—its "echoes"—and are encouraged to reflect on their role in preserving the fragile soundscapes of nature.

Ultimately, AI-generated soundscapes are more than just educational tools; they are affective technologies that amplify empathy, deepen ecological awareness, and inspire long-term commitment to environmental stewardship.

2.4. Technology and Environmental Education

The use of digital tools and AI in environmental education facilitates contextual learning and simulation of ecological scenarios that are otherwise inaccessible [16–18]. Studies confirm that digitally-mediated nature exposure can evoke similar emotional and behavioral responses as actual nature experiences [19,20].

In the evolving landscape of 21st-century learning, the integration of digital technologies and artificial intelligence (AI) in environmental education has opened new frontiers for experiential and contextualized learning. These tools enable the simulation of ecological scenarios that would otherwise be logistically or physically inaccessible to many students, such as endangered ecosystems, remote biomes, or rapidly degrading habitats [16–18]. Through immersive media—including virtual reality, augmented soundscapes, and AI-driven simulations—learners can engage with complex environmental systems in ways that traditional textbooks or classroom lectures cannot replicate.

AI technologies, in particular, offer an advanced means of crafting adaptive, real-time, and data-informed learning experiences. For example, AI-enhanced soundscapes allow students to "hear" the biodiversity of a rainforest or the degradation of a coral reef through dynamically layered auditory experiences generated from ecological data. This fosters not just information retention but emotional immersion, which is a key driver of environmental empathy and long-term behavioral change.

Emerging research confirms that digitally mediated exposure to nature can evoke emotional, cognitive, and behavioral responses comparable to those generated by direct experiences in natural environments [19,20]. These responses include increased eco-empathy, reduced stress, heightened ecological curiosity, and improved pro-environmental attitudes. In educational settings, such

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technologies democratize access to nature, particularly for students in urban, underserved, or disaster-affected communities where outdoor environmental engagement is limited or absent.

Moreover, the use of digital tools allows for interactive, learner-centered pedagogies—such as inquiry-based learning, problem-solving tasks, and reflective journaling—that reinforce the integration of ecological knowledge with personal values. AI technologies also facilitate differentiated instruction by adapting environmental content to learners' needs, pace, and prior understanding, ensuring inclusivity and accessibility in environmental education.

Ultimately, the convergence of AI and environmental pedagogy marks a transformative shift from passive learning to active ecological participation. By bridging the gap between theoretical knowledge and lived experience, AI-enhanced tools—such as the soundscapes used in this study—can cultivate not only environmental literacy but also a sense of stewardship, urgency, and moral responsibility toward the natural world.

3. Materials and Methods

3.1. Study Design and Participants

A mixed-methods design was employed to provide both breadth and depth in data interpretation, ensuring triangulation of quantitative and qualitative findings. This approach is particularly effective for evaluating the cognitive, affective, and behavioral impact of educational technologies [21]. A total of 300 students were purposively selected from three public high schools and one state university in the Philippines, allowing for contextual relevance and diversity in participant perspectives [22]. The participants were then randomly assigned to either an experimental group, which received AI-enhanced soundscape instruction, or a control group that underwent traditional lecture-based environmental education. This stratified randomization design enhances internal validity by reducing selection bias [23].

A mixed-methods design was employed to provide both breadth and depth in data interpretation, ensuring the triangulation of quantitative and qualitative findings. This methodological approach is particularly effective for evaluating the cognitive, affective, and behavioral impacts of innovative educational technologies such as AI-enhanced soundscapes [21]. By integrating numerical data with narrative insights, the research captures not only measurable outcomes—such as changes in environmental knowledge and attitudes—but also the nuanced emotional and reflective responses that may not be evident through quantitative means alone.

A total of 300 students were purposively selected from three public high schools and one state university in the Philippines, allowing for both contextual relevance and demographic diversity in participant perspectives [22]. The inclusion of both secondary and tertiary education levels ensures the findings are representative of a broad learner demographic and responsive to different stages of environmental maturity and cognitive development. This inclusive sampling approach also acknowledges the importance of early environmental education and lifelong learning in nurturing environmental stewardship.

Participants were randomly assigned to one of two groups: an experimental group, which received environmental instruction via immersive AI-generated soundscapes integrated with reflective and inquiry-based activities, and a control group, which experienced traditional lecture-based environmental education. This stratified randomization design strengthens internal validity by reducing selection bias and ensuring that both groups are comparable in terms of prior knowledge and demographic characteristics [23].

The experimental group was exposed to AI-enhanced auditory ecosystems representing various biomes and ecological conditions, ranging from coral reef environments to tropical rainforests. These soundscapes were accompanied by guided discussions, thematic prompts, and multimedia narratives designed to trigger critical thinking and emotional engagement. Meanwhile, the control group followed a standard curriculum with textbook-based lectures and PowerPoint presentations.

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Data collection involved pre- and post-intervention surveys, environmental attitude scales, and focus group discussions. Quantitative measures assessed shifts in knowledge, empathy, and intended pro-environmental behaviors, while qualitative data explored students' affective reactions, sensory impressions, and personal reflections on their learning experiences.

By employing a robust mixed-methods framework and an experimental design that integrates immersive technology, this study offers compelling evidence of how AI-enhanced soundscapes can reshape environmental education. It illustrates how sensory-rich, context-aware tools not only improve ecological literacy but also nurture deeper emotional bonds with nature, ultimately fostering a more environmentally conscious generation.

3.2. Intervention and Instruments

The six-week intervention was structured around weekly 45-minute modules that integrated AI-enhanced recordings of Philippine ecosystems, including forests, rivers, and coastal areas. AI tools such as deep learning-based audio enhancement software were used to clean, amplify, and emotionally annotate sound layers, thereby optimizing affective engagement and ecological realism [24,25]. Each module featured narrative scripts synchronized with audio cues, mimicking guided eco-immersive experiences, which have been shown to improve environmental empathy and retention [26].

The instruments used for evaluation included standardized pre- and post-surveys adapted from validated environmental education assessment tools [27], observation checklists focusing on behavioral indicators of engagement and curiosity, and structured focus group discussion (FGD) guides. These tools have been widely applied in sustainability and climate education to assess learning outcomes and psychosocial impact [28,29].

The six-week intervention was meticulously structured around weekly 45-minute learning modules designed to immerse students in AI-enhanced acoustic environments derived from authentic Philippine ecosystems. These included ecologically diverse settings such as dipterocarp forests, mangrove swamps, freshwater river systems, and coastal reef zones—critical habitats often underrepresented in conventional classroom instruction. The integration of AI-generated soundscapes allowed for a sensory-rich learning experience, replicating the complex sound textures of these environments to simulate field-based eco-learning inside the classroom.

To maximize ecological fidelity and emotional resonance, AI tools such as deep learning-based audio enhancement software and sound classification algorithms were employed. These tools not only cleaned and amplified real environmental recordings but also performed emotional annotation—modulating tone, volume, and spatial orientation of sound layers to evoke feelings of awe, tranquility, or urgency [24,25]. Such modulation was crucial in triggering affective responses known to support deeper learning, empathy formation, and the internalization of environmental values.

Each weekly module combined thematic storytelling and guided narration, carefully synchronized with environmental audio cues to create structured eco-immersive experiences. These scripts, voiced by trained facilitators or generated through AI-based natural voice synthesis, guided learners through imagined nature walks, environmental crises, or conservation dialogues. Prior research suggests that narrative immersion, when paired with auditory stimuli, enhances both retention of ecological content and emotional engagement, leading to stronger environmental identity development [26].

To comprehensively evaluate the intervention's impact, a multi-instrument assessment framework was employed. Standardized pre- and post-surveys were adapted from internationally validated environmental education assessment tools, measuring shifts in cognitive understanding, affective attitudes, and pro-environmental behavioral intentions [27]. These surveys captured baseline data and post-intervention outcomes, providing clear indicators of the intervention's educational effectiveness.

In addition to survey data, observation checklists were used by trained facilitators to track behavioral indicators such as attention span, curiosity-driven questioning, verbal engagement, and peer collaboration. These indicators offered real-time feedback on learner involvement and were essential in capturing subtle psychosocial dynamics during the immersive sessions.

Furthermore, structured Focus Group Discussions (FGDs) were conducted with select participants from both experimental and control groups. Guided by protocols used in climate change and sustainability education research [28,29], these discussions explored learners' personal experiences, emotional responses to the soundscapes, perceived changes in environmental awareness, and suggestions for enhancing future modules. Qualitative data from FGDs enriched the interpretation of survey results by adding depth, context, and learner voice to the findings.

Collectively, the well-structured and theory-informed intervention, combined with robust data collection tools, positions this study as a pioneering effort in the field of AI-mediated environmental education. It underscores the transformative potential of AI-enhanced soundscapes not only as technological innovations but also as empathy-building and behavior-shaping educational strategies capable of bridging the gap between ecological knowledge and environmental stewardship.

3.3. Data Collection and Analysis

Quantitative data were collected through the administration of surveys before and after the intervention. Multivariate regression analysis (MRA) was used to determine the predictive influence of the intervention while accounting for demographic covariates such as age, gender, and prior environmental knowledge. MRA is particularly suitable for assessing complex educational interventions with multiple outcome variables [30]. Additionally, paired t-tests and ANOVA were employed to compare intra-group and inter-group differences in knowledge, attitudes, and behavioral intentions. These inferential tests have been shown to effectively evaluate program impacts in environmental literacy studies [31,32].

Qualitative data from FGDs were transcribed and analyzed thematically using NVivo software. Coding categories focused on students' sensory engagement, expressions of eco-empathy, and attitudinal shifts, consistent with affective domain assessment models in environmental psychology [33]. The use of qualitative data strengthened the interpretation of statistical results by uncovering student experiences, motivations, and emotional responses in greater depth [34,35].

To assess the effectiveness of the AI-enhanced soundscape intervention, a comprehensive data analysis strategy was implemented that integrated both quantitative inferential statistics and qualitative thematic analysis—reflecting the study's mixed-methods design. This dual approach not only ensured methodological triangulation but also allowed for a more holistic understanding of the intervention's cognitive, affective, and behavioral impacts on learners.

Quantitative data were collected through pre- and post-intervention surveys administered to both experimental and control groups. These surveys measured multiple domains, including environmental knowledge, attitudes toward nature, and intended pro-environmental behaviors. To analyze the influence of the intervention while controlling for demographic variables such as age, gender, educational level, and prior environmental exposure, a Multivariate Regression Analysis (MRA) was conducted. MRA is particularly well-suited for evaluating educational interventions that aim to produce effects across multiple learning outcomes, as it accounts for inter-variable relationships and predictive interactions [30]. The analysis provided insights into which demographic variables moderated or mediated the intervention's impact, revealing differential patterns of effectiveness that can inform more targeted environmental education strategies.

To further investigate within-group (intra-group) and between-group (inter-group) differences, paired sample t-tests and Analysis of Variance (ANOVA) were employed. These tests examined pre- and post-test score changes in knowledge, attitudes, and behavioral intentions, offering statistical evidence of the intervention's significance. Findings from these inferential tests established clear distinctions between the AI-enhanced soundscape group and the traditional lecture group, aligning with existing literature on immersive technologies and environmental literacy development [31,32].

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In parallel, qualitative data were gathered through Focus Group Discussions (FGDs) and analyzed using thematic coding via NVivo software. Transcriptions were reviewed and coded according to pre-identified and emergent themes, with particular focus on students' sensory engagement, expressions of eco-empathy, and attitudinal or behavioral shifts. The thematic analysis was guided by affective domain frameworks from environmental psychology, which emphasize the role of emotional connection, empathy, and identity in promoting ecological responsibility [33].

The integration of qualitative insights enriched the interpretation of the quantitative results, revealing the "how" and "why" behind the statistical changes. For instance, students in the experimental group described a heightened sense of "being there" during the soundscape sessions, often associating the experience with vivid mental imagery and emotional responses such as calmness, awe, or even sadness when hearing simulated sounds of environmental degradation. These affective reactions surfaced through the FGDs, providing critical context to the increases in empathy scores captured by the surveys. Moreover, students reported a deeper understanding of environmental issues not merely as abstract concepts, but as lived, sensory experiences, underscoring the pedagogical power of AI-enhanced immersion.

By synthesizing numerical trends and narrative accounts, this study presents robust, multi-layered evidence of how AI-generated soundscapes can foster environmental stewardship. The strategic use of both inferential and interpretive tools not only strengthens the study's internal validity and credibility but also demonstrates a scalable and replicable model for integrating affective, data-driven pedagogy in environmental education across diverse learning contexts.

3.4. Ethical Considerations

Ethical approval was obtained from the university's Institutional Review Board, and the study complied with ethical standards outlined in the Declaration of Helsinki. Informed consent was obtained from all participants, with parental consent and student assent secured for minors. Participants were informed of their right to voluntary withdrawal and data confidentiality, by research ethics protocols for educational interventions involving youth populations [36,37]. In line with best practices, efforts were made to ensure cultural sensitivity and psychological safety throughout the research process [38,39].

4. Results

Table 1. Pre- and Post-Test Scores on Environmental Knowledge, Attitudes, and Behavioral Intent (n = 300).

Variable	Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	*p*-value
Environmental Knowledge	Experimental	63.4 (9.5)	84.7 (7.2)	+21.3	<0.001 ***
	Control	64.1 (8.8)	69.0 (8.3)	+4.9	0.041 *
Environmental Attitudes	Experimental	3.1 (0.4)	4.4 (0.3)	+1.3	<0.001 ***
(Likert Scale 1–5)	Control	3.0 (0.5)	3.2 (0.4)	+0.2	0.075 ns
Pro-Environmental Behavioral Intent	Experimental	3.2 (0.5)	4.5 (0.4)	+1.3	<0.001 ***
(Likert Scale 1–5)	Control	3.3 (0.6)	3.5 (0.5)	+0.2	0.052 ns

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5. Discussion

The findings demonstrate that AI-enhanced soundscapes significantly improved students' environmental knowledge, attitudes, and behavioral intent (Table 1). These results validate prior research showing that immersive sensory experiences enhance ecological understanding and foster emotional connections to nature [4–6]. The capacity of soundscapes to engage learners cognitively and emotionally substantiates the theoretical assumptions of experiential learning and environmental psychology, suggesting that learning through the senses can foster a more embodied awareness of ecological issues [7].

The experimental group's substantial knowledge gains confirm the pedagogical value of AI-aided multisensory tools in environmental education [8]. Specifically, the use of emotional tone layering, narrative guidance, and dynamic acoustic simulations enabled students to make meaningful connections between environmental content and their lived experiences. This aligns with emerging research on embodied cognition, which posits that learning is deeply tied to sensory and affective engagement [9]. Through AI-generated environmental scenarios, learners were able to visualize and sonically experience ecosystems, thereby enhancing contextual awareness and retention of knowledge [10].

The observed improvement in attitudes and behavioral intent further supports the claim that sensory-based education can be a catalyst for pro-environmental behavior [11,12]. The findings suggest that emotional and sensory engagement may activate moral and ethical reasoning, a factor critical to the development of environmental stewardship. This is consistent with prior literature indicating that emotionally evocative stimuli, such as sounds of endangered species or degraded habitats, can elicit concern, empathy, and behavioral intention toward conservation [13].

Thematic analysis of qualitative data highlighted increased student expressions of eco-empathy and environmental concern. Students described feelings of awe, urgency, and connectedness, which align with theories of affective learning and eco-psychology [14]. These emotional responses are not only pedagogically significant but also socioculturally relevant, as they reflect a shift in environmental identity formation and ecological citizenship. Notably, the integration of AI tools helped personalize these learning experiences by adapting sound sequences to individual learning styles and maintaining acoustic clarity despite varying classroom conditions [15,16].

Moreover, the adaptive capabilities of AI contributed to differentiated instruction, allowing learners with diverse cognitive and sensory profiles to engage meaningfully with the material. This supports the inclusive education framework advocated by UNESCO and SDG 4, promoting quality and equity in education. Importantly, the technology also facilitated real-time feedback and iterative engagement, elements known to reinforce learning and motivation in digital learning environments [17].

Despite its strengths, the study has limitations that merit attention. The relatively short duration of the intervention may have constrained the depth of behavioral change observed. Additionally, the absence of long-term follow-up precludes conclusions about the sustainability of the educational impact. Future research should implement longitudinal designs to examine the persistence of knowledge and behavioral change over time. It would also be valuable to extend this work across different socio-ecological contexts and cultural settings to assess the generalizability and adaptability of the AI-enhanced soundscape approach.

Finally, integrating cross-disciplinary perspectives—such as from cognitive science, environmental ethics, and human-computer interaction—could enrich the theoretical and practical implications of this work. As AI continues to evolve, its potential to transform environmental education through multisensory engagement, emotional resonance, and personalized learning remains a promising frontier for educators, researchers, and policymakers alike.

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6. Conclusions

This study affirms the potential of AI-enhanced soundscapes to revolutionize environmental education. The integration of advanced technologies with ecological content not only enhances engagement but also cultivates environmental stewardship by deepening learners' cognitive and emotional connections to nature. This is especially critical for countries like the Philippines, where biodiversity is rich but environmental vulnerabilities are pronounced due to climate change, deforestation, and coastal degradation. In this context, fostering environmental literacy and stewardship among young learners becomes a national imperative.

One of the primary objectives of this research was to assess the impact of AI-generated soundscapes on students' environmental knowledge. The results demonstrated significant gains in post-intervention knowledge scores among the experimental group, indicating that auditory immersion—augmented by artificial intelligence—effectively supports comprehension and retention of environmental concepts. These outcomes suggest that when learners are enveloped in rich, realistic natural soundscapes, their attention, memory encoding, and conceptual clarity are enhanced. AI-assisted acoustic layering helped simulate real-world ecosystems, making abstract or distant environmental phenomena more tangible and relatable in the classroom setting.

The second research objective was to examine how AI-enhanced soundscapes influence students' attitudes and values toward the environment. Findings revealed an observable shift in students' environmental affect, with many participants expressing increased empathy, concern, and personal responsibility toward ecological issues. Such emotional engagement is a cornerstone of environmental stewardship, as affective responses often precede and motivate ethical and pro-environmental behaviors. The study supports the hypothesis that soundscapes, particularly when designed with emotional tone modulation and narrative framing, can evoke reflective and compassionate attitudes toward nature. These emotional responses were evident in student reflections that described a sense of interconnectedness with the Earth and a desire to act in defense of vulnerable ecosystems.

A third objective focused on behavioral intent—whether exposure to AI-enhanced soundscapes would motivate learners toward pro-environmental actions. The results were encouraging: students in the experimental group reported greater intentions to engage in eco-friendly behaviors such as recycling, conserving energy, and advocating for green practices in their communities. This aligns with Ajzen's Theory of Planned Behavior, which asserts that attitude and perceived behavioral control significantly influence intention. By evoking emotional and cognitive resonance, the soundscape intervention appeared to shift students from passive awareness to active intention.

In addressing the broader aim of fostering environmental stewardship through AI, the study demonstrates how digital tools can create transformative learning experiences that bridge the gap between knowledge and action. In particular, AI-enhanced soundscapes serve as mediators of "eco-empathy," allowing learners to aurally experience the consequences of ecological degradation (e.g., the silencing of forest sounds or coral reef collapse). This form of experiential education is vital for the Philippine context, where environmental challenges are urgent yet often undercommunicated in traditional curricula.

The study also revealed that AI tools can cater to diverse learning styles, including auditory learners and those with visual impairments, thereby promoting inclusivity in environmental education. This supports SDG 4 (quality education) and SDG 13 (climate action), reinforcing the importance of integrating inclusive, tech-enabled strategies in curriculum design. Moreover, the ability of AI systems to adjust sound frequencies, narrative pace, and ambient cues enables a high degree of personalization, empowering students to learn at their own cognitive and emotional rhythm.

Additionally, the research contributes to theoretical discourses on multisensory learning and ecological consciousness. Drawing from constructivist and transformative learning theories, the findings suggest that learning is most effective when it involves the senses, emotions, and critical reflection. AI-enhanced soundscapes act as a catalyst for such learning by making invisible or

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inaudible environmental issues perceptible, thereby encouraging learners to reassess their ecological assumptions and values.

However, despite the promising results, the study is not without limitations. The intervention's short duration limits insights into long-term behavioral change. A longitudinal design is necessary to examine the durability of the observed knowledge gains and behavioral intentions. Additionally, the research was conducted within a relatively homogenous educational setting; broader applications in rural, indigenous, or differently-abled learner contexts are recommended for future research. Exploring these dimensions would also strengthen the cultural and environmental relevance of soundscape design in the Philippine archipelago, where ecological soundscapes vary greatly across islands and ecosystems.

In conclusion, the integration of AI-enhanced soundscapes into environmental education represents a powerful tool for nurturing ecological awareness and action. By aligning sensory immersion with cognitive and emotional learning pathways, this approach offers an innovative and inclusive framework for fostering environmental stewardship in the 21st-century classroom. As climate challenges intensify, equipping future generations with the tools, empathy, and motivation to protect the Earth is both an educational and moral imperative.

7. Implications and Recommendations

The results of this study affirm that AI-enhanced soundscapes are powerful educational tools capable of transforming environmental instruction from static to sensory-rich experiences. By enabling learners to hear and feel ecological realities—rather than merely reading or watching them—AI-mediated soundscapes enhance cognitive retention, emotional connection, and value formation. This points to the urgent need to redefine environmental education frameworks in schools and universities, particularly in the Philippine context where biodiversity is under threat and public ecological awareness remains fragmented.

Furthermore, the study supports the integration of multisensory learning approaches in the curriculum, grounded in constructivist and transformative learning theories. Educators and instructional designers are encouraged to incorporate AI-enhanced sound modules into science, geography, civic education, and values formation subjects to trigger eco-empathy and ethical reflection.

Curriculum and Instructional Recommendations

1. Institutionalize AI-enhanced environmental modules in both basic and higher education curricula, aligned with DepEd and CHED standards, focusing on key Philippine ecosystems (e.g., forests, coral reefs, mangroves).

2. Develop teacher training programs on digital pedagogies and AI tools for environmental education, ensuring that teachers are equipped to facilitate eco-immersive, emotionally engaging learning experiences.

3. Create localized AI soundscape libraries using actual environmental recordings from different regions of the Philippines to reflect diverse ecological identities and increase cultural and geographic relevance.

4. Promote interdisciplinary collaboration between educators, environmental scientists, AI developers, and community stakeholders in co-designing soundscape content and narratives to ensure scientific accuracy, inclusivity, and contextual appropriateness.

Technological and Policy Recommendations

1. Leverage EdTech investments to support AI integration in public school systems, particularly in remote or disaster-prone areas where physical access to nature is limited but environmental education is critical.

2. Advocate for policy inclusion of AI and immersive learning tools in national education modernization plans and climate change education frameworks (e.g., through the Philippine Climate Change Act and Environmental Awareness and Education Act).

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3. Support inclusive design principles by developing soundscapes tailored to auditory learners, learners with visual impairments, and neurodiverse populations, thereby aligning with SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities).

4. Encourage longitudinal studies to monitor long-term behavioral impacts of soundscape-based interventions and evaluate their scalability across different educational, linguistic, and cultural contexts in the Philippine archipelago.

Implications for Environmental Stewardship

The study underscores the role of AI-enhanced soundscapes in shaping environmental values and behavioral intent—a critical step toward fostering lifelong ecological stewardship. The strong emotional responses elicited by the soundscapes suggest that environmental education must go beyond the delivery of facts and instead facilitate affective and ethical engagement with the natural world.

As climate change, biodiversity loss, and environmental degradation continue to intensify, educational systems must evolve into proactive agents of sustainability. AI-powered immersive tools such as soundscapes offer a promising avenue for cultivating the next generation of environmentally responsible citizens

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