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Abstract

The increasing complexity of environmental issues in the 21st century requires learners to develop a deeper, systems-based understanding of ecological processes. However, traditional instruction often struggles to make abstract ecology concepts accessible. This study investigates the effectiveness of AI-assisted visual hooks in enhancing environmental awareness within a Problem-Based Learning (PBL) framework. Specifically, it examines whether AI-generated visual scaffolds improve learning outcomes, identifies which ecology concepts benefit most, and explores students' perceptions of the approach. An embedded mixed-methods quasi-experimental design was employed with two groups of senior high school students (n = 40 per group). The experimental group received instruction supported by AI-generated visual hooks, while the control group experienced conventional PBL. Quantitative data were analyzed using descriptive statistics and ANCOVA, while qualitative data from student reflections and focus group discussions were examined thematically. Results showed that the experimental group significantly outperformed the control group in environmental awareness, $F(1,77) = 43.56$, $p < .001$, $\eta^2 = 0.36$, particularly in climate change and food web concepts. Students also reported improved conceptual clarity, engagement,

and confidence in problem-solving. These findings suggest that AI-assisted visual hooks are an effective instructional strategy for enhancing ecology learning and can inform science instruction and teacher development initiatives.

Keywords: AI-assisted learning; Environmental awareness; Problem-based learning; AI in education; Ecology education

Introduction

In recent decades, the world has witnessed an alarming acceleration of ecological crises, including biodiversity loss, climate change, and widespread environmental pollution. These interconnected challenges threaten not only natural ecosystems but also human health, economic stability, and global sustainability (Cury et al., 2023; Yang et al., 2025). Biodiversity decline, driven by habitat destruction and anthropogenic pressures, has reached unprecedented levels, while climate change continues to intensify extreme weather events and disrupt ecological balance. Simultaneously, pollution—particularly plastic waste and chemical contaminants—has further degraded terrestrial and aquatic ecosystems (Masud et al., 2018; Rushton et al., 2024). In light of these pressing concerns, education has been identified as a critical mechanism for fostering environmental awareness and promoting sustainable behaviors among future generations (Esteban et al., 2016; Lin et al., 2022; Mitchell et al., 2024).

Within the Philippine context, ecology education is embedded in the K–12 science curriculum, particularly at the senior high school (SHS) level, where students are expected to develop a deeper understanding of ecological principles and sustainability issues. The curriculum emphasizes competencies such as analyzing ecosystem interactions, understanding biogeochemical cycles, and evaluating human impacts on the environment (Muñoz-Losa et al., 2025). These competencies are designed not only to build conceptual knowledge but also to cultivate environmental awareness and responsibility. However, despite these curricular intentions, a persistent gap remains between students' cognitive understanding of ecological concepts and their actual awareness and pro-environmental behavior (Erol et al., 2026; Srisathan et al., 2024).

This disconnect suggests that while students may be able to recall and explain ecological theories, they often fail to internalize their relevance or translate knowledge into meaningful action. Environmental awareness, which encompasses attitudes, values, and a sense of responsibility toward the environment, requires more than rote learning; it demands experiential, engaging, and contextually meaningful instruction (King-Chan et al., 2021; Sarkar & Islam, 2025). Consequently, there is a growing need to explore innovative pedagogical approaches that can bridge this gap and make ecology education more impactful and transformative.

Problem Statement

One of the fundamental challenges in teaching ecology lies in the abstract nature of its core concepts. Topics such as nutrient cycling, energy flow, and ecosystem dynamics involve complex, often invisible processes that are difficult for students to conceptualize (Esteban et al., 2016). For instance, understanding the carbon cycle requires learners to mentally integrate processes occurring across different spatial and temporal scales, while ecosystem interactions demand the ability to visualize dynamic relationships among multiple organisms. These cognitive demands can overwhelm learners, particularly when instruction relies heavily on text-based or static representations.

Moreover, traditional teaching methods in ecology—characterized by lecture-based delivery and textbook-centered instruction—tend to limit student engagement and hinder deep understanding (King-Chan et al., 2021). Such approaches often prioritize content coverage over conceptual clarity and fail to provide opportunities for active learning. As a result, students may develop only superficial knowledge, lacking the ability to apply concepts to real-world environmental issues. This limitation is

particularly problematic in sustainability education, where the goal is not merely to inform but to inspire critical thinking and action.

Compounding this issue is the difficulty of visualizing ecological processes. Unlike laboratory-based sciences where phenomena can be directly observed, many ecological interactions occur over long periods or in inaccessible environments. Without effective visualization tools, students may struggle to grasp the interconnectedness and complexity of ecosystems (Erol et al., 2026). Consequently, there is a pressing need for instructional strategies that can make abstract ecological concepts more concrete, engaging, and relevant to students' lived experiences.

Role of AI-Assisted Visual Hooks

In response to these challenges, the integration of artificial intelligence (AI) in education has emerged as a promising avenue for enhancing teaching and learning. AI-assisted visual hooks—defined as AI-generated visual stimuli designed to capture attention and facilitate understanding—offer a novel approach to addressing the limitations of traditional ecology instruction. These visual hooks can take various forms, including ecosystem simulations, before-and-after environmental scenarios, and interactive food web visualizations.

For example, AI-generated simulations can dynamically model ecosystem changes in response to variables such as deforestation or climate shifts, allowing students to observe cause-and-effect relationships in real time. Similarly, before-and-after scenarios can vividly illustrate the impact of human activities on natural environments, thereby fostering emotional engagement and ethical reflection. Food web visualizations, enhanced by AI, can present complex trophic interactions in an intuitive

and interactive manner, helping students better understand ecological interdependence (Schmälzle, R., & Lim, 2026; Uyanık, 2025).

The theoretical basis for using visual hooks is grounded in cognitive and multimedia learning theories, which suggest that well-designed visual representations can reduce cognitive load and enhance comprehension (Bai et al., 2026; Chien et al., 2025). Furthermore, attention is a critical precursor to learning; by capturing students' interest at the outset, visual hooks can facilitate deeper processing of information. In this regard, AI-assisted visuals are hypothesized to initiate a learning sequence wherein increased attention leads to improved comprehension, which in turn fosters greater environmental awareness.

Importantly, the integration of AI-generated visuals aligns well with Problem-Based Learning (PBL), an instructional approach that emphasizes real-world problem solving and student-centered inquiry. In a PBL context, visual hooks can serve as entry points for presenting authentic environmental problems, thereby stimulating curiosity and guiding investigation (Han et al., 2026; Li & Bahari, 2026). By situating learning within meaningful contexts, AI-assisted visual hooks have the potential to enhance both cognitive and affective dimensions of ecology education.

Research Gap

Despite the growing interest in AI applications in education, there remains a notable lack of research examining the combined use of AI-generated visuals, ecology content, and Problem-Based Learning. Existing studies have primarily focused on the effectiveness of multimedia tools in general science education or the use of AI for personalized learning and assessment (Ding & Song, 2026; Mohamed, 2026). While

these studies provide valuable insights, they do not specifically address the unique challenges of teaching ecology or the role of visual engagement in fostering environmental awareness.

Furthermore, research on environmental education has often emphasized knowledge acquisition and attitude change but has paid less attention to the specific instructional strategies that can effectively bridge the gap between understanding and awareness (Lin et al., 2026; Ren et al., 2025). In particular, there is limited empirical evidence on how AI-assisted visual tools influence students' environmental awareness, especially within the context of senior high school education.

In the Philippine setting, this gap is even more pronounced. Although the K–12 curriculum advocates for innovative and learner-centered approaches, the integration of advanced technologies such as AI in classroom practice remains relatively underexplored. Consequently, there is a need for empirical studies that investigate how AI-assisted visual hooks can be effectively implemented in ecology-focused PBL environments and how they impact students' learning outcomes.

Research Questions

In light of the foregoing discussion, this study seeks to address the identified gaps by examining the effects of AI-assisted visual hooks on senior high school students' environmental awareness within an ecology-focused Problem-Based Sustainability Education framework. Specifically, the study is guided by the following research questions:

1. Do AI-assisted visual hooks in problem-based learning significantly improve environmental awareness in ecology topics?

2. How do students perceive AI-generated visuals in Problem-Based Learning contexts?

By addressing these questions, the study aims to contribute to the growing body of literature on AI in education, while also providing practical insights for enhancing ecology instruction and promoting environmental awareness among senior high school students.

Literature Review

Ecology Education in Senior High School

Ecology education occupies a central role in senior high school science curricula, particularly as nations respond to intensifying environmental challenges and the need for sustainability-oriented competencies. In the Philippines, the K–12 science framework emphasizes ecological literacy as a foundational outcome, requiring students to engage with complex topics such as ecosystem structure and function, energy flow, biogeochemical cycles, biodiversity conservation, and human impacts on the environment (Pinuela, 2025). These domains collectively aim to develop not only conceptual understanding but also the capacity to analyze environmental issues critically and make informed decisions.

To begin with, ecosystem structure and function provide the conceptual backbone of ecology education. Students are expected to understand how biotic and abiotic components interact within ecosystems, forming dynamic systems characterized by feedback mechanisms and resilience (Meek, 2019). This foundational knowledge is crucial, as it underpins more advanced ecological concepts and enables learners to interpret environmental phenomena holistically. However, the abstract and systems-

oriented nature of these topics often poses instructional challenges, particularly when learners lack prior exposure to systems thinking (Schneller et al., 2022).

Closely related to this is the concept of energy flow, typically taught through food chains and food webs. Unlike matter, which cycles within ecosystems, energy flows unidirectionally from primary producers to higher trophic levels, dissipating as heat at each transfer (Tusoy et al., 2025). Understanding this distinction is critical for grasping ecosystem efficiency and trophic dynamics. Nevertheless, students frequently struggle to differentiate between energy flow and matter cycling, leading to persistent misconceptions that hinder deeper comprehension (Maharramli et al., 2021).

In addition, biogeochemical cycles—such as the carbon and nitrogen cycles—represent another core component of ecology education. These cycles illustrate the movement of essential elements through the biosphere, atmosphere, hydrosphere, and lithosphere, highlighting the interconnectedness of Earth systems (Casas et al., 2021). While these topics are essential for understanding global environmental issues like climate change, their complexity and scale often make them difficult for students to visualize and internalize (Honra, 2025a).

Furthermore, biodiversity and conservation are increasingly emphasized in response to accelerating species loss and ecosystem degradation. Students are introduced to concepts such as species richness, ecosystem services, and conservation strategies, fostering an appreciation for the intrinsic and instrumental value of biodiversity (Cederlöf et al., 2025). At the same time, instruction on human impacts—ranging from deforestation and pollution to climate change—encourages learners to examine the consequences of anthropogenic activities and consider sustainable alternatives (Asikin et al., 2026).

Taken together, these core topics highlight the breadth and complexity of ecology education at the senior high school level. While the curriculum is comprehensive, the challenge lies in ensuring that students not only understand these concepts but also develop a meaningful connection to environmental issues. This challenge, in turn, necessitates a closer examination of the learning difficulties associated with ecology.

Learning Challenges in Ecology

Despite the importance of ecology education, numerous studies have documented persistent learning challenges that impede students' understanding. Among the most significant are misconceptions, particularly regarding fundamental ecological processes. For instance, students often conflate energy flow with nutrient cycling, mistakenly believing that energy is recycled within ecosystems in the same way as matter (Cao & Zhang, 2025). Such misconceptions are not merely superficial errors; rather, they reflect deeply rooted cognitive frameworks that can resist traditional instruction.

In addition to misconceptions, students face considerable difficulty in visualizing ecological systems. Ecology inherently involves dynamic processes that unfold over time and across spatial scales, making them less accessible to direct observation (Gupta et al., 2019). For example, understanding how changes in one component of an ecosystem affect others requires the ability to mentally simulate interactions and feedback loops. However, many learners lack the representational skills needed to construct and manipulate such mental models (Reimann, 2024).

Moreover, the concept of interdependence—central to ecological thinking—poses another layer of complexity. Ecosystems are characterized by intricate networks of relationships among organisms and their environment, and disruptions in one part of the system can have cascading effects (Neumann et al., 2026). Students often struggle to

appreciate these connections, tending instead to adopt linear or fragmented perspectives. This limitation can hinder their ability to analyze environmental problems and propose effective solutions.

Compounding these cognitive challenges is the prevalence of traditional teaching methods, which may not adequately address the demands of ecology learning. Lecture-based instruction, while efficient for content delivery, often fails to engage students actively or support the development of higher-order thinking skills (Kranz et al., 2023; Wolfram et al., 2019). As a result, learners may acquire factual knowledge without achieving conceptual understanding or the ability to apply their knowledge in real-world contexts.

Given these challenges, there is a clear need for pedagogical approaches that can facilitate deeper understanding and support the development of systems thinking. One such approach is Problem-Based Learning (PBL), which has gained prominence in science education for its potential to enhance engagement and critical thinking.

Problem-Based Learning in Ecology

Problem-Based Learning (PBL) is an instructional approach that centers on the investigation and resolution of authentic, real-world problems. In the context of ecology education, PBL offers a particularly valuable framework, as it aligns closely with the interdisciplinary and applied nature of environmental issues (Heystek et al., 2025). By engaging students in the analysis of complex ecological problems, PBL encourages the integration of knowledge, skills, and values.

For instance, issues such as deforestation, plastic pollution, and urban flooding provide rich contexts for PBL activities. These problems are not only relevant to students' lives but also inherently complex, requiring the consideration of ecological, social, and economic factors. Through collaborative inquiry, students can explore the

causes and consequences of these issues, evaluate potential solutions, and reflect on their own roles as environmental stewards (Mohd-Yusof et al., 2026).

Importantly, PBL promotes systems thinking, a critical competency in ecology. By examining the interrelationships among system components, students develop a more holistic understanding of environmental problems and their potential solutions (Honra, 2025b). This shift from linear to systems-oriented thinking is essential for addressing the multifaceted challenges of sustainability.

Furthermore, PBL has been shown to enhance student engagement and motivation, as it provides opportunities for active learning and meaningful participation (Manning & LaDue, 2025). Rather than passively receiving information, students take on the role of problem solvers, constructing knowledge through inquiry and collaboration. This active engagement can lead to deeper learning and greater retention of concepts.

However, while PBL offers significant advantages, its effectiveness depends on the availability of appropriate instructional supports. In particular, students may require scaffolding to navigate complex problems and visualize ecological processes. This need has prompted interest in the use of technological tools, including AI-assisted visualizations, to enhance PBL environments.

AI-Assisted Visual Learning

The integration of artificial intelligence (AI) into education has opened new possibilities for enhancing teaching and learning, particularly in domains that require visualization and simulation. In ecology education, AI-assisted visual learning tools can address many of the challenges associated with abstract and dynamic content. By generating interactive and context-specific visuals, AI can help students construct more accurate mental models of ecological systems (Mohamed, 2026).

One key application of generative AI is scenario building. For example, students can explore hypothetical situations such as the removal of mangrove ecosystems and observe the resulting impacts on coastal stability, biodiversity, and local communities. Such “what-if” scenarios enable learners to experiment with variables and observe outcomes, thereby deepening their understanding of cause-and-effect relationships (Li & Bahari, 2026).

In addition, AI can facilitate the creation of infographics and conceptual diagrams that simplify complex information. These visual representations can highlight key relationships and processes, making it easier for students to grasp abstract concepts such as nutrient cycling or trophic interactions (Chien et al, 2025). By reducing cognitive load, well-designed visuals can enhance comprehension and support learning.

Moreover, AI-assisted tools can be integrated into PBL environments to provide just-in-time support. For instance, visualizations can serve as entry points for problem exploration or as scaffolds during inquiry. This integration aligns with constructivist principles, which emphasize the importance of active engagement and contextualized learning (Schmälzle & Lim, 2016).

Nevertheless, while the potential of AI-assisted visual learning is widely recognized, empirical research on its effectiveness in ecology education remains limited. In particular, there is a need to examine how such tools influence not only cognitive outcomes but also affective and behavioral dimensions of learning, such as environmental awareness.

Environmental Awareness Framework

Environmental awareness is a multifaceted construct that encompasses cognitive, affective, and behavioral components. The cognitive dimension to knowledge and understanding of environmental issues, including ecological concepts and the causes

and consequences of environmental problems (Hadjichambis et al., 2024). This dimension is often the primary focus of formal education, as it involves the acquisition of factual and conceptual knowledge.

However, knowledge alone is insufficient to drive meaningful action. The affective dimension, which includes attitudes, values, and emotional responses toward the environment, plays a crucial role in shaping individuals' willingness to engage in pro-environmental behaviors (Lin et al., 2022; Kang & Hong, 2021). Positive attitudes and a sense of environmental responsibility can motivate individuals to act in ways that support sustainability.

Complementing these dimensions is behavioral intention, which reflects an individual's readiness to perform specific actions, such as reducing waste or conserving resources. According to the Theory of Planned Behavior, behavioral intention is influenced by attitudes, subjective norms, and perceived behavioral control (Miller, 2017; Warner & Diaz, 2021). In the context of environmental education, fostering strong behavioral intentions is a key objective, as it represents a precursor to actual behavior.

Importantly, effective educational interventions should address all three dimensions of environmental awareness. By integrating cognitive, affective, and behavioral components, educators can create learning experiences that not only inform but also inspire action. This holistic approach is particularly relevant in sustainability education, where the ultimate goal is to promote responsible and informed citizenship.

Conceptual Framework

Building on the preceding discussion, this study proposes a conceptual framework that examines the relationship between AI-assisted visual hooks and environmental awareness in an ecology-focused PBL context. Specifically, AI-generated visual hooks

are conceptualized as an instructional intervention designed to enhance students' engagement and understanding of ecological concepts.

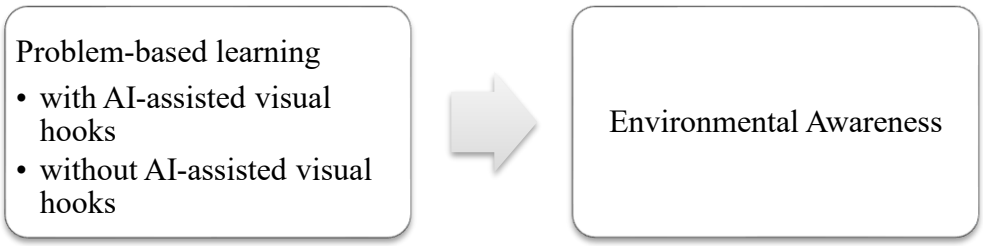
Within this framework, students are divided into experimental and control groups, with the former exposed to AI-assisted visual hooks and the latter receiving traditional instruction. The use of visual hooks is expected to capture students' attention, facilitate comprehension, and support the development of accurate mental models. In turn, these cognitive gains are hypothesized to influence affective and behavioral dimensions of environmental awareness.

Thus, the framework posits a causal pathway from AI-assisted visual hooks to environmental awareness, mediated by attention and comprehension. By examining this relationship, the study aims to provide empirical evidence on the effectiveness of AI-assisted visual learning in enhancing ecology education outcomes.

In summary, the literature highlights the complexity of ecology education, the challenges faced by learners, and the potential of innovative pedagogical approaches to address these challenges. While PBL and AI-assisted visual learning offer promising avenues, there remains a need for research that integrates these approaches and examines their impact on environmental awareness. This study seeks to fill this gap, contributing to both theory and practice in science and sustainability education (Figure 1).

Figure 1

Conceptual Framework of the Study



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Methods

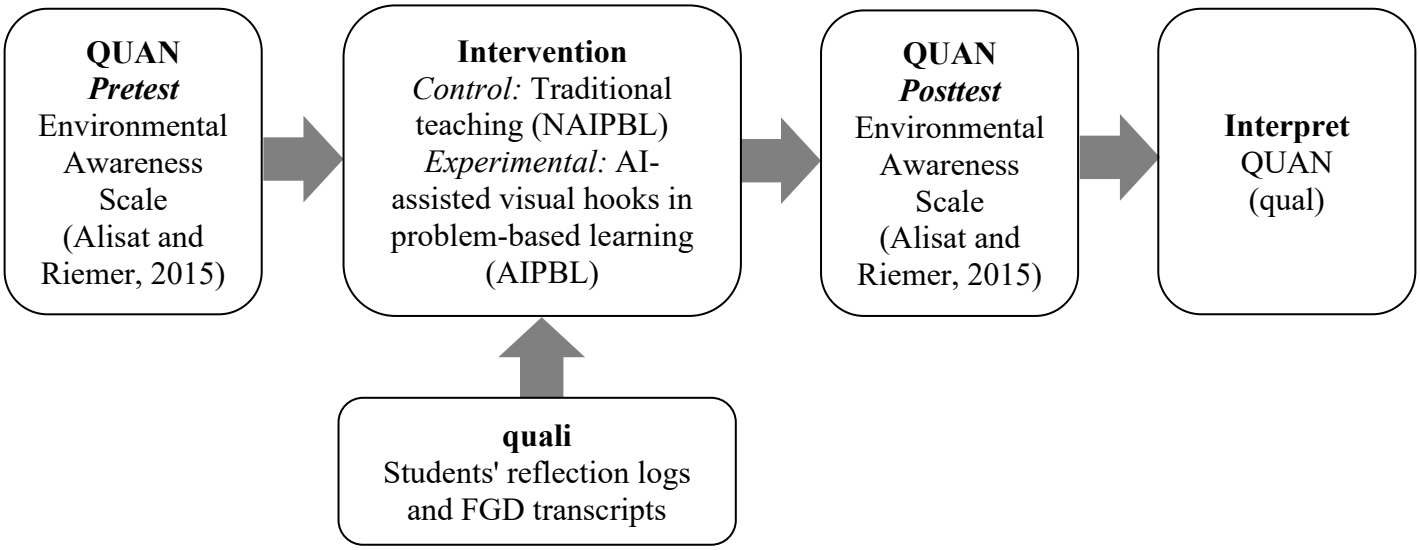
Research Design

This study employed a quasi-experimental, non-equivalent control group design within an embedded mixed-methods framework to investigate the effects of AI-assisted visual hooks on senior high school students' environmental awareness in an ecology-focused Problem-Based Learning (PBL) setting. Two intact groups were used: a control group (NAIPBL) receiving traditional instruction (teacher-led discussions, textbook-based learning, and static visuals) and an experimental group (AIPBL) exposed to AI-assisted visual hooks integrated into PBL activities. This design allows comparison under authentic classroom conditions while accounting for pre-existing differences between groups (Fetters et al., 2013).

Quantitatively, both groups completed pre-test and post-test assessments, with ANCOVA applied to control for baseline differences and determine the effect of the intervention on environmental awareness. Qualitatively, reflection journals and focus group discussions from the experimental group were used to capture students' experiences, engagement, and perceptions of the intervention. These qualitative data were embedded within the quantitative framework and used primarily at the interpretation stage to explain and enrich statistical findings, particularly in clarifying how AI-assisted visual hooks influenced learning processes and student understanding (Figure 2).

Figure 2

Visual representation of research design following embedded mixed methods



Participants

The participants of this study were senior high school students enrolled in Grade 12 under the Science, Technology, Engineering, and Mathematics (STEM) strand or the General Academic Strand (GAS) in a selected secondary school in the Philippines. The selection of these cohorts is grounded on curricular alignment and scientific relevance, as both strands engage in ecology-related and inquiry-based science learning under the K–12 curriculum (Pinuela, 2025). STEM students generally demonstrate stronger preparation in scientific reasoning, while GAS students represent a more heterogeneous academic profile. Including both strands strengthens the ecological validity and representativeness of the study. A total sample size of 80 students was determined based on statistical power requirements for quasi-experimental research, ensuring sufficient sensitivity to detect intervention effects using inferential analyses such as ANCOVA

(Cohen, 1977). Participants were assigned to groups through intact class sections using a non-randomized cluster sampling approach, preserving natural classroom structures while maintaining methodological feasibility. Baseline equivalence between groups was strengthened through matching of key variables such as age, gender distribution, and prior academic performance, with pre-test scores used to confirm initial comparability.

This study employed a quasi-experimental embedded mixed-methods design, where the quantitative strand served as the primary component for determining the effect of the intervention on environmental awareness, while the qualitative strand was embedded within the experimental group to provide explanatory depth. Quantitative data were obtained through pre-test and post-test assessments administered to both groups, while qualitative data were gathered from reflection journals and focus group discussions in the experimental group to capture students' learning experiences with AI-assisted visual hooks in Problem-Based Learning (PBL). Integration of both strands occurred during interpretation, where qualitative findings helped explain the mechanisms behind observed quantitative differences in environmental awareness (Table 1).

Table 1

Distribution of Participants and Data Sources by Group

Group	Strand	Instructional Condition	*n*	Quantitative data	Qualitative data
Control - NAIPBL	STEM	Traditional ecology instruction (teacher-led discussion, textbook-based	40	Pre-test and post-test (environmental awareness)	None

		learning, static visuals)			
Experimental -AIPBL	STEM	AI-assisted visual hooks integrated into Problem-Based Learning (PBL)	40	Pre-test and post-test (environmental awareness)	Reflection journals; focus group discussions

Note. n = number of participants per group

Teaching Intervention

The intervention was structured around three core ecology modules: (1) food webs and energy flow, (2) carbon cycle and climate change, and (3) biodiversity loss and conservation. These topics were selected based on their alignment with the senior high school ecology curriculum and their strong relevance to real-world environmental issues. The control group was taught using traditional instruction (lecture-discussion, textbook-based explanations, and static visuals), while the experimental group received the same content but enhanced with AI-assisted visual hooks integrated within Problem-Based Learning (PBL) sequences. Each weekly lesson followed a consistent structure to ensure comparability across groups while isolating the effect of the intervention.

Table 2 presents the 8-week instructional sequence, showing how content delivery and learning experiences differed between the control and experimental groups. In the control condition, learning primarily relied on teacher explanation and guided discussion. In contrast, the experimental condition embedded AI-generated visual hooks at strategic points (lesson entry or problem trigger stage), followed by PBL activities involving inquiry, group investigation, and solution formulation. This structured difference highlights how the intervention operationalized visual and inquiry-based enhancements without altering the core curriculum content. Additionally, this structure

ensures content equivalence across groups while introducing a clear instructional differentiation through AI-assisted visual hooks and PBL integration. The design allows the study to isolate the pedagogical effect of the intervention while maintaining curriculum fidelity and instructional consistency.

Table 2

Eight-Week Instructional Sequence for Control and Experimental Groups

Week	Ecology Topic	Instructional Activities	
		Control Group (Traditional Teaching)	Experimental Group (AI-Assisted Visual Hooks + PBL)
1	Orientation & Baseline Concepts	Introduction to ecology; lecture-discussion; baseline pre-test	Same orientation + pre-test; introduction to AI visual hook approach
2	Food Webs & Energy Flow I	Discussion of trophic levels using textbook diagrams	AI visual hook: collapsing food web simulation → PBL group problem analysis
3	Food Webs & Energy Flow II	Teacher-led explanation of energy transfer and ecological pyramids	AI visual hook: interactive ecosystem imbalance scenario → group modeling task
4	Carbon Cycle	Lecture on carbon reservoirs and processes	AI visual hook: animated carbon cycle disruption (climate change scenario) → inquiry task

5	Climate Change Impacts	Discussion of greenhouse effect and global warming	AI visual hook: AI-generated climate impact projections → solution brainstorming
6	Biodiversity Concepts	Reading and discussion on biodiversity importance	AI visual hook: species loss simulation → case-based group analysis
7	Biodiversity Conservation	Teacher explanation of conservation strategies	AI visual hook: before-and-after ecosystem restoration visuals → PBL solution design
8	Integration & Post-Test	Review and post-test administration	PBL synthesis activity + reflection journals + post-test

Note. The control group followed a traditional lecture-based ecology approach, while the experimental group integrated AI-assisted visual hooks within a Problem-Based Learning (PBL) cycle across all instructional weeks.

Data Collection and Analysis Procedures

This study employed a convergent embedded mixed-methods approach, where quantitative data served as the primary basis for determining the effectiveness of AI-assisted visual hooks, while qualitative data were embedded to explain and enrich the quantitative findings. Data were collected using standardized pre-test and post-test measures for both groups, while qualitative data were gathered exclusively from the experimental group through reflection journals and focus group discussions. These data sources were aligned with each research question to ensure systematic and coherent analysis of outcomes.

Quantitative data were collected using the Environmental Action Scale (Alisat & Riemer, 2015), which measures environmental awareness across cognitive, affective,

and behavioral domains. The instrument demonstrated acceptable internal consistency (Cronbach's $\alpha \geq 0.70$). Responses were aggregated to generate composite scores, which were treated as interval data to allow the use of parametric statistical techniques. Moreover, descriptive statistics, including mean and standard deviation, were computed for pre-test and post-test scores. To examine the effect of the intervention for Research Questions 1 and 2, Analysis of Covariance (ANCOVA) was performed, with post-test scores as the dependent variable, instructional group as the independent variable, and pre-test scores as the covariate. All relevant assumptions, including normality, homogeneity of variance, linearity, and homogeneity of regression slopes, were tested and met. Effect size was reported using partial eta squared (η^2).. For qualitative analysis (Research Question 3), thematic analysis (Braun & Clarke, 2006) was applied to reflection journals and focus group transcripts to identify patterns in students' perceptions of AI-generated visuals within PBL contexts. These qualitative themes were then used to explain and contextualize quantitative outcomes (Table 3).

Table 3

Data Collection Instruments and Analysis per Research Question

Research Question	Data Source / Instrument	Type of Data	Statistical / Analytical Technique
RQ1: Do AI-assisted visual hooks improve environmental awareness in ecology topics?	Environmental Action Scale (pre-test and post-test)	Quantitative	Descriptive comparison of gain scores

RQ2: Which ecology concepts benefit most from the use of AI-assisted visual hooks?	Post-test scores per ecology module (food webs, carbon cycle, biodiversity)	Quantitative	ANCOVA (pre-test as covariate), Effect size (Cohen's d)
RQ3: How do students perceive AI-generated visuals in Problem-Based Learning contexts?	Reflection journals; Focus group discussions	Qualitative	Thematic analysis (Braun & Clarke, 2006)

Note. Quantitative data were used as the primary analytical strand, while qualitative findings were embedded to explain and deepen interpretation of results within the mixed-methods framework.

Ethical Considerations

Ethical considerations were observed throughout the study to ensure participant protection and research integrity. The principles of beneficence and non-maleficence were upheld by designing the intervention to provide educational value while ensuring that no physical, psychological, or academic harm occurred. Both control and experimental groups received instruction aligned with curriculum standards, ensuring that no group was disadvantaged. Participants were informed about the study's purpose and procedures, and their voluntary participation was emphasized.

The principle of justice was maintained through fair selection procedures and equal access to learning resources. After the study, instructional materials used in the experimental group were shared with the control group to ensure equitable learning opportunities. Confidentiality and anonymity were also ensured by assigning participant codes and securely storing all data in accordance with established ethical guidelines for educational research (American Educational Research Association, 2011). Overall,

these measures support the study's methodological rigor and ethical integrity in examining the effects of AI-assisted visual hooks on environmental awareness.

Results

This study employed an embedded mixed-methods design, where the quantitative quasi-experimental component served as the primary strand, while qualitative data were embedded to explain and enrich the statistical outcomes. Accordingly, results are presented in three integrated sections aligned with the research questions: (1) the effect of AI-assisted visual hooks on environmental awareness, (2) the differential effects across ecology concepts, and (3) students' perceptions supported by qualitative evidence and triangulation.

RQ1: Do AI-assisted visual hooks in problem-based learning significantly improve environmental awareness in ecology topics?

To examine whether AI-assisted visual hooks in problem-based learning improve environmental awareness in ecology, pre-test and post-test scores were analyzed for both groups (n = 40 per group). Prior to inferential testing, normality was assessed to ensure the suitability of parametric analyses (Table 4).

Table 4

Test of Normality for Gain Scores

Group	*W*	*df*	*p*-value	Interpretation
Control	0.971	40	0.384	Normally distributed
Experimental	0.969	40	0.327	Normally distributed

Note. Shapiro-Wilk test results indicate that gain scores for both groups are normally distributed ($p > 0.05$).

Both groups satisfied the assumption of normality ($p > .05$), indicating that gain scores were appropriately analyzed using parametric statistical procedures.

To further assess the assumption of homogeneity of variance, Levene's test was conducted (Table 5).

Table 5

Levene's Test of Homogeneity of Variance for Gain Scores

F	*df1*	*df2*	*p*-value	Interpretation
1.27	1	78	0.263	Homogeneity assumed

Note. Levene's test indicates that the variances of gain scores between groups are equal ($p > 0.05$).

The non-significant result of Levene's test ($p > .05$) confirms that the assumption of homogeneity of variance was met.

Following assumption testing, descriptive statistics were examined (Table 6). The experimental group exposed to AI-assisted visual hooks obtained higher mean gain scores in environmental awareness than the control group, indicating greater improvement following the intervention. To determine whether this observed difference is statistically significant, the data were further analyzed using ANCOVA.

Table 6

Descriptive Statistics of Environmental Awareness Gain Scores

Group	*N*	Mean Gain	*SD*
Control	40	3.51	3.08
Experimental	40	4.89	3.75

Note. Gain scores represent the difference between post-test and pre-test environmental awareness scores.

The results indicate that the experimental group obtained a higher mean gain score than the control group. This observed difference suggests a possible effect of integrating AI-assisted visual hooks into Problem-Based Learning activities. To further examine whether this difference is statistically meaningful, an Analysis of Covariance (ANCOVA) was conducted while controlling for relevant covariates.

Furthermore, to examine the overall effect of AI-assisted visual hooks on post-test environmental awareness while controlling for prior knowledge, an Analysis of Covariance (ANCOVA) was conducted using pre-test scores as the covariate (Table 7).

Table 7

ANCOVA Results for Post-Test Environmental Awareness Scale Scores

Source	*SS*	*df*	*MS*	*F*	*p*-value	Partial η^2
Pretest (covariate)	412.36	1	412.36	9.84	0.002	0.11
Group (Control vs Experimental)	1824.51	1	1824.51	43.56	<0.001	0.36
Error	3250.77	77	42.22	-	-	-

Total	5487.64	79	-	-	-	-

Note. $N = 80$ (Control = 40, Experimental = 40). Dependent variable: post-test environmental awareness score. Covariate: pre-test score.

The ANCOVA results reveal a statistically significant main effect of instructional group on post-test environmental awareness after controlling for pre-test scores, $\underline{F}(1, 77) = 43.56$, $p < .001$, $\eta^2 = 0.36$. This indicates a large effect size, suggesting that approximately 36% of the variance in post-test scores is attributable to the use of AI-assisted visual hooks. Thus, the covariate (pre-test scores) was also significant, confirming that prior knowledge contributed to learning outcomes, but the treatment effect remained strong even after adjustment.

These results provide robust evidence that AI-assisted visual hooks significantly enhance environmental awareness beyond the influence of prior knowledge. The large effect size suggests that visual augmentation plays a substantial role in improving conceptual understanding in ecology. The findings support constructivist learning theory, where learners actively build knowledge structures, particularly when supported by visual representations of complex systems.

RQ3: How do students perceive AI-generated visuals in Problem-Based Learning contexts?

Qualitative data from reflection journals and focus group discussions were analyzed using thematic analysis. These findings were embedded to explain the quantitative outcomes.

Theme 1: Improved Conceptual Clarity

Students reported that AI-generated visuals made ecological concepts easier to understand.

> *"I finally understood how ecosystems work because I can see the process clearly in the AI images."* (S5, FGD)

> *"Before, I only memorized terms, but now I understand how everything is connected."* (S17, Reflection)

This suggests that AI visual hooks function as cognitive scaffolds that transform abstract ecological concepts into concrete mental models.

Theme 2: Increased Engagement in Learning

Students expressed higher engagement and interest during PBL sessions.

> *"The lesson became more interesting because the visuals looked realistic and easy to follow."* (S10, FGD)

> *"I was more active in class discussions because I could visualize the problem."* (S2, Reflection)

This indicates that AI-generated visuals enhance affective engagement, which is critical in sustaining inquiry-based learning.

Theme 3: Enhanced Problem-Solving Confidence

Students reported improved confidence in analyzing ecological problems.

> *"The images helped me understand the problem faster, so I could answer better."* (S14, FGD)

> *"It was easier to connect ideas when solving environmental issues."* (S21, Reflection)

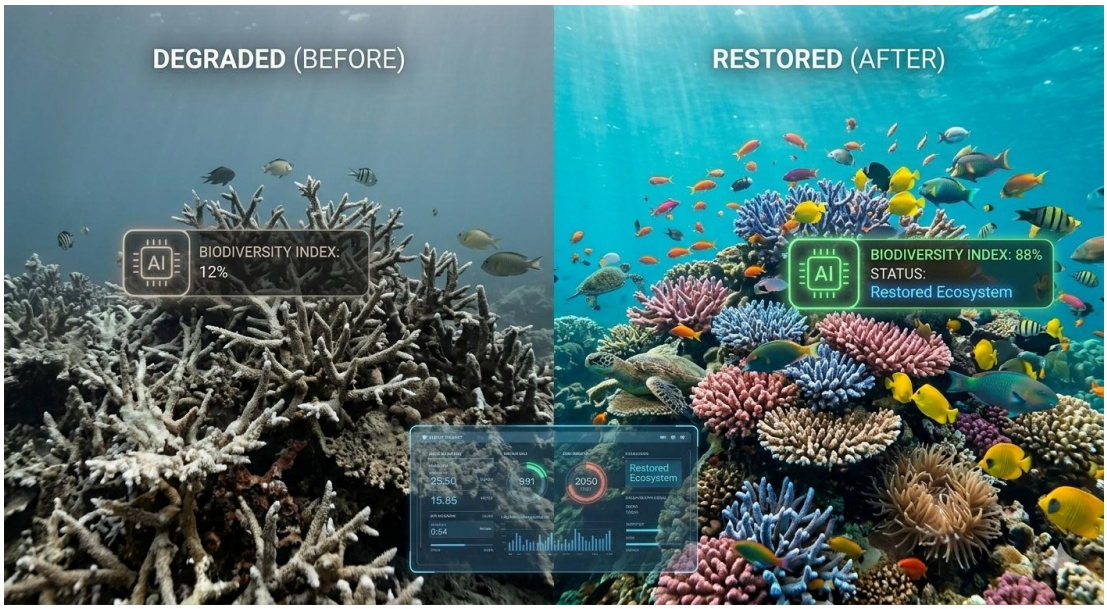
This suggests that visual scaffolding supports higher-order thinking by reducing cognitive overload and improving information organization.

Embedded Instructional Visual Hooks

The sample visual hook (Figure 3) focused on biodiversity loss and conservation using a before-and-after comparison of a coral reef ecosystem. The image presented two contrasting conditions of the same location: a degraded reef with bleached corals and minimal marine life, and a restored reef with diverse species and complex coral structures. This clear visual contrast helped students recognize key indicators of biodiversity such as color variation, species richness, and habitat complexity, supporting their understanding of ecosystem health and recovery.

Figure 3

AI-Generated Visual Hook on Biodiversity Loss and Conservation



Note. This visual hook uses localized, photorealistic projections comparing a Metro Manila waterfront under current conditions and projected 2050 climate impacts to illustrate the effects of sea-level rise and extreme heat on a familiar Philippine setting.

An additional strength of the embedded instructional visual hooks lies in their capacity to situate abstract ecological concepts within concrete and contextually relevant representations. By presenting localized and photorealistic projections, the visual hook enables learners to connect theoretical knowledge on biodiversity loss and conservation to real-world environmental conditions. The juxtaposition of degraded and restored reef systems facilitates comparative analysis, allowing students to identify observable changes and infer underlying ecological processes. This approach supports visual literacy and promotes deeper cognitive processing by engaging learners in interpretation rather than passive observation. Consequently, the use of AI-generated visual hooks within instructional materials may contribute to more meaningful learning experiences by reinforcing conceptual understanding through context-rich and visually salient stimuli.

Additionally, the analysis of reflection journals and focus group discussions showed that students were able to explain how higher biodiversity contributes to ecosystem resilience and stability. Many also proposed practical conservation actions, such as reducing pollution and protecting marine habitats. One student (S23, AIPBL) noted, *"I realized that when there are more species in the reef, it becomes stronger and can recover from damage faster."* For rigor and transparency, the visual was documented as a photorealistic diptych with AI-generated biodiversity indices, showing low biodiversity in the degraded panel and high biodiversity in the restored panel. This detailed description supports the triangulation of qualitative insights with the study's quantitative findings on environmental awareness. Table 8 presents the PBL scaffolding elements used when this visual hook was introduced to the students.

Table 8

Problem-based Learning (PBL) Scaffolding Elements

Scaffolding Element	Content
Hook Scenario	Students view an AI-generated, photorealistic projection of a recognizable Metro Manila waterfront. The visual is a diptych comparison: the left side is a healthy, current baseline (lush mangroves, functioning carbon sink); the right side is a projected 2050 high-emissions scenario (Image 10). The hook is the emotional weight of seeing their own coastline altered by climate change, with dead mangroves and recognizable Philippine buildings inundated by sea-level rise under a severe heat haze.
Process Questions	1. Identify three distinct environmental changes visualized on the '2050 Projection' side compared to the current Metro Manila 'Baseline' side. 2. The 'Baseline' side visualizes a glowing green indicator ('Baseline: Healthy Carbon Sink'). How do the native mangroves see in that panel function as a carbon sink? What visual evidence on the right shows this function has been destroyed? 3. Using your knowledge of the carbon cycle, propose three specific human interventions that could halt the progression from the 'Baseline' image to the 2050 'Impact' projection shown.

Triangulation of Findings

To synthesize and contextualize the findings of the study, the results from both the quantitative and qualitative strands were integrated using a triangulation approach. This integration allows for a more comprehensive interpretation of how AI-assisted visual hooks influence students' environmental awareness in ecology. Table 9 presents the convergence of evidence from gain scores, ANCOVA results, and student narratives, highlighting not only the statistical effectiveness of the intervention but also the underlying cognitive and affective processes that explain these outcomes.

Table 9

Integration of Quantitative and Qualitative Findings

Evidence Source	Key Finding	Interpretation
Gain Scores	Higher mean gain scores in the experimental group	Suggests greater improvement following the intervention
ANCOVA ($F = 43.56$, $\eta^2 = 0.36$)	Statistically significant group effect with large effect size	Indicates a substantial impact of the intervention on environmental awareness
Student Narratives	Improved clarity, engagement, confidence	Explains cognitive and affective mechanisms

The convergence of quantitative and qualitative findings provides strong methodological triangulation. Quantitative evidence confirms that AI-assisted visual hooks significantly improve environmental awareness, while qualitative data explain the

mechanisms behind this improvement—enhanced visualization, increased engagement, and improved cognitive processing.

Albeit, the findings of the study indicate that AI-assisted visual hooks significantly enhance students' environmental awareness in ecology, as evidenced by the superior performance of the experimental group compared to the control group. This is further supported by the overall ANCOVA results, which reveal a large and statistically significant effect of the intervention, $F(1,77) = 43.56$, $p < .001$, $\eta^2 = 0.36$, even after controlling for prior knowledge. Complementing these quantitative outcomes, students' qualitative responses suggest that AI-generated visuals are highly beneficial in improving conceptual clarity, sustaining engagement, and strengthening problem-solving confidence within Problem-Based Learning contexts, thereby reinforcing the instructional value of the intervention across cognitive and affective dimensions.

Discussion

The present study investigated whether AI-assisted visual hooks improve students' environmental awareness in ecology within a Problem-Based Learning (PBL) context, which ecology concepts benefit most from this intervention, and how students perceive AI-generated visuals in supporting their learning. Overall, the findings provide clear and converging evidence that AI-assisted visual hooks significantly enhance environmental awareness, as demonstrated by the higher post-test performance of the experimental group compared to the control group. This is strongly supported by the ANCOVA results, which revealed a large and statistically significant effect of the intervention ($F(1,77) = 43.56$, $p < .001$, $\eta^2 = 0.36$), even after controlling for prior knowledge. In addition, qualitative findings consistently showed that students perceived AI-generated visuals as highly beneficial in improving conceptual clarity, engagement, and problem-

solving confidence, indicating that the intervention was effective across both cognitive and affective domains of learning.

Interpreting these results more deeply, the findings suggest that AI-assisted visual hooks function as cognitive scaffolds that reduce the complexity of abstract ecological systems and make them more accessible to learners. Ecology involves highly interconnected processes such as energy transfer, population dynamics, and climate feedback loops, which are often difficult for students to visualize using traditional text-based instruction alone. The significant gains in the experimental group indicate that AI-generated visuals helped students construct more coherent mental models of these systems, thereby improving conceptual understanding and environmental awareness. Importantly, the large effect size from the ANCOVA analysis suggests that the observed improvements were not merely due to prior knowledge differences but were directly influenced by the instructional intervention. An interesting observation is that the strongest gains were reported in system-heavy topics such as climate change and food web interactions, suggesting that AI visuals are particularly effective when dealing with dynamic, multi-layered ecological processes.

These findings are consistent with Cognitive Theory of Multimedia Learning, which argues that learners understand information more effectively when verbal explanations are combined with meaningful visual representations. As posited by Mayer (2009), dual-channel processing enhances cognitive integration and reduces extraneous cognitive load, especially in complex scientific domains. The results of this study strongly align with this framework, as students exposed to AI-generated visuals demonstrated significantly higher learning gains compared to those who received traditional instruction. Similarly, prior research in science education has established that visual representations improve conceptual understanding in ecology and environmental

science (Honra & Villamin, 2026;). However, this study extends these findings by demonstrating that AI-generated visuals—rather than static diagrams—can further amplify learning outcomes by providing more context-specific, dynamic, and scenario-based representations of ecological systems. In this sense, the study contributes to emerging literature on AI in education, which suggests that generative AI tools can enhance instructional design and learner engagement (), but it also advances this field by embedding AI visualization within a structured PBL framework.

At the same time, the findings partially diverge from earlier studies that reported only moderate effects of visual aids in science instruction. This difference may be attributed to the adaptive and context-rich nature of AI-generated visuals used in this study, which go beyond traditional static diagrams by simulating real-world ecological scenarios. In particular, the integration of AI visuals within problem-based tasks may have enhanced their instructional impact by situating learning within authentic environmental problems. This aligns with constructivist learning theory, which emphasizes that knowledge is best developed through active engagement with meaningful contexts. Therefore, the present study not only confirms prior findings but also extends them by showing that AI-enhanced visualization can significantly strengthen inquiry-based science learning when properly embedded within pedagogical structures such as PBL.

Despite these promising outcomes, several limitations must be acknowledged. First, the quasi-experimental design without random assignment limits the ability to draw strong causal inferences, even though ANCOVA was used to control for initial differences. Second, the sample size of 80 students, while adequate for statistical analysis, remains relatively small and drawn from a single educational setting, which may limit the generalizability of the findings to other contexts. Third, the study focused

primarily on short-term learning outcomes, meaning that it cannot confirm whether improvements in environmental awareness are retained over time. The absence of delayed post-testing is therefore a methodological limitation. Additionally, the novelty effect associated with AI-generated visuals may have influenced student engagement and perceptions, potentially inflating positive responses during the intervention period. Finally, while qualitative data provided rich insights, they were based on self-reported experiences, which may be subject to social desirability bias.

In terms of implications, the findings have important theoretical, practical, and policy-related significance. Theoretically, the study reinforces and extends multimedia learning theory by demonstrating that AI-generated visual scaffolds can significantly enhance conceptual understanding in complex scientific domains. It also supports constructivist perspectives, highlighting the importance of contextualized, inquiry-based learning environments in fostering deep understanding. Practically, the results suggest that educators should consider integrating AI-assisted visual hooks into ecology instruction, particularly when teaching abstract or system-based topics. These tools can help teachers present complex environmental processes in more engaging and comprehensible ways, thereby improving both student motivation and understanding. Moreover, within PBL environments, AI-generated visuals can serve as powerful triggers for inquiry, discussion, and problem-solving.

From a policy perspective, the findings support the integration of AI tools into science education curricula, particularly in STEM strands at the secondary level. However, successful implementation will require investment in teacher professional development to ensure that educators are equipped not only with technical skills but also with pedagogical knowledge for effectively using AI-generated instructional materials. Schools and education systems should also consider developing guidelines

for ethical and effective use of AI in classroom instruction to ensure consistency and quality.

Finally, future research should expand on this study by exploring longitudinal effects of AI-assisted visual learning to determine whether improvements in environmental awareness are sustained over time. Larger-scale studies involving multiple schools and diverse populations would also enhance the generalizability of findings. Additionally, future investigations could examine how individual differences such as spatial ability, prior academic achievement, or digital literacy influence the effectiveness of AI-generated visuals. There is also a need for design-based research focusing on optimizing the characteristics of AI-generated visual hooks, including their level of abstraction, interactivity, and alignment with specific ecological concepts. By addressing these areas, future studies can further refine the integration of AI technologies in science education and maximize their pedagogical impact.

Conclusions and Recommendations

This study provides strong empirical evidence that AI-assisted visual hooks significantly enhance students' environmental awareness in ecology within a Problem-Based Learning context. The quantitative results demonstrated a substantial improvement in the experimental group compared to the control group, supported by a large and statistically significant ANCOVA effect ($F(1,77) = 43.56$, $p < .001$, $\eta^2 = 0.36$), even after controlling for prior knowledge. These findings indicate that the intervention meaningfully improved students' conceptual understanding of ecological systems, particularly in complex topics such as climate change, food web interactions, and ecosystem dynamics. The qualitative results further reinforced these outcomes, revealing that students experienced improved conceptual clarity, higher engagement, and greater confidence in problem-solving. Taken together, the convergence of

quantitative and qualitative evidence confirms that AI-generated visual scaffolds are not merely supplementary tools but powerful instructional mechanisms that enhance both cognitive and affective dimensions of learning in ecology education.

Based on these findings, it is recommended that educators integrate AI-assisted visual hooks into science instruction, particularly in ecology topics that involve abstract, dynamic, and system-based concepts. Teachers should be trained in designing and implementing AI-generated visuals within structured pedagogical frameworks such as Problem-Based Learning to maximize their instructional effectiveness. At the institutional level, schools should support the adoption of AI tools by providing adequate technological infrastructure and professional development programs focused on AI literacy and instructional design. For future research, it is recommended that longitudinal studies be conducted to examine the retention effects of AI-assisted visual learning, as well as multi-site studies to enhance generalizability across diverse educational contexts. Further investigations may also explore how learner differences, such as spatial ability and digital literacy, moderate the effectiveness of AI-generated visuals, and how design features of these visuals can be optimized for different ecological concepts.

Declaration

The authors declare no conflict of interest.

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AI Use Statement

This study acknowledges the use of artificial intelligence tools to generate the visual hooks used in the instructional intervention, which were subsequently reviewed and validated by the researcher to ensure their accuracy and alignment with the ecology learning objectives.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Declaration

This study was conducted in accordance with ethical standards involving human participants. Participation was voluntary, and informed consent was obtained from all participants prior to data collection.

Ethics Approval Declaration

Prior to the conduct of the study, a formal letter request for implementation was submitted to and approved by the Schools Division Superintendent of the Department of Education Quezon City, Philippines.

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References

Alisat, S., & Riemer, M. (2015). The environmental action scale: Development and psychometric evaluation. Journal of Environmental Psychology, 43, 13–23. https://doi.org/10.1016/j.jenvp.2015.05.006

Asikin, N., Suwono, H., Sumitro, S. B., & Dharmawan, A. (2026). Teaching ocean literacy in science education: a systematic review. Environmental Education Research, 32(3), 812–837. https://doi.org/10.1080/13504622.2025.2490227

Bai, S., Yeung, S. S., & Lo, C. K. (2026). Enhancing the effect of AI-assisted learning: the use of scaffolding strategies to develop students' prompt engineering skills. Interactive Learning Environments, 1–22. https://doi.org/10.1080/10494820.2026.2649547

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cao, L., & Zhang, J. (2025). Exploring the use of productive failure to learn ecology in a virtual world: influence of self-efficacy and the use of learning strategies. Interactive Learning Environments, 33(3), 2117–2135. https://doi.org/10.1080/10494820.2024.2391058

Casas, E. V., Pormon, M. M., Manus, J. J., & Lejano, R. P. (2021). Relationality and resilience: Environmental education in a time of pandemic and climate crisis. The Journal of Environmental Education, 52(5), 314–324. https://doi.org/10.1080/00958964.2021.1981205

Cederlöf, G., Burman, A., & Hornborg, A. (2025). Swedish human ecology, political ecology, and the struggle for interdisciplinarity: bridging the socio-natural divide in research and education. Geografiska Annaler: Series B, Human Geography, 1–14. https://doi.org/10.1080/04353684.2025.2467268

Chien, C. C., Chan, H. Y., & Hou, H. T. (2025). Learning by playing with generative AI: design and evaluation of a role-playing educational game with generative AI as scaffolding for instant feedback interaction. Journal of Research on Technology in Education, 57(4), 894–913. https://doi.org/10.1080/15391523.2024.2338085

Cohen, J. (1977). Statistical power analysis for the behavioral sciences. San Diego, CA: Academic Press. https://psycnet.apa.org/record/1987-98267-000

Cury, R., Kennelly, M., & Howes, M. (2023). Environmental sustainability in sport: a systematic literature review. European Sport Management Quarterly, 23(1), 13–37. https://doi.org/10.1080/16184742.2022.2126511

Ding, J., & Song, Y. (2026). Descriptive writing using generative AI as a cognitive scaffold in the metaverse environment: university students' perceptions, learning engagement, and performance. Educational Psychology, 46(1), 183–207. https://doi.org/10.1080/01443410.2025.2568189

Erol, M., Erol, A., & Tabaru Örnek, G. (2026). The impact of place-based STEM education on primary school students' environmental awareness. Innovation: The European Journal of Social Science Research, 1–24. https://doi.org/10.1080/13511610.2026.2651715

Esteban, M., Valenzuela, V. P., Matsumaru, R., Mikami, T., Shibayama, T., Takagi, H., … Leon, M. D. (2016). Storm Surge Awareness in the Philippines Prior to Typhoon Haiyan: A Comparative Analysis with Tsunami Awareness in Recent Times. Coastal Engineering Journal, 58(1), 1640009-1-1640009–28. https://doi.org/10.1142/S057856341640009X

Fetters, M.D., Curry, L.A. and Creswell, J.W. (2013), Achieving Integration in Mixed Methods Designs—Principles and Practices. Health Serv Res, 48: 2134-2156. https://doi.org/10.1111/1475-6773.12117

Gupta, R., Fraser, J., Rank, S. J., Brucker, J. L., & Flinner, K. (2019). Multi-Site Case Studies About Zoo and Aquarium Visitors' Perceptions of the STEM Learning Ecology. Visitor Studies, 22(2), 127–146. https://doi.org/10.1080/10645578.2019.1661737

Hadjichambis, A., Paraskeva-Hadjichambi, D., Georgiou, Y., & Adamou, A. (2024). How can we transform citizens into 'environmental agents of change'? Towards the citizen science for environmental citizenship (CS4EC) theoretical framework based on a meta-synthesis approach. International Journal of Science Education, Part B, 14(1), 72–92. https://doi.org/10.1080/21548455.2023.2199129

Han, F., Yan, T., & Deng, M. (2026). Effectiveness of AI-generated visual scaffolds for reading comprehension in Chinese inclusive classrooms. International Journal of Inclusive Education, 1–21. https://doi.org/10.1080/13603116.2026.2630218

Heystek, S., Richter, B., Muller, I., & Golightly, A. (2025). The implementation of problem-based learning in education for sustainable development: preservice teachers' voices. International Research in Geographical and Environmental Education, 1–17. https://doi.org/10.1080/10382046.2025.2485913

Honra, J. R. (2025a). Understanding the influence of biomimetic projects on transdisciplinary thinking in biology education. Innovations in Education and Teaching International, 1–15. https://doi.org/10.1080/14703297.2025.2512386

Honra, J. R. (2025b). Enhancing High School Biology Education Students' Transdisciplinary Thinking Through Design Thinking. The Journal of Experimental Education, 1–17. https://doi.org/10.1080/00220973.2025.2606241

Honra, J. R., & Villamin, J. L. A. (2026). Convergent effects of design thinking and flipped classroom learning on the agentic engagement of college students. Innovations in Education and Teaching International, 1–16. https://doi.org/10.1080/14703297.2026.2648045

Kang, J., & Hong, J. H. (2021). Framing effect of environmental cost information on environmental awareness among high school students. Environmental Education Research, 27(6), 936–953. https://doi.org/10.1080/13504622.2021.1928607

Kang, J., & Hong, J. H. (2021). Framing effect of environmental cost information on environmental awareness among high school students. Environmental Education Research, 27(6), 936–953. https://doi.org/10.1080/13504622.2021.1928607

King-Chan, M. S. E., Capistrano, R. C. G., & Lopez, E. L. F. (2021). Tourists really do behave responsibly toward the environment in Camiguin Province, Philippines. Tourism Geographies, 23(3), 573–598. https://doi.org/10.1080/14616688.2020.1833970

Kranz, J., Baur, A., & Möller, A. (2023). Learners' challenges in understanding and performing experiments: a systematic review of the literature. Studies in Science Education, 59(2), 321–367. https://doi.org/10.1080/03057267.2022.2138151

Li, Q., & Bahari, A. (2026). AI-mediated scaffolding in academic writing: a longitudinal mixed-methods study on foundational skill development and dialogic engagement among EFL postgraduate students. Interactive Learning Environments, 1–29. https://doi.org/10.1080/10494820.2026.2635539

Lin, W. C., Nguyen, L. H. P., Tran, N. H., & Huang, C. F. (2022). Impact of an action-oriented environmental education course on students' environmental awareness. Applied Environmental Education & Communication, 21(4), 331–347. https://doi.org/10.1080/1533015X.2022.2099482

Lin, Y. R., Jiao, X., & Hung, C. Y. (2026). Enhancing scientific argumentation with visual scaffolding in generative AI-supported environments. International Journal of Science Education, 1–26. https://doi.org/10.1080/09500693.2026.2630293

Maharramli, B., Bredow, V. L., & Goodwin, L. (2021). Using civic ecology education to foster social-ecological resilience: A case study from Southern California. The Journal of Environmental Education, 52(6), 445–462. https://doi.org/10.1080/00958964.2021.1999886

Manning, C. L. B., & LaDue, N. D. (2025). Geo-STEM learning ecosystems: A transdisciplinary theory-based framework to establish and engage communities in the geosciences. Journal of Geoscience Education, 73(2), 172–186. https://doi.org/10.1080/10899995.2024.2351028

Masud, M. M., Kari, F. B., Banna, H., & Saifullah, Md. K. (2018). Does income inequality affect environmental sustainability? Evidence from the ASEAN-5. Journal of the Asia Pacific Economy, 23(2), 213–228. https://doi.org/10.1080/13547860.2018.1442146

Meek, D. (2019). The Geography of Education and the Education of Geography: Agricultural Extension and the Political Ecology of Education. The Professional Geographer, 71(1), 65–74. https://doi.org/10.1080/00330124.2018.1455522

Miller, Z. D. (2017). The Enduring Use of the Theory of Planned Behavior. Human Dimensions of Wildlife, 22(6), 583–590. https://doi.org/10.1080/10871209.2017.1347967

Mitchell, D., Laurie, E. W., Williams, R. D., Fryirs, K. A., Brierley, G. J., & Tolentino, P. L. M. (2024). Developing an equitable agenda for international capacity strengthening courses: environmental pedagogies and knowledge co-production in the Philippines. Journal of Geography in Higher Education, 48(2), 281–311. https://doi.org/10.1080/03098265.2023.2235668

Mohamed, R. A. A. (2026). Designing traceable, prompt-scaffolded generative AI feedback to support EFL grammar accuracy and writing complexity: evidence from male Saudi undergraduates. Interactive Learning Environments, 1–26. https://doi.org/10.1080/10494820.2026.2649549

Mohd-Yusof, K., Sadikin, A. N., Phang, F. A., Rosli, A., Abdul-Aziz, A., & Malim-Busu, T. Z. (2026). Beyond awareness: instilling environmental sustainability

knowledge through cooperative problem-based learning. European Journal of Engineering Education, 1–25. https://doi.org/10.1080/03043797.2026.2642803

Muñoz-Losa, A., Sandoval-Aliseda, T., Crespo-Martín, J., & Corbacho-Cuello, I. (2025). Evolution of pupils' environmental awareness during the primary education stage. International Research in Geographical and Environmental Education, 1–22. https://doi.org/10.1080/10382046.2025.2606283

Neumann, M. M., Park, E., Barry, R. J., Soong, H., & Nichols, S. (2026). The opportunities and challenges of online learning in middle level education: Perspectives of students, parents, and school staff in the post-pandemic era. Middle School Journal, 57(1), 8–23. https://doi.org/10.1080/00940771.2025.2585773

Pinuela, M. F. G. (2025). Design and development of instructional materials to enrich K to 12 STEM Biology II curriculum guide: a case of the province of Iloilo, Philippines. Cogent Education, 12(1). https://doi.org/10.1080/2331186X.2025.2495530

Reimann, P. (2024). Methodological challenges of research on interdisciplinary learning. Journal of the Learning Sciences, 33(2), 443–449. https://doi.org/10.1080/10508406.2024.2354153

Ren, B., Dong, Y., & Zhang, B. (2025). From errors to excellence: AI-driven scaffolding for advancing L2 writing skills. Cogent Education, 12(1). https://doi.org/10.1080/2331186X.2025.2588512

Rushton, E., Dunlop, L., Atkinson, L., Stubbs, J., Diepen, M. T. van, & Wood, L. (2024). Researching education for environmental sustainability through intergenerational dialogue. International Research in Geographical and Environmental Education, 33(2), 157–172. https://doi.org/10.1080/10382046.2023.2270399

Sarkar, B., & Islam, A. (2025). Assessing environmental awareness activism to river decay and recurring pollution using parallel multiple mediator model. International Journal of River Basin Management, 23(3), 425–437. https://doi.org/10.1080/15715124.2024.2326127

Schmälzle, R., & Lim, S. (2026). From blank page to campaign plan: Using the campAIgnR AI tool to scaffold public communication campaign design. Communication Teacher, 40(2), 160–169. https://doi.org/10.1080/17404622.2025.2545366

Schneller, A. J., Lacy, G., Kellogg, S., Pettigrew, S. M., Denny, C., Feldman-Schwartz, G., … Bardin, I. (2022). Urban ecojustice education: Transformative learning outcomes with high school service learners. The Journal of Environmental Education, 53(3), 127–140. https://doi.org/10.1080/00958964.2022.2063784

Srisathan, W. A., Malai, K., Narathawaranan, N., Coochampoo, K., & Naruetharadhol, P. (2024). The impact of citizen science on environmental attitudes, environmental knowledge, environmental awareness to pro–environmental citizenship behaviour. International Journal of Sustainable Engineering, 17(1), 360–378. https://doi.org/10.1080/19397038.2024.2354269

Tusoy, C., Gueco, S. L., Pelias, S. L., & Toquero, C. M. (2025). Measuring the knowledge, awareness, attitudes, and behaviors of Filipino Teacher education students toward sustainability during the pandemic. Journal of Human Behavior in the Social Environment, 35(5), 789–810. https://doi.org/10.1080/10911359.2024.2343940

Uyanık, G. (2025). Communicating the environment through artificial intelligence: ChatGPT's potential for raising environmental awareness. The Journal of Educational Research, 1–11. https://doi.org/10.1080/00220671.2025.2571680

Warner, L. A., & Diaz, J. M. (2021). Amplifying the Theory of Planned behavior with connectedness to water to inform impactful water conservation program planning and evaluation. The Journal of Agricultural Education and Extension, 27(2), 229–253. https://doi.org/10.1080/1389224X.2020.1844771

Wolfram, M., van der Heijden, J., Juhola, S., & Patterson, J. (2019). Learning in urban climate governance: concepts, key issues and challenges. Journal of Environmental Policy & Planning, 21(1), 1–15. https://doi.org/10.1080/1523908X.2018.1558848

Yang, Y., Shen, W., & Derudder, B. (2025). Environmental sustainability in polycentric urban regions: an urban resilience perspective. Regional Studies, 59(1). https://doi.org/10.1080/00343404.2025.2496417