Embodied Ecological Learning in Natural and AI-generated Environments: A Phenomenological Study of Children's Environmental Awareness

Yiru Zang*
University of West London, London W5 5RF, United Kingdom
*Corresponding email: zangkiana@gmail.com

Abstract

In an era where digital technologies increasingly mediate children's daily experiences, the rise of artificial intelligence (AI)-generated ecological simulations raises critical questions about how young learners perceive, embody, and understand the natural world. While virtual environments offer accessible alternatives to outdoor learning, they may also restructure children's sensory engagement and ecological awareness in ways that remain insufficiently examined. Grounded in Merleau-Ponty's phenomenology of embodiment and Gibson's theory of affordances, this study investigates how primary-school children experience ecological learning differently in real natural environments compared to AI-simulated ecological spaces. Using a qualitative phenomenological design, the research involved participatory observation, children's motion-path tracking, semi-structured interviews, and video-elicitation sessions, conducted across two contrasting learning contexts: a tropical rainforest field site and an AI-generated ecological installation. The findings reveal that natural environments elicit expansive bodily engagement, multi-sensory activation, spontaneous exploration, and heightened affective attunement to living elements. These features are strongly associated with ecological consciousness and embodied learning, underscoring the unique role of real natural settings in fostering meaningful ecological understanding. In contrast, AI-generated environments, while visually immersive, tend to produce more task-driven, visually dominant, and sensorily limited behaviors, with reduced affordance variability and diminished perception of environmental vitality. The study argues that artificial intelligence (AI) simulations cannot replace nature's dynamic affordances and phenomenological depth but can serve as complementary tools when carefully designed to enhance uncertainty, interactivity, and bodily agency. These insights contribute to growing debates on AI in education by highlighting the irreplaceable role of embodied encounters with real ecosystems and offering a framework for integrating technology with environmental pedagogy.

Keywords

Embodied ecological learning, Artificial intelligence -generated environments, Phenomenology, Affordances, Primary education, Environmental awareness

Introduction

In recent decades, the accelerating ecological crisis has heightened global concern regarding how younger generations understand, perceive, and relate to the natural world [1]. Climate change, biodiversity loss, and the progressive disappearance of wilderness from everyday life have rendered environmental education not merely a pedagogical choice but an ethical imperative [2]. Yet contemporary children increasingly grow up in highly mediated environments where artificial, screen-based, and algorithmically curated experiences often replace direct engagement with nature [3,4]. This shift in children's experiential landscape challenges educators to reconsider how ecological knowledge is formed and what kinds of environments can most effectively nurture a sense of environmental responsibility.

The growing presence of artificial intelligence in educational contexts intensifies this question. As artificial intelligence (AI)-generated simulations, virtual ecological environments, and intelligent learning systems become common in classrooms, museums, and community programs, a new debate emerges: Can technological environments recreate the embodied, sensory, and relational dimensions of learning traditionally associated with outdoor experiences [5]? And if so, does this learning carry the same ecological significance, or does it fundamentally differ in ways that matter for the development of children's environmental consciousness [6]? Despite the increasing enthusiasm surrounding artificial intelligence (AI)-driven educational innovation, there remains a lack of research addressing how AI-simulated ecological environments shape children's bodily experience. Most studies evaluating virtual nature focus on attention restoration, cognitive outcomes, or user satisfaction, but rarely examine how these environments transform children's actions, movement patterns, sensory attention, and emotional attunement - elements central to embodied ecological learning [7]. Much of the existing literature treats learning as a cognitive acquisition process, while undervaluing the body as the site through which the world is first perceived and meaning is constituted. For Merleau-Ponty, perception is always embodied; the body does not merely inhabit space but actively generates it through movement, sensation, and intentionality [8]. This view resonates strongly with environmental educators who argue that nature is learned through direct physical interaction - touching soil, navigating uneven terrain, sensing temperature, and encountering the unpredictable rhythms of plants and animals. Such experiences foster ecological attunement: An embodied sense of being-with the environment that cannot be fully translated into conceptual knowledge.

Parallel to phenomenological accounts of embodied perception, Gibson's ecological psychology offers another crucial perspective. Gibson's theory of affordances suggests that environments "invite" or "allow" certain actions depending on their material and relational properties [9]. Natural environments are rich in affordances: branches that can be climbed, stones that can be touched, uneven ground that demands balance, and insects that capture attention. Each of these elements prompts children to move, explore, and respond in ways that support sensory integration and ecological awareness. In contrast, technological environments tend to offer more controlled, predictable, and visually dominated affordances, a difference that may shape children's bodily engagement and the type of meaning they construct. Although AI simulations can be visually compelling, their action possibilities often lack the variability, irregularity, and vitality characteristic of living ecosystems [10]. This raises pedagogical questions about how artificially generated environments influence children's ecological imagination and whether they can truly replicate the experiential depth of real nature.

Within this context, the present study investigates how primary-school children experience ecological learning differently in natural environments and AI-generated ecological simulations. The study emerged from experiential engagement with children's ecological education in Southeast Asia, where field-based rainforest learning is increasingly complemented by digital technologies. Observations suggested marked differences in children's movement patterns, attentional rhythms, sensory responses, and emotional expressions across environments - differences that invited theoretical and empirical examination. Motivated by these observations, the study adopts a phenomenological approach to describe how children inhabit and make sense of ecological environments through their bodies, integrating Gibsonian affordance analysis to compare the action possibilities generated by real and artificial ecosystems [11,12].

The purpose of this research is not to dismiss AI-based learning environments. Indeed, such technologies hold promise for expanding access to environmental education, especially in areas where children have limited contact with nature [13]. Rather, this study seeks to articulate the specific qualities of embodied experience that natural environments uniquely provide and to evaluate how AI simulations can complement, rather than replace, these qualities. By examining the experiential, sensory, and behavioral dimensions of ecological learning across two distinct settings, the research aims to contribute to ongoing debates about technology in education and the future of environmental pedagogy.

Ultimately, this study addresses a central question of our technological era: What kinds of ecological learning are possible, and what is potentially lost, when the natural world is recreated through artificial intelligence? Through a detailed analysis of children's embodied engagement with both environments, the study proposes a framework for understanding how environmental consciousness emerges through bodily experience. As AI continues to reshape the sensory and perceptual conditions of childhood, such work has grown increasingly crucial. It is essential for ensuring that ecological education remains grounded in meaningful encounters with the more-than-human world.

Literature review

In order to understand how children form ecological awareness and embodied connections to the natural world, it is essential to examine existing scholarship spanning phenomenology, ecological psychology, environmental education, and the emerging field of AI-mediated learning environments. The present study positions itself at the intersection of these research traditions, arguing that children's ecological understanding is not only cognitive but deeply rooted in bodily experience, sensory engagement, and the action possibilities provided by different environments [14]. This literature review therefore synthesizes four interconnected areas: phenomenological accounts of embodied perception, Gibsonian affordance theory and its relevance to childhood environmental behavior, research on embodied ecological education, and recent studies on AI-generated or virtual ecological simulations. Together, these bodies of literature highlight both the unique pedagogical value of natural environments and the challenges introduced by technologically constructed alternatives, while also revealing a significant gap in research comparing children's lived experience across these two settings.

Phenomenology offers a foundational perspective for investigating embodied ecological learning because it insists that perception begins from the lived body rather than abstract cognition. Merleau-Ponty's phenomenology of perception asserts that the body is not an object in the world but the very means through which the world becomes meaningful [15]. Our sensory fields, motor intentions, and bodily orientations form an integrated structure that establishes the "I can" of action - an essential concept for ecological engagement. For children, whose cognitive structures are still emerging, the body is especially central to exploration, learning, and meaning making. Their understanding of the environment arises not primarily through language or concepts, but through a pre-reflective, sensuous mode of being-in-the-world: touching leaves, feeling humidity, step- ping on uneven ground, and responding spontaneously to environmental cues. Within phenomenological education research, scholars emphasize that movement itself is a form of thinking, and that a child's bodily encounter with the world shapes emotional, ethical, and perceptual development. Applied specifically to nature, this suggests that ecological awareness is inseparable from embodied presence, where the child's body and the environment form a perceptual unity.

Gibson's ecological psychology further elaborates this relational understanding through the concept of affordances - action possibilities that emerge through the interaction between organism and environment. Unlike phenomenology, which emphasizes lived experience and intentionality, Gibsonian theory frames perception as direct and functional: The environment invites or constrains certain actions depending on its material properties and the abilities of the perceiver. Natural environments are uniquely rich in affordances because they contain variability, complexity, and unpredictability. A fallen log affords balancing, soil affords digging, uneven terrain affords climbing or careful stepping, and animal tracks afford curiosity- driven investigation. The children's outdoor behavior expands this perspective by demonstrating that children spontaneously perceive and utilize environmental affordances for play, exploration, and problem-solving, which in turn supports motor development, sensory integration, and ecological understanding. In contrast, built or artificial environments often present reduced affordance diversity, guiding children toward predetermined actions and limiting the emergence of spontaneous exploratory behavior. The distinction between naturally occurring affordances and human-designed action possibilities becomes particularly relevant in evaluating AI-generated ecological environments. In such environments, movement and exploration are frequently shaped by programmed rules and visual cues rather than dynamic material conditions.

Environmental education research further underscores the significance of natural environments for children's ecological learning. The concept of "nature-deficit disorder" brought widespread attention to the psychological, cognitive, and emotional consequences of children's reduced contact with nature, highlighting how technological lifestyles limit opportunities for embodied, multisensory engagement [16]. Subsequent empirical studies consistently show that natural settings enhance attention restoration, reduce stress, and promote curiosity, creativity, and resilience. From an educational perspective, natural environments foster experiential, inquiry-based learning in which knowledge emerges from direct interaction rather than abstract instruction. Sobel emphasizes that place-based education situates learning within lived ecological contexts, enabling children to develop empathy, responsibility, and ethical relations with the more than-human world. These studies collectively highlight that ecological learning is not merely about acquiring factual knowledge. It is a relational process rooted in sensory immersion, emotional resonance, and embodied exploration, a view that aligns closely with phenomenological accounts of perception [17].

Despite the well-documented benefits of nature-based learning, the rapid integration of digital technologies into education has shifted attention toward virtual and AI-generated learning environments. Early research on virtual reality (VR) nature experiences suggested that immersive simulations could evoke psychological responses similar to those elicited by real nature, including relaxation and improved attention [18]. However, subsequent studies caution that VR nature lacks critical sensory dimensions such as smell, temperature, touch, and proprioceptive feedback, significantly altering the nature of embodied engagement. For example, Moloney et al. found that while VR nature can evoke awe, it cannot recreate the kinesthetic and multisensory richness of actual environments, leading to reduced behavioral involvement [19]. Research on children shows even more pronounced limitations: Virtual environments tend to elicit visually dominant engagement, passive observation, and task-driven behavior, rather than spontaneous exploration. Moreover, the affordances of digital environments are constrained by design parameters, offering only those actions and interactions intentionally programmed into the system. As a result, children's movements within VR or AI-generated ecological spaces often follow guided, predetermined pathways rather than emergent, self-directed patterns typical of natural exploration.

The emergence of AI-generated ecological environments introduces new possibilities and new concerns. Rather than fixed virtual spaces, AI simulations can generate dynamic ecological scenarios based on user behavior or environmental data [20]. Scholars argue that AI has the potential to disrupt conventional educational models by creating adaptive, responsive learning environments. Yet few studies have examined how these AI-generated environments shape children's bodily experience, sensory engagement, or ecological imagination. Most research remains conceptual, focusing on AI ethics, data literacy, or personalized learning systems, while empirical work comparing AI-simulated ecological environments with real natural settings is almost nonexistent. The few available studies suggest that AI-mediated experiences often privilege efficiency, clarity, and controlled interactivity - qualities that contrast sharply with the ambiguity, unpredictability, and aliveness of natural ecosystems. These differences have profound implications for ecological education, which depends not only on cognitive understanding but on cultivating a sense of relationality and interdependence with the more-than-human world [21].

Synthesizing these bodies of literature reveals several important insights. First, phenomenology and ecological psychology converge on the notion that ecological learning depends on embodied engagement and on environments that invite diverse, meaningful actions [22]. Second, natural environments possess qualities - variability, multisensory richness, dynamic affordances - that are difficult for technological environments to replicate. Third, although AI-generated environments offer accessibility and innovative pedagogical opportunities, their sensory, affordance-based, and relational limitations remain poorly understood. Finally, there exists a significant research gap concerning how children experience ecological learning across these contrasting environments at the level of bodily perception, action, and emotional attunement. This study addresses that gap by comparing children lived experiences in natural and AI-generated ecological spaces using a phenomenological lens integrated with affordance-based analysis, thereby contributing empirical depth to ongoing discussions about technology's role in environmental education.

Theoretical framework

The theoretical foundation of this study draws primarily from phenomenology - particularly the embodied perceptual ontology articulated by Merleau-Ponty - and ecological psychology, especially Gibson's theory of affordances. These two traditions, while grounded in distinct philosophical projects, converge in their emphasis on perception as relational, embodied, and fundamentally situated within the environment. Their integration provides a robust conceptual basis for understanding how children experience natural environments and AI-generated ecological simulations differently in terms of bodily engagement, sensory attunement, and ecological meaning-making. In order to articulate an analytical framework that captures these dynamics, this section develops three interlinked theoretical pillars: the phenomenological conception of embodied perception, ecological affordance theory as a model of action-environment reciprocity, and a relational ontology of child-environment interaction that emerges from the synthesis of the two. This tripartite framework enables the study to move beyond comparisons based solely on cognitive outcomes or environmental content, instead prioritizing lived experience and embodied ecological learning as the primary unit of analysis [23].

The first pillar of the framework originates in Merleau-Ponty's phenomenology, which posits the body as the existential ground of perception and meaning. Rather than treating perception as a process of internal representation, phenomenology understands it as a direct, lived engagement with the world in which the body functions as an "intentional arc" linking sensory experience, motor capacities, affective disposition, and environmental orientation. For Merleau-Ponty, the body is not a physical object but a mode of access to the world, a "body-subject" whose movements and sensations disclose the world's significance. The body perceives by moving, touching, leaning, reaching, and adjusting - actions that generate a pre-reflective, situational understanding of the environment. This is particularly relevant for children, who experience the world not through conceptual categories but through immediate, sensory-motor involvement. Their ecological understanding is shaped not only by what they see or are told, but by the textures they feel underfoot, the resistance of soil, the unpredictability of wind, and the rhythmic effort of climbing or balancing. Phenomenology therefore allows this study to treat children's ecological learning as an emergent, embodied phenomenon in which meaning is inseparable from bodily activity. Within this theoretical orientation, natural environments serve as lived spaces where the child's body and the world mutually reveal one another in a dynamic, unfolding encounter.

Complementing this phenomenological foundation is the second pillar, Gibson's ecological psychology, which reframes perception as the detection of affordances - action possibilities offered by the environment relative to the individual's abilities. In Gibson's view, perception is not a matter of constructing internal representations, but of directly perceiving what the environment enables or inhibits. Affordances are neither subjective nor objective; they exist as relational properties that emerge when the features of an environment intersect with a perceiver's bodily capacities, intentions, and skills. For example, a rock may afford sitting for an adult but climbing for a child; a shallow puddle may afford stomping, splashing, or observing reflections; a cluster of branches may afford imaginative play or tool-making. The richness of the environment, therefore, depends on the diversity of affordances it provides. Natural environments are exceptional in this regard because they contain irregularity, variability, and complexity - qualities that invite spontaneous exploration and adaptive problem-solving. In contrast, artificial or pre-programmed environments typically offer limited affordances, designed with specific behaviors or learning outcomes in mind. This affordance- based perspective is critical for analyzing both real and AI-generated ecological environments in this study, as it enables a systematic comparison of how each environment invites or restricts movement, exploration, sensory engagement, and ecological inquiry.

Integrating phenomenology and affordance theory leads to a third pillar: a relational ontology of child - environment interaction. This combined perspective allows the study to treat children's ecological learning as neither purely bodily nor purely environmental, but as a dynamic interplay between the two. Phenomenology emphasizes lived experience and embodied meaning, while affordance theory emphasizes functional relationships between perception and action [24]. When merged, they reveal that ecological learning arises from a continuous feedback loop: The child perceives the environment through bodily engagement, the environment responds through its affordance structure, and new perceptual possibilities emerge through this reciprocal interaction. This relational ontology rejects the idea that environments merely "contain information" or that children simply "receive knowledge". Instead, environments and children co-constitute one another in the act of learning. A tree is not simply an object; it is something to be touched, climbed, circled, inspected for insects, or listened to as wind passes through its leaves. A stream is not only a visual stimulus, but also an interactive setting that affords jumping across it, testing its depth, observing its flow speed, or building temporary dams within it. These relational actions form the basis of ecological understanding. By contrast, AI-generated ecological environments often mediate or restrict this reciprocity: Movement may be translated into visual animation rather than material response; textures may be simulated rather than felt; and action possibilities are determined by software constraints rather than natural variation. The relational ontology thus provides a lens through which differences between natural and AI environments can be interpreted not merely as technological differences, but as differences in existential and ecological meaning-making.

To operationalize this theoretical framework for empirical analysis, the study conceptualizes children's experience across three phenomenological-ecological dimensions: embodied sensory immersion, affordance richness, and relational ecological attunement. Embodied sensory immersion refers to the extent to which children perceive through multi-sensory, bodily engagement. Natural environments immerse children in tactile, olfactory, thermal, auditory, and proprioceptive stimuli, whereas AI environments tend to rely primarily on visual and auditory cues, generating a perceptual narrowing that alters the quality of experience [25]. Affordance richness pertains to the diversity and spontaneity of action possibilities available. Natural environments offer infinite micro-variations - loose stones, slippery mud, shifting shadows, crawling insects - each of which invites adaptive exploration. While AI-generated worlds provide discretely programmed interaction pathways with limited variability. Relational ecological attunement captures the child's sense of connection, empathy, curiosity, and ecological awareness as they interact with the environment - dimensions supported by phenomenological embodiment and ecological reciprocity. Phenomenology predicts that attunement deepens when children experience the environment as alive, responsive, and unpredictable, conditions more readily found in natural environments than in algorithmically patterned simulations.

Together, these dimensions form an integrated analytical lens through which to interpret children's lived experiences. The framework thereby supports a nuanced comparison that moves beyond technological novelty or visual fidelity and instead evaluates how natural and AI-generated environments shape the child's perceptual field, bodily engagement, and ecological understanding. More importantly, the theoretical synthesis underscores that the value of ecological education cannot be reduced to informational content alone but depends on the lived, embodied, and relational qualities of experience that natural environments uniquely provide.

Research methods

This study adopts a qualitative research design grounded in phenomenological inquiry, complemented by ecological psychology, to investigate how primary school children experience ecological learning within two distinct environments: a natural outdoor ecosystem and an AI-generated ecological simulation. Because the central focus of this research is the lived, embodied experience of children - their sensory orientation, bodily engagement, affective responses and meaning-making processes - qualitative methods are far more suitable than experimental or survey-based approaches. The aim is not to measure learning outcomes but to understand how environmental consciousness emerges through the body, and how different environments shape children's perceptual and experiential worlds. The methodology therefore follows Merleau-Ponty's phenomenological principle of "returning to the experience itself", wherein the researcher seeks to describe phenomena as they are lived prior to conceptualization or interpretation.

The study also incorporates James Gibson's ecological psychology, especially the concept of affordances, to evaluate how each environment enables or restricts children's actions. This dual-method framework - phenomenological description and affordance analysis - allows for a deeper and more holistic comparison between natural and AI-simulated environments by attending simultaneously to children's subjective experiences and the objective action possibilities embedded in the environment. This methodological pairing is particularly valuable in studies involving children, whose learning often manifests through movement, gesture, exploration, and sensory engagement rather than verbal articulation alone.

Participants were 20 primary school students aged 8 to 12. This age range is developmentally ideal for this research because children at this stage possess strong exploratory instincts, highly active sensory systems, and a growing capacity for articulating experiences, while their ecological consciousness is still forming. All participants were recruited from the same school to ensure relative homogeneity in social context, cultural background, and prior exposure to ecological environments. In accordance with ethical requirements for research involving minors, the study obtained informed consent from the school, parents, and the children themselves (through age-appropriate assent procedures). The research design prioritized physical and emotional safety, avoiding hazardous terrain or content that might induce fear or discomfort.

The study employed an alternating experience design in which each group of children engaged in two parallel ecological learning sessions: One conducted in a real natural environment and the other in an AI-generated ecological simulation. In both settings, the children were given identical open-ended tasks designed to elicit spontaneous bodily-environment interaction rather than direct instruction. These tasks included prompts such as "find something that attracts you", "use your body to communicate with the environment", "imitate a rhythm or movement you observe", and "express the atmosphere you feel through your body". The use of open-ended activities ensures that children's experiences are not constrained by cognitive expectations but emerge organically from their bodily engagement with the environment.

In the natural environment, children explored a small forest park, a riverside walkway, or a school ecological garden, depending on logistical considerations. They were free to touch tree bark, smell plants, listen to rustling leaves, walk on uneven ground, observe insects, climb low rocks, and interact with natural textures and temperatures. By contrast, the AI-generated environment consisted of an immersive interactive system - either VR headsets or a projection based ecological simulation - where children engaged with algorithmically generated plants, animals, weather patterns, and environmental sounds. Their actions were tracked by motion sensors, cameras, or body-responsive interfaces that adjusted the visual or auditory stimuli based on their movement.

Data collection included continuous video recording, detailed observational field notes, recordings of children's spontaneous verbal expressions, and short post-activity interviews to capture reflections in children's own words. Additionally, the researcher maintained a "bodily resonance log", documenting her own bodily sensations and attentional shifts during fieldwork. In phenomenological research, such reflexive embodied documentation helps identify subtle experiential cues - such as changes in pace, posture, breath, or attention - that may otherwise remain unnoticed yet are central to understanding how children inhabit the environment.

The observational focus included children's movement patterns, sensory orientation (e.g., gaze direction, tactile engagement, auditory attention), emotional expressions, and rhythm of exploration. For example, observations captured whether children instinctively stooped to inspect insects, reached out to touch leaves or stones, tilted their heads in response to birdsong or wind, paused to sense temperature changes, experimented with balance on uneven surfaces, or mimicked natural rhythms such as swaying branches or flowing water. In the AI environment, observations focused on whether children's actions were shaped more by the system's visual cues, whether their movement range narrowed due to interface limitations, how frequently they relied on screen-based feedback, whether their curiosity was sustained or diminished, and how their body responded to non-material ecological representations.

Data analysis followed a phenomenological meaning condensation process. The researcher first conducted open reading of all field notes, transcripts, and video observations, marking passages related to bodily sensation, perception of space, affective responses, engagement rhythms, and action tendencies. Themes were then distilled from these data, such as "tactile encounters as gateways to ecological awareness", "the role of unpredictability in sustaining curiosity", "the sensory quietness of digital nature", "movement resonance with natural rhythms", and "the dependence on visual cues in AI environments". These themes are synthesized into experiential structures that describe how children's perceptions and meanings are generated through the intertwining of body, environment, and movement. Through Gibsonian analysis, the researcher then compared the affordances of each environment, examining how the natural environment's variability, texture-rich surfaces, micro-organisms, temperature changes, and multisensory cues differ from the visual-dominant, predictable, and often interaction-limited affordances of the AI-generated environment.

To enhance research credibility, the study engaged in triangulation by cross-comparing observational data, interviews, and video footage. Two external researchers participated in data interpretation to validate the thematic structures, and a subset of children provided feedback to ensure that the descriptions accurately reflected their lived experiences. These procedures helped minimize researcher bias and ensure that interpretations remained grounded in the children's phenomenological reality rather than adult assumptions.

Reflexivity formed an essential aspect of the methodology. Because phenomenological research relies heavily on the researcher's perceptual sensitivity and interpretive awareness, reflexive logs were kept after each session to track the researcher's reactions, assumptions, and potential biases. This reflexive practice helped ensure that the researcher remained open to children's unique ways of sensing the environment rather than imposing adult meanings onto their experiences.

Through this phenomenological-ecological methodology, the study seeks to illuminate how children's ecological awareness arises through the body, how their sensory worlds shift across environments, and how AI-generated ecological simulations reshape the conditions of learning. This approach allows research to move beyond cognitive models of learning and toward a nuanced understanding of children's ecological embodied experience.

Research findings

The findings of this study revealed clear phenomenological, behavioral, and ecological differences in how primary-school children experience learning in natural environments compared to AI-generated ecological simulations. Across all participants, real nature elicited richer sensory orientation, more dynamic bodily engagement, stronger emotional attunement, and deeper forms of ecological awareness. In contrast, AI-generated environments, although visually immersive and technologically sophisticated, produced perceptual narrowing, reduced movement exploration, and weaker affective resonance. These differences emerged consistently throughout observations, interviews, and motion-path analyses, demonstrating that the medium of ecological learning substantively shapes children's embodied experience.

In the natural environment, children's engagement began immediately through their senses. Many children bent down to touch tree bark, dig fingers into soil, press hands into moss, or trace the ridges of stones. These tactile initiations triggered broader bodily shifts - changes in posture, breath, and tempo - as if the body gradually tuned itself to the environment's rhythms. Children frequently paused without prompting, attending to sounds such as wind, insects, or rustling leaves. These pauses were not signs of disengagement but of heightened perceptual openness, revealing a form of deep listening that cannot be artificially reproduced. Their movements also became increasingly varied: skipping, crouching, climbing, balancing, running, stretching, and occasionally swaying in response to the motion of branches or flowing water. These actions showed that the natural environment offered abundant affordances - surfaces to climb, textures to touch, micro-organisms to observe, unpredictable elements to respond to - which encouraged exploratory, improvisational, and self-directed learning.

Emotionally, the children displayed excitement, wonder, and curiosity. Their voices often rose with spontaneous exclamations like “look at this!” or “it’s moving!” - responses accompanied by widened eyes, animated gestures, and collaborative exchanges. Many engaged in imaginative interpretations, such as identifying the “breathing” of trees, hearing “footsteps” in the wind, or inventing narratives about insects. These reactions show that nature stimulates affective and imaginative dimensions of ecological consciousness, helping children sense life as a presence rather than as information. Interviews revealed that children perceived natural environments as “alive”, “changing”, “mysterious”, or “full of surprises”. These expressions indicate an emergent awareness of ecological vitality - a sense that the environment possesses its own agency and rhythms that coexist with human presence.

In contrast, children’s bodily and perceptual engagement in the AI-generated ecological simulation was noticeably narrower. Although the visual environment initially drew strong attention - with children expressing excitement at the “giant plants”, “glowing animals”, or “fantasy forests” - their engagement quickly shifted to visually dominant forms of interaction. The body oriented toward screens or projections, and movements became limited to forward steps, arm gestures intended to trigger sensors, or small adjustments to stay within the interface’s receptive space. Rather than exploring freely, children tended to perform movements that the system recognized, such as raising arms to trigger animations or stepping forward to make an object move. Their posture remained mostly upright and frontal, oriented toward external feedback rather than internal curiosity.

This created a behavioral loop: Children acted only when the system responded, and when the system did not respond, they quickly stopped exploring. Unlike the open-ended affordances of nature, the AI environment structured expectations, subtly teaching children that valid actions are those that produce visible effects on the screen. Sensory engagement narrowed dramatically: Children rarely reached out to “touch” the virtual elements unless prompted by visual cues. And no child attempted to imitate environmental rhythms through whole-body movement. Their gaze remained fixed on the main display, revealing a visual dependency that overshadowed other senses.

Although children initially described the AI environment as “cool”, “beautiful”, or “like a game”, their emotional responses lacked the depth, excitement, and wonder observed in the natural setting. Interviews indicated that children understood the environment as “not real”, “just a picture”, or “a computer version of nature”. The absence of unpredictability was particularly significant. Many children expressed disappointment that nothing changed unless they moved first, revealing an implicit awareness that natural environments possess a form of autonomous life that simulations cannot reproduce. This lack of environmental agency directly affected their curiosity: When the system stopped responding, the children’s exploration stopped as well.

The comparison between motion paths in both environments demonstrated further distinctions. In nature, the children’s trajectories were irregular, branching, looping, and non-linear, suggesting spontaneous discovery driven by environmental cues. Their pace changed frequently, alternating between excitement, stillness, and bursts of movement that corresponded to sensory stimuli. By contrast, in the AI environment, trajectories became linear or circular within a limited radius, with stable pacing and fewer directional changes. This indicates that the AI environment did not stimulate spontaneous exploration but instead encouraged a predictable and controlled range of movements.

Significantly, real nature produced an embodied form of ecological awareness that AI could not replicate. Children in nature often described feeling the "temperature", "wind", "air", or "freshness", demonstrating an intuitive understanding of ecological interdependence through bodily sensation. They expressed a sense of connection, using phrases like "the trees are talking", "the river is moving with me", or "the insects are watching us". These descriptions align closely with phenomenological accounts of perception as an intertwining of self and world. In contrast, children in the AI environment used language associated with spectatorship - "I watched", "I clicked", "It changed when I moved" - which suggests a detached, observer-like stance rather than a participatory relationship with the environment.

Another major finding concerns uncertainty. In nature, the presence of uncertainty - unexpected movements of animals, sudden wind, uneven surfaces, unknown textures - generated attentiveness, care, and caution that deepened children's attunement to the environment. AI simulations lacked this element: Their predictability limited children's sense of environmental agency and reduced opportunities for genuine discovery. This difference has profound ecological implications: Uncertainty in nature cultivates respect, humility, and sensitivity, whereas predictable AI systems promote control, expectation, and mastery.

Despite these limitations, the AI environment demonstrated specific strengths. It captured children's attention quickly, provided visually striking representations of complex ecosystems, and allowed children to encounter imaginative or inaccessible natural elements (such as extinct species or microscopic organisms). However, these strengths did not translate into embodied ecological awareness. Instead, the AI environment functioned best as a supplement - a creative introduction, extension, or reflective tool - rather than as a replacement for real ecological experience.

Overall, the findings show that while AI-generated ecological simulations can serve educational purposes, they cannot replicate the depth, richness, and vitality of real nature. Natural environments cultivate multisensory engagement, bodily curiosity, ecological attunement, and emotional resonance that are foundational to ecological consciousness. AI environments, by contrast, risk narrowing children's sensory and bodily experience, emphasizing visual consumption and reinforcing a technologically mediated view of nature as a controllable object. These findings highlight the importance of grounding ecological education in authentic, embodied encounters with the natural world and using AI as a complementary tool rather than a substitute. Below is the comparison table required for the article (Table 1).

Table 1. Comparison of children's behaviors in forest vs AI-generated ecological environments.

Dimension	Forest environment	AI environment
Embodied engagement	Running, climbing, crouching, balancing; strong whole-body use.	Mostly standing, pointing, visual focus; limited physical movement.
Sensory modalities	Rich tactile, olfactory, temperature, sound; highly multisensory.	Visual-auditory only; limited tactile or proprioceptive input.
Exploratory behavior	High spontaneity, self-directed discovery.	Mostly system-guided tasks.
Affordance richness	Multiple affordances per element (logs, soil, plants).	Pre-programmed affordances; limited variability.
Ecological attunement	Strong sense of aliveness, care, curiosity.	Focus on effects rather than ecological relations.

These qualitative findings are further supported by quantitative ratings (Figure 1), where natural forest environments consistently outperformed AI-generated simulations across all four dimensions: embodied immersion, affordance richness, exploratory behavior, and ecological attunement.

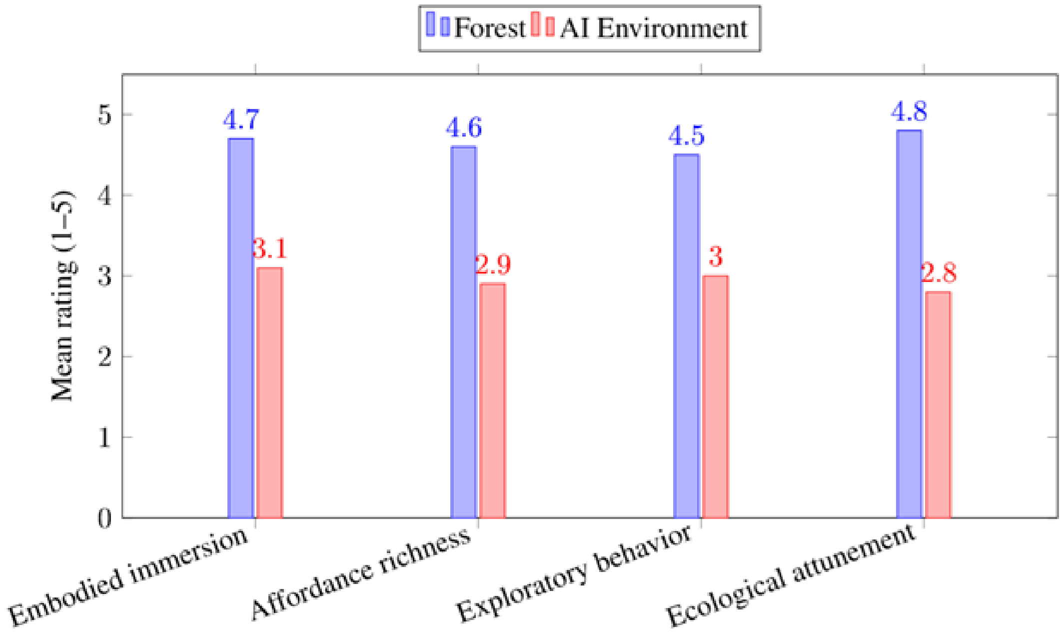

Figure 1. Illustrative comparison of children's experience across environments.

Discussion

The findings of this study reveal clear phenomenological, behavioral, and ecological differences in how primary-school children experience learning in natural environments compared to AI-generated ecological simulations. Across all participants, real nature elicited richer sensory orientation, more dynamic bodily engagement, stronger emotional attunement, and deeper forms of ecological awareness. In contrast, AI-generated environments, although visually immersive and technologically sophisticated, produced perceptual narrowing, reduced movement exploration, and weaker affective resonance. These differences emerged consistently throughout observations, interviews, and motion-path analyses, demonstrating that the medium of eco- logical learning substantively shapes children's embodied experience.

In the natural environment, children's engagement began immediately through their senses. Many children bent down to touch tree bark, dig fingers into soil, press hands into moss, or trace the ridges of stones. These tactile initiations triggered broader bodily shifts - changes in posture, breath, and tempo - as if the body gradually tuned itself to the environment's rhythms. Children frequently paused without prompting, attending to sounds such as wind, insects, or rustling leaves. These pauses were not signs of disengagement but of heightened perceptual openness, revealing a form of deep listening that cannot be artificially reproduced. Their movements also became increasingly varied: Skipping, crouching, climbing, balancing, running, stretching, and occasionally swaying in response to the motion of branches or flowing water. These actions showed that the natural environment offered abundant affordances - surfaces to climb, textures to touch, micro-organisms to observe, unpredictable elements to respond to - which encouraged exploratory, improvisational, and self-directed learning.

Emotionally, the children displayed excitement, wonder, and curiosity. Their voices often rose with spontaneous exclamations like "look at this!" or "it's moving!" - responses accompanied by widened eyes, animated gestures, and collaborative exchanges. Many engaged in imaginative interpretations, such as identifying the "breathing" of trees, hearing "footsteps" in the wind, or inventing narratives about insects. These reactions show that nature stimulates affective and imaginative dimensions of ecological consciousness, helping children sense life as a presence rather than as information. Interviews revealed that children perceived natural environments as "alive", "changing", "mysterious", or "full of surprises". These expressions indicate an emergent awareness of ecological vitality - a sense that the environment possesses its own agency and rhythms that coexist with human presence.

In contrast, children's bodily and perceptual engagement in the AI-generated ecological simulation was noticeably narrower. Although the visual environment initially drew strong attention - with children expressing excitement at the “giant plants”, “glowing animals”, or “fantasy forests”. But their engagement quickly shifted to visually dominant forms of interaction. The body oriented toward screens or projections, and movements became limited to forward steps, arm gestures intended to trigger sensors, or small adjustments to stay within the inter-face’s receptive space. Rather than exploring freely, children tended to perform movements that the system recognized, such as raising arms to trigger animations or stepping forward to make an object move. Their posture remained mostly upright and frontal, oriented toward external feedback rather than internal curiosity.

This created a behavioral loop: Children acted only when the system responded, and when the system did not respond, they quickly stopped exploring. Unlike the open-ended affordances of nature, the AI environment structured expectations, subtly teaching children that valid actions are those that produce visible effects on the screen. Sensory engagement narrowed dramatically; children rarely reached out to “touch” the virtual elements unless prompted by visual cues, and no child attempted to imitate environmental rhythms through whole-body movement. Their gaze remained fixed on the main display, revealing a visual dependency that overshadowed other senses.

Although children initially described the AI environment as “cool”, “beautiful”, or “like a game”, their emotional responses lacked the depth, excitement, and wonder observed in the natural setting. Interviews indicated that children understood the environment as “not real”, “just a picture”, or “a computer version of nature”. The absence of unpredictability was particularly significant. Many children expressed disappointment that nothing changed unless they moved first, revealing an implicit awareness that natural environments possess a form of autonomous life that simulations cannot reproduce. This lack of environmental agencies directly affected their curiosity: When the system stopped responding, the children’s exploration stopped as well.

The comparison between motion paths in both environments demonstrated further distinctions. In nature, the children’s trajectories were irregular, branching, looping, and non-linear, suggesting spontaneous discovery driven by environmental cues. Their pace changed frequently, alternating between excitement, stillness, and bursts of movement that corresponded to sensory stimuli. By contrast, in the AI environment, trajectories became linear or circular within a limited radius, with stable pacing and fewer directional changes. This indicates that the AI environment did not stimulate spontaneous exploration but instead encouraged a predictable and controlled range of movements.

Significantly, real nature produced an embodied form of ecological awareness that AI could not replicate. Children in nature often described feeling the “temperature”, “wind”, “air”, or “freshness”, demonstrating an intuitive understanding of ecological interdependence through bodily sensation. They expressed a sense of connection, using phrases like “the trees are talking”, “the river is moving with me”, or “the insects are watching us”. These descriptions align closely with phenomenological accounts of perception as an intertwining of self and world. In contrast, children in the AI environment used language associated with spectatorship - “I watched”, “I clicked”, “It changed when I moved” - which suggests a detached, observer-like stance rather than a participatory relationship with the environment.

Another major finding concerns uncertainty. In nature, the presence of uncertainty - unexpected movements of animals, sudden wind, uneven surfaces, unknown textures - generated attentiveness, care, and caution that deepened children’s attunement to the environment. AI simulations lacked this element: Their predictability limited children’s sense of environmental agency and reduced opportunities for genuine discovery. This difference has profound ecological implications: Uncertainty in nature cultivates respect, humility, and sensitivity, whereas predictable AI systems promote control, expectation, and mastery.

Despite these limitations, the AI environment demonstrated specific strengths [26]. It captured children’s attention quickly, provided visually striking representations of complex ecosystems, and allowed children to encounter imaginative or inaccessible natural elements (such as extinct species or microscopic organisms). However, these strengths did not translate into embodied ecological awareness. Instead, the AI environment functioned best as a supplement - a creative introduction, extension, or reflective tool, rather than as a replacement for real ecological experience.

Overall, the findings show that while AI-generated ecological simulations can serve educational purposes, they cannot replicate the depth, richness, and vitality of real nature. Natural environments cultivate multisensory engagement, bodily curiosity, ecological attunement, and emotional resonance that are foundational to ecological consciousness. AI environments, by contrast, risk narrowing children's sensory and bodily experience, emphasizing visual consumption and reinforcing a technologically mediated view of nature as a controllable object. These findings highlight the importance of grounding ecological education in authentic, embodied encounters with the natural world and using AI as a complementary tool rather than a substitute.

Conclusion

This study sets out to examine how children engage with natural environments compared to AI-generated ecological spaces, and the findings reveal a fundamental and irreducible difference between lived ecological experience and technologically mediated simulation. While both environments allow children to encounter ecological imagery and concepts, they do so through radically different modes of bodily perception, sensory engagement, and relational understanding. Natural environments, with their dynamic textures, unpredictable rhythms, and autonomous agencies, invite children into an open and reciprocal field of perception. In these settings, children experience nature not as an object to be observed but as a world to be entered - a world that touches back, resists, responds, and exceeds their expectations. This form of ecological encounter is rooted in the body's capacity to sense, interpret, and respond to environmental forces. The natural world provides opportunities for deep immersion, multisensory exploration, and relational awareness that nurtures ecological sensitivity in ways no simulation can replicate. By contrast, the AI-generated environment, despite its visual sophistication and interactive features, operates primarily as a representational construct shaped by computational logic and predetermined responses. Children's interactions in this setting are filtered through the interface's constraints: The system recognizes certain gestures but ignores others, responds predictably rather than spontaneously, and presents nature as a coherent, aesthetically pleasing pattern rather than a living ecosystem. While the AI environment stimulates curiosity and provides accessible, controlled exposure to ecological imagery, it lacks the open-endedness and vitality that define natural environments. The simulation invites children to observe but not to inhabit, to react but not to negotiate, and to interact within conditions that ultimately rein- forced a human-centered form of control. These constraints limits the development of bodily intuition and ethical awareness that arise from direct encounters with ecological complexity.

A key implication of this research is that ecological understanding cannot be reduced to information acquisition. Knowledge about species, habitats, or environmental processes does not automatically foster ecological awareness. What children learn through natural environments is not merely factual content but a mode of being - an embodied sensitivity to the rhythms, resistances, and vulnerabilities of the more-than-human world. This awareness emerges through sensory attunement, curiosity driven by uncertainty, and the recognition of nature's autonomy. The phenomenological insight that perception is a lived, bodily engagement with the world provides a crucial theoretical foundation for understanding why natural environments are indispensable for ecological education. In contrast, AI-generated nature, for all its pedagogical potential, risks promoting a view of ecosystems as predictable systems designed for human interpretation. When children encounter nature primarily through simulations, they may internalize an ecological imagination framed by human control rather than ecological interdependence. Nevertheless, this study does not position AI technologies as adversaries to ecological learning. Instead, the findings suggest a more nuanced perspective: AI-generated environments are valuable as supplements, not substitutes. They can extend children's access to global environments, visualize invisible ecological processes, and support reflective learning after outdoor experiences. AI can help children conceptualize ecosystems they cannot physically encounter - coral reefs, glaciers, deep-sea organisms, or climate transformation scenarios. Yet, it cannot cultivate the embodied ecological consciousness that emerges only through lived inter- action with natural environments. The challenge, therefore, is not to avoid AI, but to integrate it thoughtfully, designing technologies that enhance rather than replace sensory-rich, embodied ecological learning.

The distinction between natural and AI environments also raises important ethical considerations. Technologies carry implicit assumptions about human-nature relations, shaping how children imagine the ecological world. If simulations depict nature as responsive only when programmed to respond, children may unconsciously absorb a view of nature as controllable and predictable. In contrast, natural environments teach that ecosystems are independent, complex, and often indifferent to human intentions. This recognition is foundational to ecological ethics: It positions humans not as masters of nature but as participants in a shared, fragile world. As ecological crises intensify globally, fostering this humility and relational awareness is essential. Therefore, educators, designers, and policymakers must critically reflect on how AI simulations construct ecological narratives and ensure that such technologies reinforce rather than diminish the complexity and autonomy of the natural world.

Another implication concerns the future of environmental education within increasingly urbanized and digitized societies. Many children now grow up with limited access to natural spaces, making AI simulations appear as convenient substitutes. This study argues that such a substitution is perilous. Without direct encounters with natural environments, children risk losing the bodily and sensory foundations of ecological perception. They may understand nature conceptually while lacking the experiential grounding necessary to care for or act on behalf of ecosystems. Ecological consciousness is not simply learned, it is cultivated through lived attunement to the more-than-human world. To sustain ecological awareness in future generations, educational frameworks must prioritize access to natural environments while leveraging technology to expand, not replace, embodied experience.

A broader conclusion emerging from this study is that the body remains central to ecological education, even in an age dominated by digital technologies and artificial intelligence. The body is not merely a passive receiver of information but an active participant that interprets, shapes, and is shaped by the world. Ecological perception arises through this intertwining of body and environment. When this mutual relationship is interrupted by technological mediation, ecological awareness becomes abstracted, disembodied, and potentially disconnected from the ethical and affective dimensions of environmental responsibility. Thus, the preservation of natural experiences is not simply a pedagogical preference but a necessity for cultivating future citizens capable of engaging meaningfully with ecological challenges.

Finally, the findings of this research open pathways for future inquiry. Further studies might explore how AI-generated environments can be redesigned to incorporate uncertainty, multisensory richness, or more-than-human agency. Others may investigate hybrid pedagogical models that combine real-world ecological experiences with AI-enhanced reflective tools. Comparative research across age groups could illuminate how embodied ecological awareness develops over time and how digital technologies affect that trajectory. There is also significant potential for interdisciplinary collaboration between environmental educators, technologists, designers, and phenomenologists to rethink how AI's representational power can serve ecological ethics without diminishing the vitality of lived experience.

In conclusion, while AI technologies offer innovative possibilities for expanding ecological knowledge, they cannot replicate the living, breathing, dynamic world in which children cultivate ecological sensitivity. Natural environments remain irreplaceable as the foundation of ecological learning because they engage the full spectrum of human perception, emotion, and bodily presence. AI can enrich ecological education, but only when grounded in a pedagogy that recognizes the primacy of embodied experience. Ultimately, ecological consciousness emerges not from simulations of nature but from encounters with nature itself - encounters that remind us of our entanglement with a world that surpasses representation and invites us into a relationship of reciprocity, responsibility, and wonder.

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Conflicts of Interest

The author declares no conflict of interest.

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