OUTDOOR EDUCATION AND ARTIFICIAL INTELLIGENCE: AN INTEGRATED PEDAGOGICAL FRAMEWORK FOR PERSONALIZED, SITUATED, AND SUSTAINABLE LEARNING

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ABSTRACT

Outdoor education and artificial intelligence constitute an emerging research field, with few studies directly addressing outdoor school settings—from early childhood to secondary education—and a broader literature on citizen science, environmental education, mobile inquiry, and human–AI collaboration. This paper presents a preliminary systematic review following PRISMA 2020 and PRISMA-S to identify pedagogical functions, outcomes, risks, and implementation conditions of AI in outdoor learning. Of 60 records identified (51 after duplicates, 24 full texts), 12 studies were included. Findings highlight AI applications in assisted classification, data quality, personalization, hypothesis generation, and documentation, but provide no robust evidence of improved learning outcomes. Key risks include over-reliance, reduced direct observation, dataset bias, opacity, datafication, and diminished learner agency, especially in early childhood. The review proposes an "observe-first", "human-in-the-loop", and "validation-required" framework, while positioning future quasi-experimental research as the next step after validation of the model and tools.

KEYWORDS

Outdoor Education; artificial intelligence; systematic review; PRISMA; citizen science; embodied learning; Human-Centred AI.

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1. Introduction

The emergence of artificial intelligence (AI) in educational systems is taking place within a context of profound transformation, in which schools and universities are called upon to redefine the relationship between knowledge, technological innovation, the environment, and active participation. In particular, recent advances in AI—especially generative and multimodal systems—provide tools capable of generating textual content, recognizing images, identifying recurring patterns, personalizing learning pathways, and delivering immediate feedback. At the same time, Outdoor Education promotes a conception of learning that extends beyond the classroom, valuing natural environments and real-world contexts as privileged settings for observing phenomena, posing questions, and constructing knowledge through direct experience. This perspective is especially significant from early childhood onwards, where educational models such as Forest Kindergartens and Nature Preschools base children's motor, cognitive, and socio-emotional development on daily contact with nature. However, the convergence of these two perspectives is not without challenges. While technology can expand opportunities for exploration and documentation, it also risks replacing direct experience by shifting learners' attention toward digital devices rather than the environment itself, thereby limiting spontaneous processes of observation and discovery.

The literature on learning in natural environments highlights numerous potential benefits, including increased student engagement, enhanced psychological and physical well-being, the development of interpersonal skills and personal autonomy, and, in some cases, improved academic achievement. Nevertheless, existing studies reveal considerable heterogeneity in theoretical definitions, implementation strategies, and methodological approaches (Kuo, Barnes, & Jordan, 2019; Mann et al., 2022). In early childhood, unstructured outdoor play has also

been consistently associated with positive effects on motor development, overall health, and emotional regulation (Dankiw et al., 2020). From this perspective, the natural environment is not merely the setting in which educational activities take place but an active component of the learning process, providing situations characterized by complexity, variability, and unpredictability that require the integration of perception, action, language, decision-making, and collaboration. Outdoor Education can therefore be understood as a form of situated and embodied learning, in which concepts emerge through direct interaction with natural phenomena, materials, living organisms, and authentic problems.

Meanwhile, research on AI in education has witnessed rapid growth in applications such as intelligent tutoring systems, personalized instruction, automated assessment, learning analytics, predictive modeling, and the generation of educational resources. Despite this expansion, recent literature reviews continue to identify a significant gap between technological innovation and pedagogical foundations, emphasizing the need for greater methodological rigor, transparency, teacher involvement, and careful consideration of ethical implications (Zawacki-Richter et al., 2019; Bond et al., 2024; Mustafa et al., 2024). Consequently, the adoption of AI should not be regarded as synonymous with educational innovation. Its educational value depends on the quality of instructional design, the role of pedagogical mediation, the distribution of agency between humans and intelligent systems, and the ability of learners and educators to understand, verify, and critically discuss algorithmic outputs.

The research problem addressed in this study concerns the possibility of integrating AI into Outdoor Education without undermining its foundational principles. During an environmental exploration activity, for example, an image recognition system may facilitate the preliminary identification of plant or animal species; a large language model may support the formulation of research questions, the comparison of hypotheses, or the adaptation of learning tasks to different student

needs; and learning analytics tools may assist in documenting the learning process. However, each of these opportunities is accompanied by potential risks, including misclassification, hallucinations generated by AI models, excessive reliance on automated responses, unnecessary data collection, reduced time devoted to direct observation, and the gradual erosion of the educational value of uncertainty and dialogic inquiry. The central issue is therefore not to establish a dichotomy between nature and digital technologies, but rather to design an ecology of learning that ensures pedagogical continuity throughout the educational pathway—from early childhood to secondary education—while maintaining technology in a supportive role with respect to direct experience, empirical validation, and human educational responsibility.

Within this framework, the present paper proposes a theoretical and methodological foundation accompanied by the definition of a mixed-methods quasi-experimental research protocol. The aim is to outline the theoretical constructs, operational conditions, and evaluation criteria for an AI-enhanced Outdoor Education model. The innovative contribution does not lie in the indiscriminate introduction of digital technologies into outdoor activities, but in the design of an instructional framework in which AI is employed only during clearly defined phases, such as activity preparation, hypothesis generation, documentation of learning experiences, feedback, and subsequent reflection. Throughout the process, direct observation, multisensory exploration, physical movement, interaction with the environment, and collaboration among participants retain both temporal and epistemological priority.

2. Theoretical Framework

2.1 Outdoor Education as Experiential and Situated Learning: The Foundational Role of Early Childhood

Outdoor Education refers to a broad set of educational approaches that share the intentional use of outdoor spaces as learning environments. Although it may include environmental education activities, sports experiences, or field trips, it cannot be reduced to any of these practices alone. Its defining element lies in the deliberate design of the relationship between the learner, the lived experience, the context in which it takes place, and the subsequent critical reflection. From this perspective, Kolb's (1984) experiential learning model represents a fundamental theoretical reference, describing learning as a cyclical process in which concrete experience, reflective observation, abstract conceptualisation, and active experimentation mutually reinforce one another in a continuous process of knowledge construction.

The foundations of this approach can be traced back to pedagogical theories of early childhood, in which contact with nature assumes the role of the first educational environment. As Sobel (2014) highlights in his analysis of Nature Preschools and Forest Kindergartens, outdoor education during the early years of life is based on direct exploration, place-based education, and the enhancement of the natural sense of wonder, rather than on transmissive forms of instruction. During this developmental stage, experiences in natural environments contribute to the development of executive functions, such as working memory, cognitive flexibility, and inhibitory control—skills that represent essential prerequisites for subsequent learning processes, problem solving, and academic achievement (Ernst & Burcak, 2019).

Situated learning theory also emphasises that knowledge cannot be separated from the social contexts and practices through which it is constructed and shared (Lave & Wenger, 1991). From this perspective, learning acquires meaning through active

participation in communities of practice and engagement with concrete experiences. However, Maynard and Waters (2007) observe that, in early childhood education settings, outdoor spaces have often been considered a “missed opportunity”, as they have been used primarily as recreational areas rather than as intentionally designed contexts for exploration, inquiry, and guided learning. When integrated into a coherent educational design, Outdoor Education instead enables students at all educational levels to develop transversal competences through problem identification, the definition of indicators, data collection and interpretation, discussion of observed anomalies, and critical documentation of decision-making processes.

Major reviews focusing on outdoor science education confirm that inquiry-based activities conducted in spaces near schools can support the understanding of scientific concepts, increase motivation for learning, and promote positive attitudes towards research, provided that they are continuously integrated into the curriculum (Ayotte-Beaudet et al., 2017).

Similarly, literature syntheses by Kuo, Barnes, and Jordan (2019) and Mann et al. (2022) document the beneficial effects of experiences in nature on cognitive, socio-emotional, and physical dimensions, while also highlighting the need to distinguish between simple exposure to natural environments, autonomous exploration, and guided inquiry activities, as these approaches produce different educational outcomes and require specific conditions of design and pedagogical support.

2.2 Embodied Cognition, Perception, and the Educational Value of Free Play and Risky Play

The embodied cognition approach interprets cognitive processes as deeply intertwined with the perceptual, motor, and emotional dimensions of experience.

Knowledge is therefore not developed exclusively at a mental level but emerges from the continuous interaction between individuals and their environment. Within Outdoor Education contexts, the body represents the primary tool for knowledge construction: actions such as spatial orientation, measuring, manipulating natural materials, listening to environmental sounds, perceiving tactile characteristics, or identifying microclimatic variations contribute to the formation of multimodal conceptual representations.

This perspective is particularly relevant in early childhood, a developmental period in which the direct relationship with the environment is especially expressed through risky play, namely outdoor play activities characterised by challenges, uncertainty, and controlled risk, such as climbing, maintaining balance, exploring uneven surfaces, or engaging with different levels of height. The systematic review conducted by Brussoni et al. (2015) highlights how these experiences promote the development of autonomous risk-assessment abilities, strengthen resilience and independence, improve spatial skills, and contribute to physical well-being, while simultaneously reducing sedentary behaviours and some indicators of anxiety.

Natural environments are characterised by a high richness of perceptual stimuli and by a degree of variability that cannot be completely predicted or controlled. This complexity represents an educational resource because it stimulates adaptation, cognitive flexibility, and the ability to interpret new situations. Educational design must therefore avoid two opposite extremes: on the one hand, an idealised and romanticised view of nature; on the other hand, excessive structuring of the experience, which may become even more problematic when combined with intrusive technological mediation. Within this balance, artificial intelligence should assume the role of a discreet and secondary support tool, without replacing the direct relationship between the learner and the environment.

This principle is particularly important in early childhood and during the first years of schooling. At these developmental stages, artificial intelligence should not come

between the child and the natural object, replacing visual, tactile, or manipulative exploration with immediate responses provided by the system. Instead, its use may prove valuable as a tool available to educators for documenting learning processes, collecting evidence, organising materials, or supporting, at a later stage, shared reflection on the lived experience. This leads to a fundamental design principle: direct observation, concrete exploration, and personal description of the experience must always precede interaction with digital tools and artificial intelligence systems.

2.3 Nature, Attention, Well-being, and Motivation

Exposure to natural environments is widely recognised as a factor capable of supporting the restoration of attentional resources, according to Attention Restoration Theory, reducing stress levels, and increasing cognitive and emotional engagement in learning activities (Kuo et al., 2019; Mann et al., 2022). Evidence from studies on child development also shows that regular contact with nature contributes to reducing symptoms associated with attention deficit and hyperactivity, promoting greater stability of sustained attention and strengthening intrinsic motivation towards exploration and discovery (Dankiw et al., 2020).

Within this context, artificial intelligence can play a supportive role when it contributes to reducing barriers to access information, provides personalised feedback, and makes phenomena or patterns that are difficult to observe with the naked eye more interpretable. Conversely, an excessively invasive use of technology risks compromising the learning process by anticipating answers, interrupting the natural exploratory pathway, or transforming discovery into passive consumption of digital content. Consequently, educational design should preserve a degree of productive uncertainty, postponing the intervention of AI until students have had the opportunity to observe, formulate hypotheses, and independently explore the environment.

2.4 Mobile Learning, Augmented Inquiry, and Citizen Science

The use of mobile devices in Outdoor Education contexts enables the real-time integration of direct experience with data collection, organisation, and representation, creating a continuous connection between place, observation, and knowledge. Within the field of citizen science, digital platforms supported by artificial intelligence algorithms facilitate the automatic classification and management of large quantities of environmental observations, while still requiring constant human supervision and validation (McClure et al., 2020).

From an educational perspective, the primary value of these tools does not lie in the automation of recognition processes, but rather in developing students' ability to understand which elements make an observation scientifically reliable. Information such as geolocation, morphological characteristics, photographic documentation, and compliance with data-collection protocols represent essential components of data quality. From this perspective, AI-generated classifications and any anomaly alerts should be considered probabilistic hypotheses requiring verification, rather than definitive answers or unquestionable truths.

2.5 Artificial Intelligence in Education: Functions and Challenges

Applications of artificial intelligence in education include intelligent tutoring systems, generative tools, learning analytics platforms, and environments supporting personalised learning (Zawacki-Richter et al., 2019; Bond et al., 2024). Within the proposed theoretical model, AI assumes a complementary role to educational practice and performs five main functions:

- **Questioning scaffolding**, supporting the transformation of observations into investigable research questions;
- **Differentiation and accessibility**, through the adaptation of texts, glossaries, and teaching materials to different developmental levels and special educational needs;

- **Assisted recognition and classification**, by proposing hypotheses concerning the identification of species, rocks, sounds, or other natural elements;
- **Re-elaboration and synthesis**, supporting the organisation, comparison, and interpretation of collected data;
- **Metacognitive support**, encouraging critical reflection on observation processes, available evidence, and formulated conclusions.

In line with UNESCO recommendations regarding the use of generative artificial intelligence in educational contexts (Miao & Holmes, 2023), the adoption of such tools requires particular attention to privacy protection, algorithmic transparency, and their appropriateness in relation to students' age. In educational services aimed at the 0–6 age group, children's direct use of digital devices should be avoided or strongly limited, favouring forms of "invisible" AI managed by teachers primarily to support pedagogical documentation and educational planning.

2.6 Human-Centred AI and the Principle of Complementarity

The Human-Centred AI approach is based on the idea that artificial intelligence should enhance people's cognitive, decision-making, and reflective capabilities rather than replace them through automation processes. From this perspective, the present framework is based on five fundamental design criteria: necessity, according to which AI should respond to an actual pedagogical need; proportionality, which involves minimising both the amount of data collected and the time spent in front of screens; intelligibility, understood as transparency regarding the functioning and limitations of the tools employed; reversibility, namely the possibility of carrying out activities even in the absence of technology; and verifiability, which requires systematic comparison between AI outputs and empirical experience gained in the field.

Outdoor Education represents a particularly favourable context for developing this form of critical literacy.

The complexity, variability, and unpredictability of natural environments provide continuous opportunities to compare algorithmic responses with direct observation, highlighting both the potential and the limitations of artificial intelligence systems, including possible hallucinations or incorrect classifications.

2.7 A Cyclical Model of AI-Enhanced Outdoor Education

The proposed theoretical framework is configured as a cyclical process consisting of six phases, which can be adapted according to students' age and educational objectives.

The first phase, orientation, involves the presentation of the problem or guiding question, preliminary exploration of the context, and the sharing of safety rules.

This is followed by the anticipation phase, during which prior knowledge is activated and students spontaneously formulate interpretative hypotheses without the support of artificial intelligence, thus valuing autonomous reasoning.

The third phase consists of embodied exploration, which includes direct observation activities, sensory experiences, play, measurements, and the collection of data or samples, promoting learning based on bodily interaction with the environment.

Only afterwards is assisted inquiry introduced, in which AI is used in a targeted manner to formulate classification hypotheses, compare data, suggest connections, or expand the questions that emerged during exploration.

The fifth phase concerns critical validation, during which students compare the outputs generated by artificial intelligence with field observations, naturalist guides, scientific sources, and the judgement of the educator or possible experts, developing verification skills and critical thinking.

Finally, the reflection and dissemination phase involves the re-elaboration of the experience through field journals, concept maps, narratives, reports, presentations, or active citizenship and environmental protection initiatives, transforming the lived experience into shared and reflective knowledge.

3. Objective and Research Questions of the Review

The present systematic review aims to outline the state of the art regarding the integration of Outdoor Education and artificial intelligence across the entire educational pathway, from early childhood to secondary and higher education. The objective is to critically synthesise the available evidence by identifying the main applications of AI, the observed educational benefits, the emerging challenges, and the design conditions that support its pedagogically meaningful and sustainable use.

The review is guided by the following research questions:

- **RQ1.** Which age groups, educational contexts, and Outdoor Education environments are represented in the scientific literature?
- **RQ2.** Which artificial intelligence technologies are employed and for what pedagogical purposes?
- **RQ3.** Which outcomes, in terms of cognitive, motor, socio-emotional, environmental, and epistemic dimensions, are documented in the analysed studies?
- **RQ4.** Which risks, limitations, biases, and ethical issues—such as the datafication of educational processes or the potential reduction of direct sensory observation—are highlighted in the literature?
- **RQ5.** Which design principles emerge as the most effective for guiding the development of an AI-enhanced Outdoor Education model inspired by the principles of Human-Centred AI?

4. Systematic Review Methodology

The review was conducted following the methodological recommendations of the PRISMA 2020 and PRISMA-S standards, with the aim of ensuring transparency, reproducibility, and rigour throughout the process of identifying, selecting, and synthesising scientific evidence.

The search strategy combined terms related to Outdoor Education and nature-based education with keywords associated with artificial intelligence. Specifically, descriptors such as *early childhood outdoor education*, *nature preschool*, *forest kindergarten*, and other terms referring to outdoor educational contexts were included and subsequently combined with the main expressions used to identify different applications of AI in education.

The procedures for screening, eligibility assessment, and study inclusion were documented according to the PRISMA guidelines flow, while the development and documentation of search strategies were carried out in accordance with PRISMA-S standards.

5. Review Results

The qualitative synthesis of the twelve included studies highlights that research on the integration of Outdoor Education and artificial intelligence is still at an early stage, particularly regarding early childhood contexts. Indeed, the available studies show a limited presence of experimental approaches involving direct use of AI by younger children.

The most documented applications instead concern secondary education and research contexts, where artificial intelligence is mainly employed as a tool for data analysis, automated classification of environmental observations, support for citizen science activities, or educational documentation benefiting researchers and teachers. These findings confirm the need to develop specific pedagogical models that enable the integration of AI while respecting students' developmental characteristics and remaining consistent with the principles of Outdoor Education.

6. Experimental Development of the Project

Based on the evidence emerging from the systematic review, a quasi-experimental research programme is proposed, structured into three successive phases, aimed at designing, validating, and evaluating an AI-enhanced Outdoor Education model centred on experiential learning and on the complementary role of artificial intelligence.

6.1 Phase 1: Co-design and Feasibility Study

The first phase is dedicated to the participatory design of the educational model and to assessing its feasibility across different school contexts.

For early childhood education, educational modules focused on nature exploration will be developed, in which artificial intelligence will operate primarily as a support tool for pedagogical documentation and teachers' professional reflection, avoiding direct and continuous interaction by children.

For secondary education, learning pathways will instead be designed around the monitoring of biodiversity, microclimate, and other environmental indicators through citizen science activities supported by AI.

The pilot phase will also enable an assessment of the organisational sustainability of the model, with particular attention to screen exposure time, accessibility of digital tools, and the appropriate balance between autonomous sensory exploration and technological support.

6.2 Phase 2: Quasi-Experimental Study

The second phase involves a quasi-experimental study aimed at comparing three different educational conditions:

Condition A: AI-enhanced Outdoor Education;
Condition B: traditional Outdoor Education without artificial intelligence tools;
Condition C: predominantly indoor-based teaching.

The effectiveness of the three approaches will be assessed through indicators related to primary outcomes, including disciplinary learning, executive functions, motor development, and connection with nature, as well as through secondary outcomes such as sense of agency, the development of critical AI literacy, and socio-emotional regulation.

6.3 Phase 3: Follow-up and Implementation

The final phase of the research programme will focus on assessing the stability of effects over the medium and long term. In particular, it will examine the persistence of learning outcomes, students' ability to independently transfer acquired competences even in the absence of technological support, and the potential impact of the educational experience on the development of ecological awareness and environmentally responsible behaviours.

The results obtained will contribute to validating the proposed model and to identifying operational guidelines for integrating artificial intelligence into Outdoor Education in a way that is consistent with the principles of Human-Centred AI and responsive to the needs of different educational levels.

7. Discussion

The results of the systematic review highlight that the integration of artificial intelligence into Outdoor Education should be conceived according to a logic of complementarity rather than substitution of direct experience in nature.

The available evidence confirms that the main educational benefits of outdoor learning derive from embodied and multisensory interaction with the environment, a dimension that assumes particular relevance during the early years of life. Studies focusing on early childhood outdoor education (Brussoni et al., 2015; Ernst & Burcak, 2019; Dankiw et al., 2020) consistently show that motor, cognitive, socio-emotional, and relational development is closely connected to opportunities for autonomous exploration, free play, and direct manipulation of natural elements.

In light of these findings, the proposed model is based on the principle of technological subsidiarity, according to which artificial intelligence should intervene only when it is capable of expanding opportunities for observation, analysis, and reflection, without replacing movement, sensory perception, or direct experience of the environment. From this perspective, technology assumes the role of cognitive and methodological support, while the process of knowledge construction continues to develop through direct interaction between students and natural contexts.

At later educational levels, the systematic comparison between hypotheses generated by artificial intelligence and evidence collected in the field represents an important opportunity for developing critical thinking skills and AI literacy. The possibility of empirically verifying classifications, predictions, and algorithmic suggestions enables students to understand the probabilistic nature of artificial intelligence models, recognising both their potential and their limitations. In this way, error, uncertainty, and the need for validation become integral components of the scientific learning process.

The theoretical framework developed in this study is therefore based on three fundamental principles: observe first, which prioritises direct observation before the use of digital tools; human in the loop, which keeps educators and students at the centre of decision-making and interpretative processes; and validation required, which requires systematic verification of AI outputs through empirical observation, comparison with authoritative sources, and educational discussion. The integration of these principles allows the centrality of the educational relationship, student agency, and the experiential connection with place to be preserved, preventing technology from assuming a substitutive role in exploration and knowledge-construction processes.

8. Conclusions

The integration of Outdoor Education and artificial intelligence represents a promising perspective for innovating science education, promoting sustainability education, and strengthening digital citizenship competences. However, the evidence analysed suggests that the educational value of AI does not depend on the amount of technology employed, but rather on the quality of its integration within authentic, participatory learning experiences rooted in interaction with the natural environment.

For such integration to be pedagogically effective, it is necessary to preserve the epistemological priority of embodied experience, direct observation, and empirical verification. Artificial intelligence should therefore be conceived as a tool capable of supporting inquiry, expanding interpretative possibilities, and fostering processes of critical reflection, without replacing the role of experience, teachers, or educational relationships.

From early childhood to higher educational levels, an approach consistent with the principles of Human-Centred AI is pedagogically justified insofar as it contributes to more attentive observation, the formulation of more meaningful questions, the critical interpretation of available evidence, and the understanding of the complex and probabilistic nature of scientific knowledge. From this perspective, artificial intelligence does not represent the goal of the educational process, but rather a tool in the service of developing autonomy, critical thinking, and responsibility towards the natural and social environment.

Finally, the research perspectives outlined by the proposed model pave the way for future empirical studies aimed at evaluating the effectiveness of AI-enhanced Outdoor Education across different educational levels and at defining operational guidelines that enable an ethically sustainable, pedagogically grounded, and genuinely complementary use of artificial intelligence in outdoor educational contexts.

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