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Smart Educational Ecosystems: AI-supported modeling for outdoor learning

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Abstract: Learning in external environments is gaining increasing international recognition as a flexible and experiential educational approach capable of integrating observation, inquiry, and digital technologies. This approach promotes active engagement with the surrounding environment and supports the development of transversal and digital competences. Within this framework, modelling—supported by artificial intelligence—plays a crucial role in transforming empirical observations into structured representations that enhance reflection and conceptual understanding. AI tools assist students in collecting, organising, and analysing data gathered outdoors, identifying patterns, and generating visual or conceptual models that sustain higher-order cognitive processes. The combination of modelling, AI, and learning in external environments leads to the creation of intelligent educational ecosystems in which students interact dynamically with space, technology, and knowledge-building processes. This contribution investigates how these elements intertwine to support situated learning, promote autonomy and collaboration, and encourage students to develop a systemic understanding of the phenomena they encounter. The proposed perspective highlights the potential of AI-supported modelling in educational contexts and, through evidence-based literature, develops an "AI-Enhanced Situated Modelling Framework" capable of guiding the design of meaningful, situated, adaptive and digitally mediated learning experiences, enhancing the interaction among learners, data, space and technologies.

Keywords: external learning environments; AI-supported modelling; intelligent educational ecosystems; experiential learning; digital competences

1. Introduction

Outdoor Education (OE) should be understood as an approach through which, at the international level, theories and educational practices are defined by the central role attributed to the outdoor environment as a privileged setting for learning and formation (Farné & Agostini, 2014, p. 10). This educational approach encompasses a broad "variety of pedagogical experiences characterised by active teaching methods that take place in environments outside the school and that are connected to the characteristics of the territory and of the social and cultural context in which the school is situated" (Giunti et al., 2021, p. 5). OE therefore entails a shift in perspective for the entire school context, placing experiential, interdisciplinary and multisensory learning at the centre, as well as the outdoor environment, considered in connection with the indoor one (Farné, Bortolotti & Terrusi, 2018, p. 15).

From this perspective, the term "environment" should be understood as an opportunity for socialisation and learning that involves the use of various "decentralised learning spaces", such as museums, libraries, and natural environments (Frabboni & Zucchini, 1985). Within OE, the underlying pedagogical principles are therefore Kolb's (1984) Experiential Learning and Sobel's (2004) Place-based Education, together with Dewey's pedagogical activism (2014). Indeed, this approach emphasises the central role of the local territory and of the learner, highlighting the importance of the learner's doing and thinking in the learning process, as well as of authentic experiences. In this sense, it draws upon the well-known Kolb learning cycle, which includes four stages: concrete experience, reflective observation, abstract conceptualisation, and active experimentation.

OE can thus be regarded as an educational approach characterised by flexible timing and modes of implementation, capable of responding to the diverse needs and learning rhythms of students. It also represents a highly innovative and inclusive model, as each learner can identify their own way of understanding and practically carrying out an activity, which consequently becomes tailored to individual needs (Bortolotti, Schenetti & Telese, 2020). However, OE is not without its limitations, including the extended time required and the increased workload for teachers; weather conditions; families' concerns regarding students' safety; the distance from suitable outdoor spaces; and the lack of equipment and transport. Nevertheless, these challenges may be overcome if attention is paid to the numerous benefits that OE offers in terms of personal and social development (Orlandini, 2020), as well as to the opportunities it provides for teachers to act as mediators between students' interests and the intended learning objectives. In this role, teachers also function as a filter between the environment and the learner, capable of promoting the sharing of experiences and encouraging discussion of real-life situations (Bortolotti, 2019).

2. Materials and Methods

The study originated from the need to explore the role of a third mediator that teachers may introduce into active outdoor teaching in order to further enhance the benefits offered by Outdoor Education (OE), namely Artificial Intelligence (AI). In particular, the research focused on how AI, within Outdoor Education, may contribute to and support the modelling function provided by the outdoor environment.

Given the originality of the topic addressed, a systematic literature review was conducted to explore the intersection between modelling, AI, and Outdoor Education. To this end, the search engines selected were Google Scholar and ERIC, while the keywords used were: "modeling" OR "modelling" AND "artificial intelligence" AND "outdoor education" AND "school".

The inclusion criteria adopted were: the relevance of the studies to the research objective; the language of publication, selecting those written in English or Italian; the availability of the full text; and the publication period, considering the time frame between 2020 and 2025. By applying these criteria, the initial corpus consisted of a total of 634 articles, of which 20 were ultimately selected and analysed (Moher et al., 2009).

3. Results

The present study aims to address the gap in the literature concerning the role of Artificial Intelligence (AI) in Outdoor Education (OE). Indeed, the limited number of articles relevant to the topic under investigation clearly indicates the need for further research. An increasing number of studies have addressed this subject, particularly following the COVID-19 pandemic and the digital transformations of contemporary society (Razani et al., 2024), mainly examining the relationship between OE and augmented reality (AR) or virtual reality (VR) devices, with particular attention to how these are employed by teachers (Razani et al., 2024; Hills et al., 2023; Maddison et al., 2025).

In this regard, studies show that Artificial Intelligence can lead to improvements in learning and in the observation of the environment, as several sensory channels are engaged simultaneously (Garden, 2024; Coppola et al., 2021; O'Neill et al., 2024; Cotic et al., 2020; Mettis et al., 2023; Anderson et al., 2015; Sultana & Hawken, 2023; Krzic, Wilson & Hoffman, 2018). Positive effects have also been observed among students in terms of motivation, interest, and enjoyment in learning (O'Neill et al., 2024; Coppola et al., 2021b; Evagelou et al., 2025; Arvola et al., 2021; Zhao, Liu, Zhu & Qi, 2021; Mourelatos & Vrigkas, 2025). Moreover, the integration of AI in OE experiences appears to foster the development of life skills, particularly problem-solving, as well as concentration and attention (Coppola et al., 2021). Indeed, students seem to feel more actively involved in their own learning process and more connected with nature and places through immersive and interactive experiences carried out in natural environments and supported by digital technologies (Coppola et al., 2021; Coppola et al., 2021b; Elvin, 2022; Sultana & Hawken, 2023).

Other benefits deriving from the integration of AI and OE include improved communication among participants in large outdoor spaces (Coppola et al., 2021; Anderson et al., 2015); greater interaction and collaboration among students (Coppola et al., 2021; Coppola et al., 2021b; Evagelou et al., 2025; Sultana & Hawken, 2023); multiple interdisciplinary connections (Coppola et al., 2021; Coppola et al., 2021b); and the presence of several moments dedicated to conceptualisation and reflection on the experience, thereby creating an interaction between outdoor activities and classroom learning (Arvola et al., 2021).

Furthermore, AI enhances the inclusive nature of OE, as it improves the processes of individualisation and personalisation of active outdoor learning, enabling the full participation of individuals with special educational needs, as well as access to and exploration of environments—both natural and otherwise—even "remotely", through adaptive experiences (Coppola et al., 2021; Coppola et al., 2021b; Sultana & Hawken, 2023; Molinario et al., 2025; Luckin et al., 2016; Elvin, 2022).

Another aspect to consider is that AI enables the collection, sharing, and analysis of data, materials, and outdoor experiences, offering students the opportunity to make recordings and take photographs, which can later be discussed and analysed (Arvola et al., 2021; Anderson et al., 2015). It also allows learners to interact with the physical world in new ways by overlaying digital information onto reality. Indeed, incorporating digital and multimedia objects so that they overlap with the physical environment enables the exploration of certain aspects in greater depth, such as the history of places and the understanding of complex phenomena (Arvola et al., 2021; Luckin et al., 2016). Mobile Augmented Reality (MAR), in particular, can help students interact with and understand their environment and objects within it by providing additional

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contextual information and enabling them to connect theoretical aspects with concrete and real experiences, thus increasing the likelihood of a deeper understanding of abstract concepts (Sultana & Hawken, 2023).

It should also be noted that the use of immersive devices can help overcome barriers related to the lack of access to suitable green spaces for outdoor educational activities (Jerowsky, 2024), as well as geographical, economic, and social barriers (Elvin, 2022), and cultural or emotional barriers (Sultana & Hawken, 2023). The integration of AI into OE may also support teachers' professional competencies and enrich teaching practices by providing additional real-time information about the environment, plants, and animals (Jerowsky, 2024; Mercier et al., 2023).

The findings highlight several ways in which AI—understood as a modelling tool—can be integrated into Outdoor Education:

- **Digitally mediated practices**, such as podcasting, digital recordings, and gamification, which encourage and enhance problem-solving and the sensory experiences that nature can offer, as well as engagement and motivation. Examples of nature-based games include Wobble, Ambient Wood, Pokémon Go, and Camelot.
- **Multimodal sensors** capable of detecting movement, temperature, or sound, making natural spaces more interactive, effective, and engaging for students. An example is the augmented reality platform Science Spots, which enables students to interact with real and virtual objects to better understand scientific concepts.
- **Multimedia resources**, such as videos, images, and interactive simulations, which offer opportunities to develop students' creativity and communication skills by providing a wide range of informational sources;
- **Augmented reality tools**, such as Google Glass, a pair of smart glasses equipped with a system that projects information within the lenses, allowing users to view their surroundings while overlaying relevant data onto elements and spaces in the real world;
- **Applications** that enable students to explore, collect, and analyse elements of the natural world, such as iNaturalist, Nature Play, Nature Passport, Savannah, Pl@ntNet, and Agents of Nature;
- **GPS-based applications** that allow students to navigate towards location-specific educational resources—such as habitats, landmarks, tourist information, and wildlife observation sites—by sending and sharing GPS coordinates. Examples include BirdNET, iBird Plus Yard Guide, and eBird by the Cornell Lab, which help students identify birds based on location, colour, shape, habitat, and other characteristics;
- **Mobile data collection**, involving the use of mobile devices to gather, compare, and geolocate data collected during fieldwork;
- **Virtual field trips**, consisting of virtual representations of fieldwork locations (Sultana & Hawken, 2023; Wang et al., 2020).

In conclusion, OE implies the use of modelling, since within this approach, both peers and teachers become models who promote reflection on the educational experiences undertaken, as well as pro-social and pro-environmental behaviours. This contribution seeks to highlight the potential existence of a third model within OE, namely AI and new digital devices—for example, intelligent virtual tutors—which can guide students in outdoor learning experiences (Nikbay & Bavlı, 2024; Pierce, 2021; Luckin et al., 2016) or support teachers in modelling activities during OE.

Alongside the numerous advantages described above and summarised in the table below (Table 1), several challenges remain, including organisational, logistical, and practical issues (Arvola et al., 2021; Millward et al., 2024); the need for adequate teacher training; the commitment required to identify suitable locations for outdoor educational experiences; concerns regarding students' safety (Arvola et al., 2021); possible adverse weather conditions; unequal access to technology and internet connectivity (Millward et al., 2024); and the risk of weakening the connection with nature, potentially undermining authentic experiences and a deep relationship with the environment (Cuthbertson et al., 2004).

Table 1. Summary of findings on the role of AI in Outdoor Education

Area/Domain	Main results	Reference studies
Multisensory learning	Improving learning and observation processes through multisensory modalities	Garden, 2024; Coppola et al., 2021; O'Neill et al., 2024; Cotic et al., 2020; Mettis et al., 2023; Anderson et al., 2015; Sultana & Hawken, 2023; Krzic et al., 2018
Motivation and interest	Increased motivation, interest and enjoyment in learning among students	O'Neill et al., 2024; Coppola et al., 2021b; Evangelou, 2025; Arvola et al., 2021; Zhao et al., 2021; Mourelatos & Vrigkas, 2025
Life skills	Development of transversal skills, particularly problem-solving	Coppola et al., 2021
Attention and concentration	Increased concentration and attention during outdoor activities	Coppola et al., 2021
Involvement and relationship with nature	Greater engagement in learning, immersive experiences and strengthening the connection with nature	Coppola et al., 2021; Coppola et al., 2021b; Elvin, 2022; Sultana & Hawken, 2023
Collaboration	Promoting collaborative learning among students	Coppola et al., 2021; Anderson et al., 2015
Communication	Improving communication in open spaces	Coppola et altri, 2021; Coppola et altri, 2021b; Evangelou, 2025; Sultana & Hawken, 2023
Interdisciplinarity	Facilitating integration between different disciplines	Coppola et al., 2021; Coppola et al., 2021b
Inclusion	Greater accessibility for students with disabilities; person-	Coppola et al., 2021; Sultana & Hawken, 2023; Mo-

	alisation and individualisation of learning; possibility of visiting natural sites remotely	linario et al., 2025; Luckin et al., 2016; Elvin, 2022
Data collection and reflection	Support for the collection, sharing and discussion of data (photos, recordings) and facilitation of reflection on the experience	Arvola et al., 2021; Anderson et al., 2015
Conceptual understanding	AR and immersive technologies help connect theory and practice and understand complex or abstract concepts	Arvola et al., 2021; Luckin et al., 2016; Sultana & Hawken, 2023
Overcoming barriers	Immersive media allows us to overcome geographical, economic, social and access barriers to green spaces	Jerowsky, 2024; Elvin, 2022; Sultana & Hawken, 2023
Support for teachers	Technologies and AI support teachers' skills by providing information on the environment, flora and fauna	Jerowsky, 2024; Mercier et al., 2023
AI-supported modeling	Intelligent virtual tutors and digital tools can support modelling and reflection processes in outdoor activities	Nikbay & Bavlı, 2024; Yu & Pierce, 2021; Luckin et al., 2016
Critical issues and limitations	Logistical and organisational problems, teacher training, safety, weather conditions, access to technology and the risk of reducing direct connection with nature	Arvola et al., 2021; Millward et al., 2024; Cuthbertson et al., 2004

4. Discussion

Outdoor Education (OE) is gaining increasing international recognition as a flexible and experiential educational approach capable of integrating observation, inquiry, and Artificial Intelligence (AI). The combination of modelling, AI, and OE leads to the creation of intelligent educational ecosystems in which students interact dynamically with space, technology, and processes of knowledge construction.

This contribution highlights the potential of AI-supported modelling within outdoor educational contexts. Starting from the relevant literature, it proposes the development of an "AI-Enhanced Situated Modelling Framework", designed to guide the planning of meaningful learning experiences that are situated, adaptive, autonomous, collaborative, and digitally mediated.

In conclusion, integrating OE with AI tools makes it possible to provide multiple models that guide students in outdoor learning experiences and to enhance learning, engagement, interdisciplinarity, interaction, collaboration, and the development of students' transversal and digital competences.

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