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From Algorithms to Awareness: AI-Enhanced Physics Education in the Framework of Education for Sustainable Development

Hanan Zaki Alhusni[1*], Binar Kurnia Prahani[1], Titin Sunarti[1], Madlazim[1], Riski Ramadani[1], Muhammad Rey Dafa Ahmadi[2]

[1]Universitas Negeri Surabaya, Surabaya, Indonesia
[2]University of Glasgow, Glasgow, Scotland

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ABSTRACT

Objective: *This study synthesizes research on the integration of Artificial Intelligence (AI) in physics education within the framework of Education for Sustainable Development (ESD). It aims to map current trends, highlight educational opportunities, and identify research gaps regarding AI's potential to enhance learning outcomes and foster sustainability competencies.* ***Method:*** *A Systematic Literature Review (SLR) was conducted following PRISMA 2020 guidelines. A total of 48 peer-reviewed studies published between 2015 and 2025 were collected from major academic databases and Google Scholar using Boolean search strings combining terms related to AI, physics education, and ESD. The data were analyzed thematically to identify recurring patterns in AI technologies, physics content areas, ESD dimensions, methodologies, and educational outcomes.* ***Results:*** *The findings indicate that machine learning, deep learning, intelligent tutoring systems, and AI-powered virtual laboratories are the most common applications in physics education. These technologies were primarily applied in mechanics, electricity, and energy-related topics, with limited studies focusing on environmental physics. While AI consistently improved motivation, achievement, and critical thinking, the integration of broader ESD competencies remained uneven, with environmental literacy, social responsibility, and ethical reasoning less frequently addressed.* ***Novelty:*** *This study contributes by linking AI, physics education, and ESD, which are often studied separately, and proposes a conceptual roadmap to align AI integration with sustainable education goals.*

INTRODUCTION

Physics education in the 21st century is expected not only to serve as a medium for transferring scientific concepts but also as a platform for developing critical thinking, problem-solving, and responsible decision-making skills (Roll & Wylie, 2016; Malik et al., 2018; Ahmad et al., 2021; Piloto et al., 2022; Ahmad et al., 2022). Beyond this, physics education is envisioned to play a pivotal role in shaping a generation that is aware of sustainability, in line with the vision of Education for Sustainable Development (ESD) (Jauhariyah et al., 2021; Kaack et al., 2022; Adeuji & Shiitu, 2023; Kamalov et al., 2023). This expectation arises from the global urgency to prepare students for complex challenges such as energy crises, climate change, and the overexploitation of natural resources (Ghahramani, 2015; He, 2021; Irrgang et al., 2021; Krenn et al., 2022; Kaack et al., 2022). Therefore, physics education is required not only to teach the laws of nature but also to instill awareness of the interconnectedness between science and the sustainability of life (Angelis et al., 2023; Jia et al., 2024).

In reality, the rapid advancement of digital technology, particularly artificial intelligence (AI), has opened new opportunities for transforming physics learning (Ilkka, 2018; Murphy, 2019; Holmes, 2020; Doroudi, 2023; Almasri, 2024; Jia et al., 2024). AI

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