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Artificial Intelligence in Physics Learning for Education for Sustainable Development: A Bibliometric Analysis

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Sections Info	ABSTRACT
	Objective: *This study aims to map the global research landscape on Artificial Intelligence (AI) in physics education within the framework of Education for Sustainable Development (ESD) using a bibliometric approach. The objective is to identify publication trends, key contributors, collaborative networks, and emerging themes that define the development of this research domain.* ***Method:*** *The analysis was based on 4,814 documents retrieved from the Scopus database for the period 2015–2025. Data preprocessing included deduplication and keyword harmonization. Bibliometric analysis was conducted using performance indicators (publication output, influential authors, journals, countries, institutions) and science mapping (co-authorship, co-occurrence, co-citation) with VOSviewer and Bibliometrix.* ***Results:*** *Findings reveal three phases of publication dynamics: initial emergence (2015–2018), growth (2019–2021), and accelerated expansion (2022–2024), with a peak in 2024. The United States dominates global output, followed by China and Indonesia. Physics-focused journals such as Physical Review Physics Education Research and Journal of Physics: Conference Series serve as major outlets. Co-authorship networks show a core cluster in Europe and North America, while Asian and Global South researchers are increasingly active. Thematic mapping highlights clusters on AI-enabled assessment, machine learning, Large Language Models (LLMs), and sustainability-oriented physics education.* ***Novelty:*** *This paper provides a systematic overview of the intellectual structure and thematic evolution of AI-based physics education for ESD. It identifies gaps, including limited cross-country collaboration, low experimental validation, and uneven global participation, while highlighting opportunities for ethical, inclusive, and sustainability-aligned AI integration in future physics learning.*

INTRODUCTION

Physics education plays a central role in shaping scientific literacy, critical thinking skills, and the younger generation's readiness to address the global challenges of the 21st century. However, physics learning often faces obstacles due to its abstract nature, low student engagement, and limitations in connecting theory with real-world applications (Prayogi & Verawati, 2024; Alhusni et al., 2025). Along with digital transformation, artificial intelligence (AI) is increasingly being adopted in education. AI enables personalized learning, automated feedback, data-driven analytics, and even the provision of adaptive brilliant tutors (Zawacki-Richter et al., 2019; Donthu et al., 2021). In the context of physics education, the application of AI includes the use of machine learning to predict student performance, natural language processing for open-ended response analysis, and large language models such as ChatGPT for formative assessment and conceptual feedback (Kortemeyer, 2023; Yeadon & Hardy, 2023; Wan & Chen, 2024). At the same time, the international community is promoting the Education for Sustainable Development (ESD) agenda, integrated into the Sustainable Development Goals (SDGs). ESD emphasizes the development of sustainability competencies such as