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Bibliometric Analysis of Earth Science Physics Learning in Higher Education: Challenges, Innovations, and Contributions to Education for Sustainable Development

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Sections Info	ABSTRACT
	Objective: This study aims to provide a comprehensive bibliometric analysis of earth science and physics learning in higher education within the framework of Education for Sustainable Development (ESD). The objectives are to identify research trends, major contributors, collaboration patterns, and thematic focuses that define the development of this field. *Method:* Data were collected from the Scopus database (2015–2025) using keywords related to earth science, physics learning, higher education, and sustainability. After screening, 413 relevant documents were analysed using Bibliometrix and VOSviewer to map publication trends, influential journals, key authors, institutional contributions, and keyword co-occurrence networks. *Results:* The findings reveal three phases of publication dynamics: early decline (2015–2017), rapid growth (2018–2019), and consolidation (2020–2025). The Journal of Geoscience Education dominates as the main publication source, while the United States and Indonesia emerge as the leading contributors. Thematic analysis highlights two clusters: pedagogical innovation and curriculum transformation for sustainability competencies, and the integration of technology (AI, STEM, computing) in science education. Despite increasing international collaboration, networks remain fragmented. *Novelty:* This study is the first bibliometric mapping that specifically connects earth science and physics learning with the ESD agenda. It identifies research gaps, particularly the lack of integration of sustainability dimensions in physics pedagogy, uneven global collaboration, and limited exploration of digital innovations for ecological literacy.

INTRODUCTION

Higher education plays a central role in realising sustainable development, particularly through the integration of Education for Sustainable Development (ESD), which has been promoted globally since UNESCO's Decade of Education for Sustainable Development in 2005–2014 (Tilbury, 2011; UNESCO, 2014). This agenda is reinforced in the Sustainable Development Goals (SDGs), particularly target 4.7, which emphasises the importance of equipping young people with sustainable competencies (Wiek et al., 2011; Rieckmann, 2012; UNESCO, 2014). A number of studies show that universities act as agents of change capable of linking scientific knowledge with concrete action (Stephens et al., 2008; Fadeeva & Mochizuki, 2010; Filho et al., 2015). This emphasis has encouraged more research on ESD, both in the form of policy analysis and curriculum implementation (Scott, 2002; Scott & Gough, 2003; Reid & Scott, 2006)