JESTRA

Journal of Education for Sustainability and Transformation
Volume 2, Number 1, 2026.
e_ISSN: xxxx-xxxx
https://journal.serral.org

Development of an Environmental-Based Robotic Learning Media: Intelligent Object Sorter (ELIO) for Pre-Service Physics Teachers

Boris Agung Ramadhan[1*]
[1] Universitas Negeri Jakarta, INDONESIA

Article Info
Keywords:

Educational robotics
Environmental Physics learning
Sustainable Development Goals
Pre-service physics teachers
Bibliometric analysis

**** Corresponding author:***
boris_1302622043@mhs.unj.ac.id
Boris Agung Ramadhan

Abstract

ABSTRACT
Rapid technological advancements and the urgent need to align education with the 2030 Sustainable Development Goals require innovative, interactive approaches in environmental physics. Traditional instruction often struggles to connect abstract theoretical concepts with real-world sustainability challenges. Consequently, this study explores research trends regarding the integration of robotics, artificial intelligence, and Android technologies in education to establish a comprehensive scientific foundation for developing the Environment Learning Intelligent Object Sorter (ELIO). Employing a bibliometric approach, publication data from 2005 to 2025 were extracted from the Scopus database and analyzed to identify dominant themes, publication trajectories, and knowledge gaps. The results reveal an exponential surge in scientific production and citation impact starting in 2020. However, the findings also expose a profound geographical divide, with research heavily dominated by the United States and China. Furthermore, current literature remains predominantly anchored in technical engineering venues, lacking explicit pedagogical integration for environmental sustainability. In conclusion, this study confirms a critical gap in the holistic application of educational robotics, providing an evidence-based justification for designing the ELIO prototype. This research enriches the theoretical intersection of cyber-physical systems and physics education, while offering strategic policy insights to address global educational inequities and guiding future empirical classroom implementations.

Received: 08 November 2025; **Received in revised form:** 11 December 2025**; Accepted:** 03 January 2026
To cite this article: Ramadhan, B. A. (2026). Development of an environmental-based robotic learning media: Intelligent Object Sorter (ELIO) for pre-service physics teachers. *Journal of Education for Sustainability and Transformation*, 2(1), 8-18.

INTRODUCTION

Rapid technological advancement, particularly the rise of artificial intelligence and digital technology, has profoundly transformed the educational landscape, demanding a shift towards more interactive and student-centered learning environments (Fombona et al., 2025). In the context of global challenges, aligning education with the 2030 Sustainable Development Goals (SDGs) has become an urgent priority, positioning education as a vital catalyst for cultivating environmental awareness and resilience (Wati et al., 2024). Environmental physics, as an applied discipline, provides the fundamental scientific framework necessary for understanding complex ecological dynamics and developing sustainable technologies (Nuroso et al., 2019). However, traditional physics instruction often relies on abstract, theoretical approaches that struggle to connect conceptual knowledge with real-world environmental issues, leaving students ill-equipped to address twenty-first-century sustainability challenges (Ajibudiarta et al., 2025).

Consequently, integrating advanced technologies into environmental physics education is crucial to transforming prospective teachers into active problem solvers and agents of sustainable change (Simanjuntak et al., 2025).

Recent literature highlights the immense potential of integrating educational robotics and mobile technologies into STEM (Science, Technology, Engineering, and Mathematics) disciplines (Ouyang & Xu, 2024). Educational robotics serve as an effective cognitive tool that visualizes abstract physics concepts through hands-on experimentation, thereby significantly improving students' conceptual understanding (Ferrarelli & Iocchi, 2021). Furthermore, the integration of the Internet of Things (IoT) and Android-based interactive multimedia provides adaptive learning platforms that enhance critical thinking, computational skills, and scientific literacy (Matsun et al., 2022). Studies demonstrate that these intelligent systems not only increase student motivation and engagement but also facilitate seamless, self-directed learning across various formal and informal settings (Sung et al., 2016). By combining artificial intelligence algorithms with physical robotic models, educators can create dynamic learning experiences that promote collaborative problem-solving and proactive environmental stewardship (Haidegger et al., 2023).

Despite the proven efficacy of educational technologies, significant gaps remain in the current literature regarding their holistic application in physics education (Wang et al., 2023). A major limitation is that most prior studies focus exclusively on the mechanical assembly of generic robotic kits or isolated technical skills, rather than adopting a multidisciplinary approach that explicitly connects robotics with urgent environmental sustainability issues (Windrawan et al., 2024). Additionally, empirical research assessing the impact of Education for Sustainable Development (ESD) competencies on students' environmental empathy through integrated technology remains underexplored, particularly in developing nations (Sari et al., 2025). Moreover, existing interactive media often fail to synergize physical modeling with real-time, adaptive cognitive evaluation, leaving a void in pedagogical tools capable of providing contextual, immediate feedback during practical environmental physics tasks (Zhu et al., 2020). The lack of comprehensive frameworks for implementing these integrated technologies hinders the ability of prospective teachers to effectively translate sustainability concepts into actionable classroom practices (Anwar et al., 2019).

Addressing these limitations is critical for modernizing physics education and responding to both academic and societal needs (Nuroso et al., 2020). Developing an innovative, technology-driven learning medium that fuses robotics, artificial intelligence, and Android interfaces offers a strategic solution to bridge the theory-practice gap in environmental physics (Marta et al., 2025). Such an integrated system provides an immersive, contextualized learning experience that enables students to directly interact with and manipulate physical variables related to environmental challenges (Saputra et al., 2021). Cultivating these advanced pedagogical instruments is essential for equipping prospective physics teachers with the interdisciplinary competencies required to foster environmental empathy and twenty-first-century skills in their future students (Valderrama et al., 2024). Ultimately, this technological integration supports the broader objective of realizing the Sustainable Development Goals by transforming theoretical physics knowledge into practical, sustainability-oriented actions (Velempini, 2025).

Based on the established rationale, the primary objective of this research is to design, develop, and evaluate an innovative, environment-based robotic learning media integrated with an Android application for environmental physics education. Specifically, this study aims to produce a valid, practical, and highly effective educational tool that enhances prospective physics teachers' critical thinking, scientific literacy, and problem-solving capabilities. Furthermore, the research hypothesizes that the implementation of this integrated robotic media will significantly improve students' environmental awareness and their capacity to practically apply physics concepts to real-world sustainability challenges.

METHOD

This study employs a bibliometric approach to systematically explore the development and research trends related to the integration of robotics, artificial intelligence, and Android-based technologies in environmental physics education. The primary focus of this research is directed at identifying dominant themes, research patterns, and knowledge gaps within the existing literature. This analysis is intended to provide a comprehensive scientific foundation that supports the development of innovative learning media aligned with current educational and technological demands.

All bibliographic data were collected from the Scopus database, which is recognized as one of the most comprehensive sources of peer-reviewed scientific publications. The use of this database ensures that the selected articles represent high-quality and globally indexed research relevant to educational technology and physics learning. The publication range was defined from 2005 to 2025 to capture the long-term evolution of research trends while still incorporating recent developments in the field.

The keywords used in this study were carefully selected to represent both the technological and educational dimensions of the research topic. These keywords include robotic, which reflects the technological aspect related to the use of robotic systems as learning media; environmental learning, which emphasizes the contextual focus on environmental-based physics education and sustainability issues; and education, which highlights the broader pedagogical framework in which these technologies are implemented. This combination of keywords enables the retrieval of relevant literature that not only addresses the application of robotics technology but also its role in supporting environmental awareness and enhancing learning processes within educational settings.

RESULTS AND DISCUSSION

Results:

Research on the development of environmental-based robotic learning media, particularly the Intelligent Object Sorter (ELIO) aimed at enhancing pre-service physics teachers’ understanding of environmental issues and strengthening their technological and problem-solving skills, has shown a growing trend during the period 2005–2025. One way to understand the evolution of this field is to analyze the stages of system development and implementation. The results obtained from each stage provide important insights into the effectiveness and functionality of the developed system. This pattern can be observed in Figure 1.

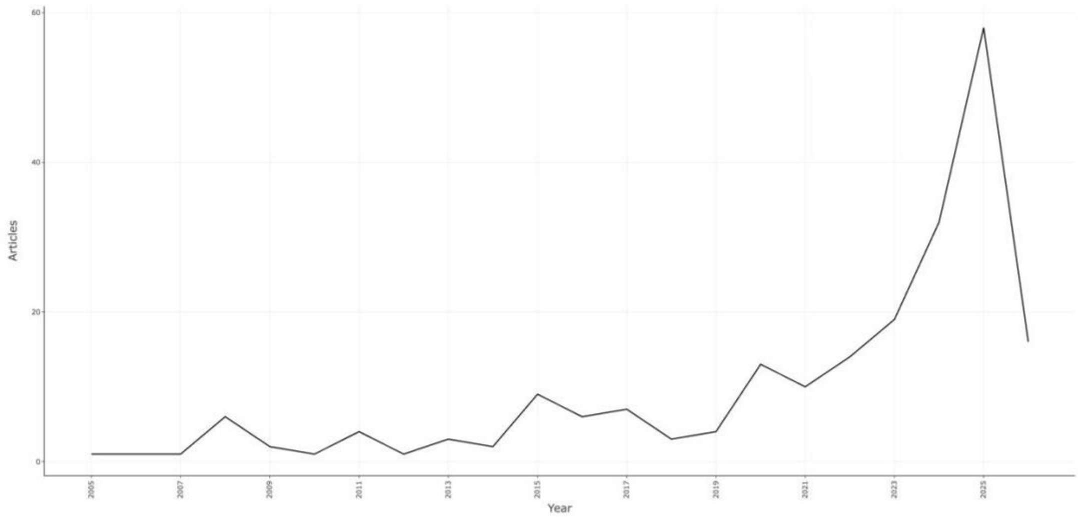

Figure 1. Annual Scientific Production

As shown in the graph, the initial phase of research in this domain was characterized by notably low and stagnant output. Between the years 2005 and 2014, the annual publication rate fluctuated minimally, consistently remaining between zero and five articles per year, which indicates that the intersection of these specific technological and pedagogical themes was still in its nascent stages and garnering limited attention. Following this initial stagnation, a transitional phase of gradual growth began around 2015; from 2015 to 2019, the annual scientific production experienced minor upward shifts, signaling a growing, albeit slow, recognition of the topic's relevance.

Building upon this gradual early growth, the most prominent feature of the annual production data is the exponential growth phase that aggressively took hold starting in 2020. The publication volume surpassed ten articles in 2020 and continued a steep upward climb, reaching nearly thirty articles by 2024 and peaking dramatically at nearly sixty articles around the 2024–2025 window. This exponential surge highlights a massive, recent academic boom, marking the topic as a highly trending area of current scientific inquiry. Furthermore, the sharp downward trend visible at the very end of the graph simply represents the incomplete indexing data for the ongoing year of 2025, rather than a genuine decline in research interest.

Corresponding to this massive surge in publication volume, the academic impact of this literature also experienced highly variable trends. An overview of the average citations per year is presented. Based on the data, the citation impact during the first decade of the observed timeframe was remarkably low, mirroring the early trends in publication volume, as shown in Figure 2. From 2005 through 2017, the average citation rate remained relatively flat, hovering just above zero and never exceeding two citations per year, This prolonged period of minimal citations suggests that the early literature either had a limited audience or had not yet established the foundational paradigms necessary to influence subsequent research comprehensively, as shown in Figure 2.

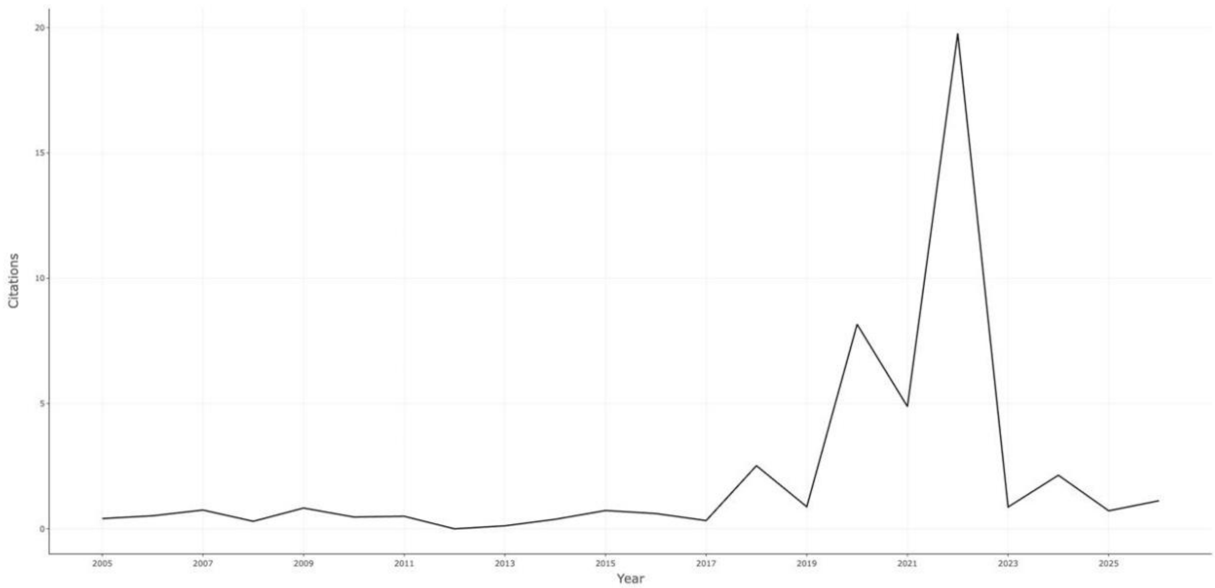

Figure 2. Average Citation Per Year

A significant shift in this academic reception occurred as the timeline approached the year 2020, leading into a period of high volatility and peak impact. In 2020, the average citation rate experienced its first major spike, reaching approximately eight citations per year, before hitting an unprecedented and sharp peak of exactly twenty average citations per year in 2022. This remarkable surge indicates that the research circulating during the 2020–2022 window contained highly influential findings that resonated strongly across the academic community. Following this massive peak, the average citation rate experienced a precipitous decline to below five citations per year between 2023 and 2025; however, this sharp decrease is a standard pattern associated with the chronological lag inherent in academic referencing for newly published articles, rather than a decrease in the quality of the research.

Understanding the geographical origins of this impactful research further contextualizes these academic trends. An overview of the country scientific production is presented. Based on the data, the global geographical distribution reveals a clear duopoly in research leadership, as shown in Figure 3. The United States and China are distinctly highlighted with the darkest shades of blue, indicating that they are the most dominant and prolific countries in terms of generating indexed publications, The heavy concentration of research in these two nations perfectly aligns with their global standing as primary hubs for technological innovation, artificial intelligence research, and advanced educational infrastructure, as shown in Figure 3.

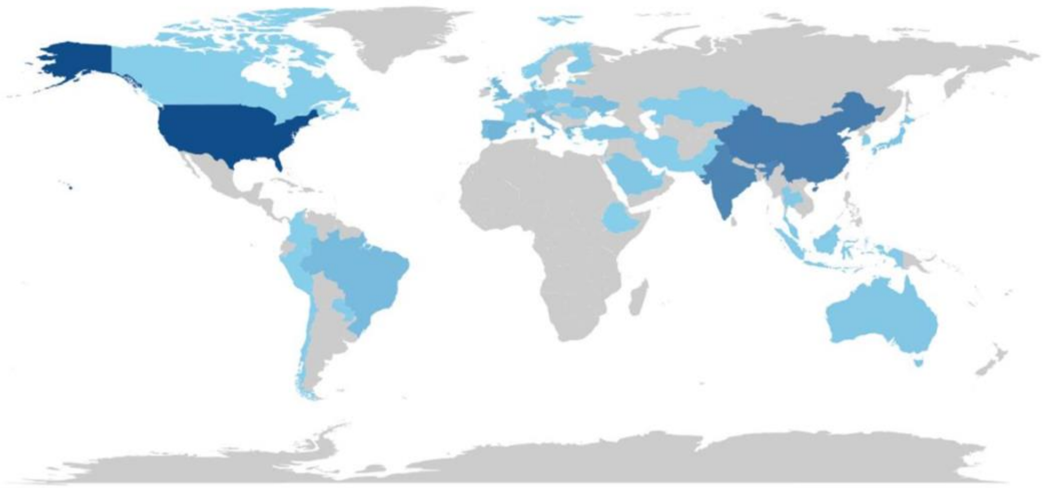

Figure 3. Country Scientific Production

Beyond these two leading nations, the map illustrates a stark contrast between a moderately active secondary tier and completely underrepresented regions. A secondary tier of moderate scientific production is distributed across several key regions globally, including India and Australia in the Asia-Pacific, Canada in North America, Brazil in South America, and several nations across the European continent. Conversely, vast expanses of the global map particularly large portions of the African continent, Central Asia, and parts of South America and Eastern Europe are shaded in grey, denoting minimal to zero indexed scientific production. This significant gap exposes a notable digital and academic divide, suggesting that the implementation of advanced robotics in environmental education remains highly concentrated in developed or rapidly developing economies.

Finally, examining where this geographically diverse research is disseminated highlights the core disciplines driving this field. An overview of the most relevant publication sources is presented. Based on the data, the literature is heavily anchored in engineering and computer science publication venues, as shown in Figure 4. The top contributor by a significant margin is *Lecture Notes in Networks and Systems*, which accounts for the highest volume with eighteen published documents, followed closely by *Lecture Notes in Computer Science* with nine documents, The prominence of these technical proceedings indicates that much of the foundational research is primarily driven by technological development and systems engineering, as shown in Figure 4.

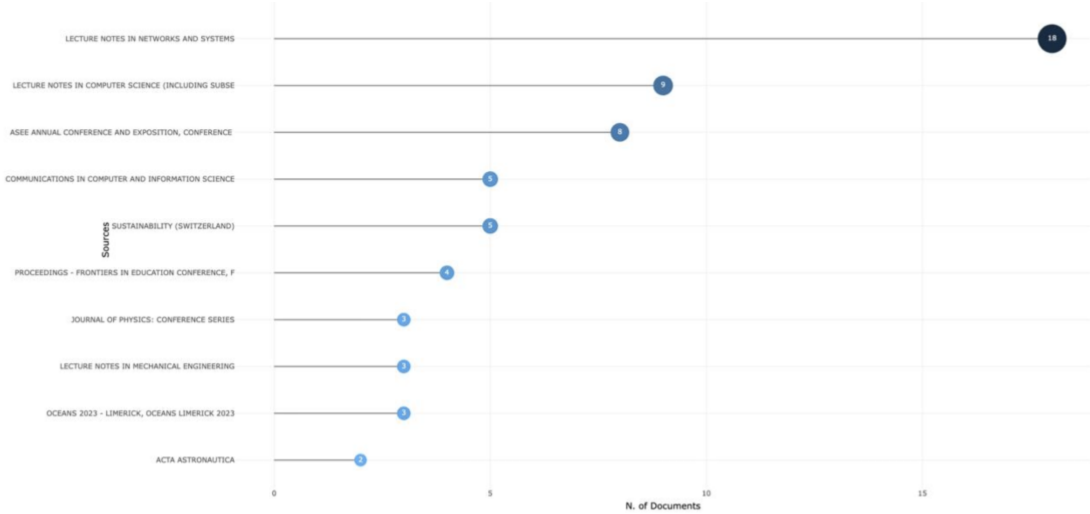

Figure 4. Most Relevan Source

While technical venues dominate, the next tier of relevant sources demonstrates a vital intersection of technology with pedagogical and sustainability-focused platforms. The *ASEE Annual Conference and Exposition* contributes eight documents, firmly linking the technological research to engineering education, while *Communications in Computer and Information Science* and the journal *Sustainability (Switzerland)* each contribute five documents. The strong presence of sustainability journals confirms that a substantial portion of this literature is being specifically framed within the context of global environmental goals. Additionally, niche venues such as the *Proceedings Frontiers in Education Conference* and the *Journal of Physics: Conference Series* further emphasize the multidisciplinary application of these technologies in formal science and physics education.

Discussion:

This study's bibliometric findings reveal a significant alignment with the theoretical frameworks emphasizing the integration of advanced technologies to meet the 2030 Sustainable Development Goals (SDGs). The exponential growth phase in scientific production that aggressively took hold starting in 2020 confirms a growing global recognition of the need for interactive, student-centered learning environments. However, the analysis of publication sources reveals that the literature remains heavily anchored in engineering and computer science venues, such as *Lecture Notes in Networks and Systems*. This indicates an inconsistency in the broader pedagogical landscape: while the technology is advancing rapidly, its holistic application within specific educational contexts like environmental physics is still in its nascent stages and overly focused on technical development rather than comprehensive pedagogical integration. Furthermore, the geographical mapping exposes a profound digital and academic divide, with the United States and China dominating scientific production, while vast regions in Africa and Central Asia exhibit minimal to zero indexed research. This empirical phenomenon highlights systemic inequalities in global STEM education and access to advanced robotic learning tools.

From a theoretical perspective, this study contributes to the development of knowledge by demonstrating how the intersection of artificial intelligence, robotics, and mobile technologies can reconstruct environmental physics education, bridging the persistent theory-practice gap. It broadens the conceptual framework of physics education to explicitly include cyber-physical systems as cognitive tools for environmental empathy. Practically, the findings provide a robust, evidence-based foundation for the direct application and design of real-world pedagogical tools, specifically supporting the development of the Environment Learning Intelligent Object Sorter (ELIO). By utilizing accessible Android-based interfaces combined with robotics, educators can facilitate seamless, self-directed learning in practical settings. From a policy perspective, the stark geographical disparities identified in the data provide strategic input for educational decision-makers. Policymakers and international educational bodies must prioritize infrastructure funding and curriculum development in underrepresented regions to ensure that the integration of robotics for environmental sustainability is a globally equitable endeavor rather than a privilege of developed nations.

This study offers significant novelty by systematically mapping a highly specialized and previously underexplored intersection: the fusion of robotics, AI, Android technology, and environmental physics education. The added value of this research lies in its ability to transition from abstract bibliometric trends to concrete developmental rationales, demonstrating exactly why innovative learning media like the ELIO prototype are necessary to address current educational and technological demands. By highlighting the specific knowledge gaps in real-time, adaptive cognitive evaluation within physical modeling, this analysis enriches the academic discourse and directs future professional practice toward more interactive, context-aware pedagogical engineering.

This research possesses several limitations that must be acknowledged proportionately. First, the scope of the analysis was restricted exclusively to bibliographic data collected from the Scopus database. While Scopus is highly reputable, this single-database approach may exclude relevant high-quality studies published in localized, non-English journals or alternative databases like Web of Science and Google Scholar. Second, the methodological design is strictly quantitative; it identifies dominant themes and research patterns but does not provide a qualitative content analysis of the specific robotic designs or the pedagogical effectiveness of the interventions discussed in the literature. Finally, the inclusion of data up to early 2025 means the final year's indexing is incomplete, which may slightly skew the most recent publication trajectories.

Several recommendations for further research and application are proposed. Methodologically, future studies should complement this bibliometric analysis with qualitative systematic literature reviews to deeply analyze the specific AI algorithms and Android architectures that yield the highest learning gains in physics education. To expand the variables and address the geographical divide, it is highly recommended to replicate empirical studies in developing nations and underrepresented educational contexts. Most importantly, strengthening the practical aspects in the field requires moving beyond theoretical design; researchers should urgently proceed with the empirical implementation, classroom testing, and rigorous evaluation of the ELIO robotic learning media to definitively measure its impact on pre-service physics teachers' critical thinking, scientific literacy, and environmental problem-solving capabilities.

CONCLUSION

This study successfully confirms the critical alignment between the initial research objectives to establish a comprehensive scientific foundation for developing the *Environment Learning Intelligent Object Sorter* (ELIO) and the bibliometric findings presented. The exponential surge in annual scientific production (Figure 1) and the significant academic impact shown by the average citations per year (Figure 2) demonstrate a rapidly increasing global demand for integrating robotics into environmental education. However, the geographical mapping (Figure 3) exposes a profound digital and academic divide, with research heavily dominated by the United States and China while leaving vast regions underrepresented. Furthermore, an analysis of the most relevant publication sources (Figure 4) reveals that the current literature remains heavily anchored in technical engineering and computer science venues, rather than focusing on pedagogical integration for sustainability. Together, these findings confirm the consistency between the problem formulation, methodology, and results achieved, providing strong, evidence-based justification for the urgent necessity of designing the ELIO prototype to bridge technical engineering with practical environmental sustainability in physics education.

The main contributions of this research offer significant prospects for theoretical, practical, and policy developments. Theoretically, this study enriches academic discourse by mapping the multidisciplinary intersection of cyber-physical systems and environmental physics, positioning educational robotics as a vital pedagogical catalyst for achieving the 2030 Sustainable Development Goals. Practically, the results provide a robust foundation for the direct application and design of real-world educational tools, specifically supporting the implementation of the ELIO media to foster active, contextualized, and self-directed problem-solving skills among pre-service physics teachers. From a policy perspective, the stark geographical disparities identified in the data provide crucial strategic input for educational decision-makers, emphasizing the need to prioritize equitable technological investments and infrastructure funding in developing nations.

The results obtained form a vital basis for more in-depth studies and broader future applications. Future research must transcend bibliometric mapping by proceeding with the physical prototyping, direct classroom implementation, and rigorous pedagogical evaluation of the ELIO media across diverse educational settings. This next phase is essential to explicitly measure the media's impact on students' critical thinking, scientific literacy, and environmental empathy. Additionally, expanding the variables to include qualitative assessments of varied artificial intelligence-driven pedagogical designs will be crucial for maximizing the global impact, accessibility, and generalizability of these technological integrations in future educational contexts.

AUTHOR CONTRIBUTION STATEMENT

The author was fully responsible for every stage of this study, starting from conceptualizing and designing the research framework for the Environment Learning Intelligent Object Sorter (ELIO), selecting and refining the bibliometric approach, and gathering relevant data from the Scopus database. The author meticulously processed and organized the bibliometric data, performed comprehensive analyses using appropriate tools to evaluate publication trends, geographical distribution, and relevant sources, and critically interpreted the findings in relation to existing theories on educational robotics and environmental physics learning. Furthermore, the author drafted, structured, and refined the manuscript to ensure clarity, coherence, and adherence to academic standards. Throughout the entire process, the author maintained full oversight of the research direction and outcomes, ensuring that each stage accurately reflected the study's objectives and maintained the highest level of scholarly rigor.

AI DISCLOSURE STATEMENT

To enhance the quality and efficiency of this research, the author integrated specific digital tools into the preparation process. The R software's Bibliometrix package was applied to process and visualize all bibliometric data. Additionally, AI-based writing aids were utilized to refine the academic phrasing and effectively organize ideas. It is important to note, however, that the author independently conducted all critical evaluations, data interpretations, and final content validations. The manuscript has been thoroughly reviewed and manually edited to ensure it meets all ethical publishing standards, meaning the author takes full accountability for the authenticity, accuracy, and validity of the research presented.

REFERENCES

Ajibudiarta, R., Khoiri, N., Patonah, S., & Hayat, M. S. (2025). Potential of STEAM-SDGs Integration in Physics Learning. *Unnes Science Education Journal*, 14(1), 88-98.

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research*, 9(2), 19–42.

Ferrarelli, P., & Iocchi, L. (2021). Learning newtonian physics through programming robot experiments. *Technology, Knowledge and Learning*, 26(4), 789–824.

Fombona, J., Sáez, J.-M., & Sánchez, S. (2025). Artificial intelligence and robotics in education: Advances, challenges, and future perspectives. *Social Sciences & Humanities Open*, 11, 101533.

Haidegger, T., Mörch, C. M., et al. (2023). Robotics - Enabler and inhibitor of the Sustainable Development Goals. *Sustainable Production and Consumption*, 43, 422–434.

Marta, A., Zen, Z., Hidayati, A., & Rahmi, U. (2025). Development of android-based interactive learning media to improve student learning outcomes in class XII MIPA SMA. *Jurnal Penelitian Pendidikan IPA*, 11(5), 514–524.

Matsun, M., Hadiati, S., & Saputri, D. F. (2022). Development of IoT-Based Physics Learning Media and Its Effect on Students' Critical Thinking Ability. *Jurnal Penelitian Pendidikan IPA*, 8(5), 2241–2246.

Nuroso, H., & Supriyadi. (2019). Environmental Physics Program: An Evaluation and Reconstruction. *International Journal of Science and Society*, 1(3), 45-56.

Nuroso, H., Sudarmin, Sarwi, & Supriyadi. (2020). Reconstruction of Environmental Physics Learning by Integrating Ethno-technology to Actualize Superior Teacher Candidates. *Advances in Social Science, Education and Humanities Research*, 574, 257-261.

Ouyang, F., & Xu, W. (2024). The effects of educational robotics in STEM education: a multilevel meta-analysis. *International Journal of STEM Education*, 11(7).

Saputra, R., et al. (2021). Integration of environmental literacy in physics learning. *Jurnal Pendidikan IPA Indonesia*, 10(4), 532–540.

Sari, W. A., Artika, W., Oktari, R. S., Safrida, Rahmatan, H., & Sasaki, D. (2025). Assessing Education for Sustainable Development (ESD) Competencies and Environmental Empathy in Disaster and Environment Knowledge to Support SDGs 2030. *Jurnal Pendidikan IPA Indonesia*, 14(1), 42-58.

Simanjuntak, Y. L. P., Rangkuti, M. A., & Hardianti, T. (2025). Perceptions of Physics Education Students at Universitas Negeri Medan on the Role of Physics Education in Sustainable Development Goals. *Jurnal Eduscience*, 12(6), 1881-1893.

Sung, Y.-T., Chang, K.-E., & Liu, T.-C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers & Education*, 94, 252-275.

Valderrama, D. A., Garzón-Velasco, M. D., & Alfonso Chaparro, L. P. (2024). Physics, Environment and Environmental Education; Perceptions from trainee Natural Science teachers. *Revista Perspectivas*, 9(2), 89-100.

Velempini, K. (2025). Assessing the Role of Environmental Education Practices Towards the Attainment of the 2030 Sustainable Development Goals. *Sustainability*, 17, 2043.

Wang, K., Sang, G. Y., Huang, L. Z., Li, S. H., & Guo, J. W. (2023). The effectiveness of educational robots in improving learning outcomes: A meta-analysis. *Sustainability*, 15(5), 4637.

Wati, A. W., Sari, D. P., Sulaeman, N. F., Syam, M., & Saparini. (2024). Integrating SDGs in Climate Change Education: Insights from Pre-Service Physics Teachers. *Jurnal Eksakta Pendidikan (JEP)*, 8(2), 86-98.

Windrawan, I. G., Wibowo, F. C., & Sugihartono, I. (2024). Bibliometric Analysis of STEM Robotics in Physics Education: Global Trends (2008-2024) Based on Scopus Data. *Jurnal Ilmiah Pendidikan Fisika*, 8(3), 462-476.

Zhu, M., Liu, O., & Lee, H. (2020). The effect of automated feedback on revision behavior and learning gains in formative assessment of scientific argument writing. *Computers & Education*, 143