



Geo-Stem Integration and Environmental Literacy in Geography Education: A Systematic Review and Bibliometric Analysis

Abdul Mufahir¹; Bagja Waluya^{2*}; Annisa Joviani Astari³

^{1,2,3}Department of Geography Education, Indonesia University of Education, Indonesia

^{2*}Corresponding Email: bagjawaluya@upi.edu

Article History:

Received: Nov 18, 2025

Revised: Dec 12, 2025

Accepted: Dec 24, 2025

Online First: Jan 23, 2026

Keywords:

Bibliometric Analysis,
Environmental Literacy,
Geography Education,
Geo-STEM,
Urban Sustainability.

Kata Kunci:

Analisis Bibliometrik,
Geo-STEM,
Keberlanjutan Perkotaan,
Literasi Lingkungan,
Pendidikan Geografi.

How to cite:

Mufahir, A., Waluya, B., & Astari, A. J. (2026). Geo-Stem Integration and Environmental Literacy in Geography Education: A Systematic Review and Bibliometric Analysis. *Edunesia : Jurnal Ilmiah Pendidikan*, 7(1), 496–516.

This is an open-access article under the CC-BY-NC-ND license



Abstract: Rapid urbanization, technological acceleration, and increasing environmental degradation have intensified the need to strengthen environmental literacy through geography education. However, previous studies tend to examine Geo-STEM integration and environmental literacy separately, with limited attention to how Geo-STEM contributes to meaningful learning and behavioral transformation. This study aims to systematically map Research trends, thematic patterns, and Research gaps related to the integration of Geo-STEM and environmental literacy in geography education. A Systematic Literature Review (SLR) combined with bibliometric analysis was conducted following PRISMA 2020 guidelines. Data were retrieved from the Scopus database, yielding 151 articles for bibliometric analysis and 29 for qualitative synthesis. VOSviewer was employed to analyze publication trends, keyword co-occurrence, and thematic clusters. The findings reveal a significant increase in Geo-STEM and environmental literacy Research after 2020, with three dominant clusters: geography education and learning outcomes, STEM-based pedagogy, and geospatial technologies such as GIS, remote sensing, and artificial intelligence. Nevertheless, gaps remain in linking Geo-STEM implementation to behavioral change and deep learning outcomes. This study contributes by synthesizing current evidence and proposing an integrative framework to support curriculum development, teacher capacity building, and sustainable geography education.

Abstrak: Urbanisasi yang pesat, percepatan teknologi, dan meningkatnya degradasi lingkungan menegaskan urgensi penguatan literasi lingkungan melalui pendidikan geografi. Namun, penelitian sebelumnya cenderung membahas integrasi Geo-STEM dan literasi lingkungan secara terpisah, dengan perhatian yang terbatas terhadap pembelajaran bermakna dan perubahan perilaku peserta didik. Penelitian ini bertujuan memetakan tren riset, pola tematik, serta kesenjangan penelitian terkait integrasi Geo-STEM dan literasi lingkungan dalam pendidikan geografi. Penelitian menggunakan pendekatan Systematic Literature Review (SLR) yang dikombinasikan dengan analisis bibliometrik berdasarkan pedoman PRISMA 2020. Data diperoleh dari basis data Scopus, menghasilkan 151 artikel untuk analisis bibliometrik dan 29 artikel untuk sintesis kualitatif. Analisis dilakukan menggunakan VOSviewer untuk mengidentifikasi tren publikasi, ko-okurensi kata kunci, dan kluster tema. Hasil penelitian menunjukkan peningkatan signifikan publikasi setelah tahun 2020, dengan tiga kluster utama yaitu pendidikan geografi, pembelajaran berbasis STEM, serta teknologi geospasial seperti GIS, penginderaan jauh, dan kecerdasan buatan. Meskipun demikian, masih terdapat kesenjangan dalam mengaitkan Geo-STEM dengan perubahan perilaku dan pembelajaran mendalam. Studi ini memberikan kontribusi teoretis dan praktis bagi pengembangan kurikulum, peningkatan kapasitas guru, dan pendidikan geografi berkelanjutan.

A. Introduction

Rapid urbanization, technological advances, and environmental crises are the main drivers of educational transformation in many parts of the world, including Indonesia (Amoah & Addoah, 2021; Arfanuzzaman & Dahiya, 2019; Santoso et al., 2020). Urban areas in developing countries increasingly face complex environmental problems, including the decline of green open spaces, escalating waste and pollution, climate change impacts, and declining public environmental awareness (Edeigba et al., 2024; Mukherjee & Bairwa, 2025). These challenges reinforce the importance of environmental literacy as a fundamental outcome of formal education, particularly geography education, which is inherently oriented toward spatial, environmental, and place-based learning (Gibson et al., 2022; Kerski, 2022).

Despite the growing emphasis on environmental education, geography learning in many urban schools remains predominantly content-oriented and examination-driven. Field-based investigations, spatial inquiry, and real environmental action projects are still limited, resulting in a persistent gap between students' environmental knowledge and their actual pro-environmental behavior (Lange, 2024). This condition highlights a critical problem in the field, namely the limited capacity of current geography instruction to foster meaningful learning experiences that lead to behavioral transformation.

Previous studies report that students' academic performance in environmental topics is relatively high, yet their environmentally responsible attitudes and behaviors remain weak in everyday life, indicating a significant behavior gap (Hermawan et al., 2024). This gap is further exacerbated by instructional designs that lack inquiry-based learning, field experimentation, and authentic environmental action projects that can stimulate long-term behavioral change (Morris, 2025). Therefore, educational innovation is needed that not only enhances conceptual understanding but also promotes more profound learning experiences in which students can connect geographic knowledge with real-world environmental action (Fullan et al., 2017).

Recent studies emphasize that Geo-STEM-based learning supported by geospatial technologies can enhance spatial reasoning, environmental awareness, and interdisciplinary problem-solving skills (Cox et al., 2014; Manning & LaDue, 2025; Peretz et al., 2023). Further demonstrate through a systematic review that artificial intelligence is increasingly integrated into STEM education, offering personalized learning pathways and automated assessments that could significantly enhance Geo-STEM pedagogies (Otero et al., 2023). The integration of Geo-STEM (Geoscience, Science, Technology, Engineering, and Mathematics) in geography education has increasingly been promoted in both international Research and educational policy as a practical approach to developing critical thinking, creativity, and real-world problem-solving competencies (Cox et al., 2014; Manning & LaDue, 2025; Peretz et al., 2023). Empirical evidence suggests that Geo-STEM-oriented project-based learning and the use of geospatial technologies such as GIS can improve students' spatial abilities, environmental analysis skills, and engagement with environmental issues (Manning & LaDue, 2025; Otero et al., 2023). However, the implementation of Geo-STEM in the

Indonesian educational context still faces substantial obstacles, including the dominance of knowledge-based instruction, examination-oriented assessment, limited school infrastructure, and restricted access to digital and geospatial technologies (Gilbertz et al., 2022; Manning & LaDue, 2025). Although a growing body of Research has examined Geo-STEM integration and environmental literacy in education, most existing studies address these themes separately or focus primarily on cognitive learning outcomes. Previous systematic reviews tend to emphasize technological integration, spatial skills development, or conceptual understanding, while paying limited attention to how Geo-STEM pedagogies contribute to meaningful learning and behavioral transformation in geography education. Moreover, bibliometric studies rarely connect publication trends with pedagogical implications for strengthening environmental literacy. This indicates a clear Research gap in synthesizing Geo-STEM, environmental literacy, and learning transformation within a single analytical framework.

Therefore, the novelty of this study lies in its integrated synthesis of Geo-STEM Research trends, environmental literacy outcomes, and learning transformation perspectives, grounded in a combined Systematic Literature Review and bibliometric analysis in the context of geography education. Based on this Research gap, the present study aims to systematically map Research trends, thematic clusters, and Research gaps related to the integration of Geo-STEM and environmental literacy in geography education. By employing a Systematic Literature Review and bibliometric analysis, this study advances geography education Research by providing an evidence-based synthesis of global Research patterns and their pedagogical implications. The findings are expected to support curriculum development, strengthen teacher capacity in geospatial learning, and inform future Research on sustainable and transformative geography education.

B. Method

This study employed a Systematic Literature Review (SLR) combined with bibliometric analysis to systematically map Research trends, thematic structures, and Research gaps related to Geo-STEM integration and environmental literacy in geography education. This mixed-review design enables both quantitative mapping of publication patterns and qualitative synthesis of pedagogical implications, ensuring methodological rigor and analytical depth. The review process followed the PRISMA 2020 guidelines, which consist of identification, screening, eligibility, and inclusion stages (Page et al., 2021).

The primary data source was the Scopus database, selected due to its comprehensive coverage of high-quality, peer-reviewed international journals in education, geoscience, and environmental studies. Scopus is widely used in bibliometric and SLR studies because of its standardized metadata structure and reliable citation indexing. The search was conducted using the following keyword combinations in titles, abstracts, and author keywords: "*Geo-STEM*" OR "*geospatial education*" OR "*GIS education*" AND "*environmental literacy*" OR "*environmental behavior*" AND "*geography education*". The search scope was limited to: Publication years 2015–2025, Document type: Journal articles, Language: English and

Indonesian. To ensure relevance and quality, explicit inclusion and exclusion criteria were applied, as summarized in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criteria Type	Description
Inclusion	Journal articles discussing Geo-STEM, geospatial learning, or environmental literacy in geography or environmental education contexts
	Published in Scopus-indexed journals
	Empirical or conceptual Research with complete metadata
Exclusion	Conference proceedings, book chapters, editorials, and review notes
	Articles unrelated to geography, environmental education, or STEM integration
	Publications without an accessible full text

Table 2 presents a summary of the article selection process conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The selection procedure began with the identification of records retrieved from the Scopus database, followed by initial screening based on the inclusion criteria, duplicate removal, and eligibility assessment through title, abstract, and full-text review. Through these stages, only studies that were relevant to Geo-STEM and environmental literacy within the context of geography education were retained for further analysis. Therefore, this table provides a transparent overview of the number of articles included and excluded at each screening stage until the final set of selected articles was obtained for the systematic review and bibliometric analysis.

Table 2. PRISMA-Based Article Selection Summary

Stage	Number of Articles
Identification (initial search)	151
Screening (title & abstract)	64
Eligibility (full-text assessment)	29
Included in qualitative SLR	29
Included in the bibliometric analysis	151

This study employed two complementary data analysis techniques: bibliometric analysis and qualitative systematic literature review (SLR). Bibliometric analysis was conducted on metadata from 151 Scopus-indexed articles using VOSviewer. The analysis focused on identifying publication trends over time, subject area distribution, country contributions, and keyword co-occurrence patterns. Overlay and density visualizations were used to detect the evolution and intensity of Research themes. A minimum threshold of three keyword occurrences was applied to ensure analytical relevance.

A qualitative SLR analysis was conducted on 29 selected articles that met the inclusion criteria. A narrative thematic synthesis was used to examine learning models, Geo-STEM integration strategies, and environmental literacy outcomes. This analysis aimed to

identify conceptual patterns, pedagogical trends, and Research gaps related to Geo-STEM and environmental literacy in geography education.

The integration of bibliometric and qualitative analyses provided a comprehensive understanding of both global Research structures and pedagogical implications, ensuring consistency between the Research objectives, methods, and findings.

The methodological quality of the included SLR articles was evaluated using the Mixed Methods Appraisal Tool (MMAT) 2018, which assesses qualitative, quantitative, and mixed-methods studies. Two reviewers independently conducted the appraisal to enhance reliability and minimize subjective bias. Discrepancies were resolved through discussion.

Figure 1 illustrates the Research flow and article selection process following the PRISMA guidelines. The study began with data retrieval from the Scopus database, followed by a systematic screening and eligibility assessment. This process ensured methodological rigor and transparency in selecting studies for both bibliometric analysis and qualitative synthesis.

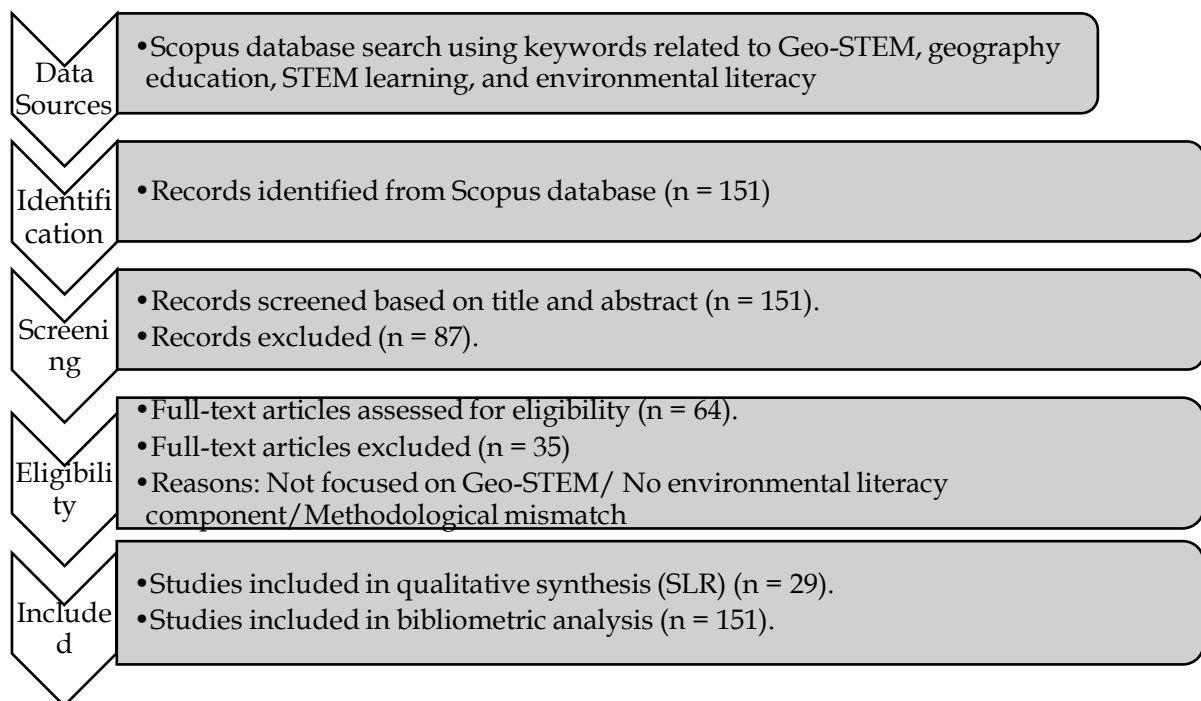


Figure 1. PRISMA Research Flow Diagram

C. Result

To provide a comprehensive overview of the studies included in the qualitative analysis, Table 3 presents the key characteristics of the articles selected for the qualitative systematic literature review (SLR). This table systematically summarizes the publication year, Research focus, and educational context of each study, enabling a structured understanding of how Geo-STEM integration and environmental literacy have been explored in geography education. By outlining these characteristics, Table 3 serves as an

analytical foundation for identifying dominant Research themes, methodological orientations, and emerging trends that inform the subsequent interpretation of the findings.

Table 3. Characteristics of Studies Included in the Qualitative SLR

No	Article Title	Authors	Journal / Source	Year	Main Focus
1	Teaching Geo Education Within the STEM Concept: A Case Study from Czechia	Karvánková et al.	<i>Geoheritage</i>	2025	Geo-STEM integration in geography education
2	Secondary School Students' Perceptions of Subjects in Integrated STEM Teaching	Kellinghusen et al.	<i>Education Sciences</i>	2025	Student perception in integrated STEM
3	Addressing Humanities Teachers' Concerns in Integrating STEM Education	Cheuk & Lam	<i>Education Sciences</i>	2025	Teacher readiness in Geo-STEM
4	Enhancing Heritage Education Through ICT	Trifi et al.	<i>Education Sciences</i>	2025	ICT-based geospatial learning
5	Systematic Review of Mobile Augmented Reality in Geography Education	Schmidt & Stumpe	<i>Review of Education</i>	2025	Technology-enhanced geography learning
6	Linguistic Features of STEM Textbooks	Cruz Neri et al.	<i>Linguistics and Education</i>	2025	STEM discourse in education
7	Problem-Based Learning in Geography to Enhance Spatial Thinking	Fadjarajani et al.	<i>E3S Web of Conferences</i>	2024	PBL and spatial thinking
8	Geography Courses and Spatial Ability: A Brain Imaging Study	Bai et al.	<i>Chinese Science Bulletin</i>	(2024).	Spatial cognition
9	Effectiveness of Spatial Training for Geology Students	Klyce & Ryker	<i>Geosphere</i>	2024	Spatial skill development
10	Google Earth as a Tool for Supporting Geospatial Thinking	Jaeger	<i>Land</i>	2024	GIS-based learning
11	Gender Differences in STEM Anxiety	Rozgonjuk et al.	<i>Int. Journal of STEM Education</i>	2024	Gender and STEM performance
12	Mathematical Techniques Used in GIS	Ye & Dale	<i>CRC Press</i>	2025	GIS analytical foundations
13	Geography of Computing Graduate Degrees	Wofford et al.	<i>Research in Higher Education</i>	2025	Geography & STEM access
14	Chinese STEM Students' Mobility to Europe	Wang & Shen	<i>Journal of Studies in International Education</i>	2025	Global STEM education

No	Article Title	Authors	Journal / Source	Year	Main Focus
15	Factors Influencing STEM Career Choice in Vietnam	Ho et al.	<i>Journal of Education and Learning</i>	2025	STEM motivation
16	Gendered Spaces in Doctoral Education	Sheppard et al.	<i>Transactions of IBG</i>	2025	Spatial-social inequality
17	Mathematical Modelling at the Periphery of STEM	Roan & Czocher	<i>IJMEST</i>	2025	STEM pedagogy
18	Antiracist Learning Communities in STEM	Louie et al.	<i>Race, Ethnicity, and Education</i>	2025	Social justice in STEM
19	Indigenous Leadership in STEM Education	Reano et al.	<i>Journal of Geography</i>	2025	Indigenous & place-based STEM
20	AI for Social Good Education	Chen et al.	<i>Springer</i>	2025	AI & culturally responsive STEM
21	Interdisciplinary Approaches in Ecological Education	Kim et al.	<i>Journal of Environmental Education</i>	2025	Environmental literacy
22	Gender and STEM Graduates: Cross-National Analysis	Lee et al.	<i>Int. Journal of Comparative Sociology</i>	2025	STEM participation
23	Earth-Moon System Using Remote Sensing in Education	Hiby et al.	<i>IAC Proceedings</i>	(2024).	Remote sensing education
24	Environmental Science & Engineering Summer Program	Quell et al.	<i>ASEE Proceedings</i>	(2024).	Experiential STEM learning
25	Engineering Education in Rural Schools	Schilling & Grohs	<i>J-PEER</i>	2024	Contextual STEM
26	Pre-Service Teachers' Confidence in Social Sciences	Deehan & Deehan	<i>Cambridge Journal of Education</i>	2024	Teacher preparedness
27	Disease Ecology in Place-Based STEM Outreach	Boz et al.	<i>IEEE ISEC</i>	(2024).	Place-based STEM
28	Innovative GIScience Teaching Using Crime Mapping	Neis et al.	<i>GIS-Zeitschrift</i>	2024	Applied GIS education
29	Inspiring the Lunar Generation	Pimenta & van Nederveelde	<i>AIAA ASCEND</i>	2024	Space-related STEM education

This table summarizes the characteristics of the 29 articles included in the qualitative systematic literature review. The selected studies predominantly focus on Geo-STEM integration, geospatial technologies, spatial thinking, and environmental literacy within geography and STEM education contexts. Most publications were published between 2024 and 2025, indicating the rapid growth and contemporary relevance of Geo-STEM Research. The diversity of journals and educational contexts reflects the interdisciplinary nature of Geo-STEM, encompassing pedagogical, technological, social, and environmental dimensions.

Publication Trends per Year

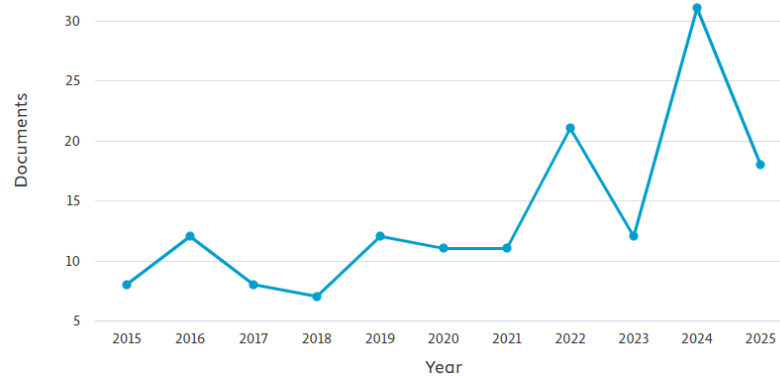


Figure 2. Publication Trends from 2015-2025

Figure 2 illustrates the annual publication trends for Geo-STEM and environmental literacy, indexed in the Scopus database between 2015 and 2025. The results show a clear upward trend in Research productivity over the past decade. During the early period (2015–2018), the number of publications remained relatively low, fluctuating between 7 and 12 documents per year, indicating that Geo-STEM was still an emerging topic within geography and environmental education Research. A notable increase in publications is observed after 2020, with a peak in 2024 reaching 31 documents, followed by a slight decline in 2025 with 18 publications. This pattern reflects a growing scholarly interest in integrating geospatial technologies and STEM-based approaches to address environmental challenges in education.

Distribution of Publications by Subject Area

To identify the disciplinary orientation of Geo-STEM and environmental literacy Research, publications were classified by subject area, as indexed in Scopus.

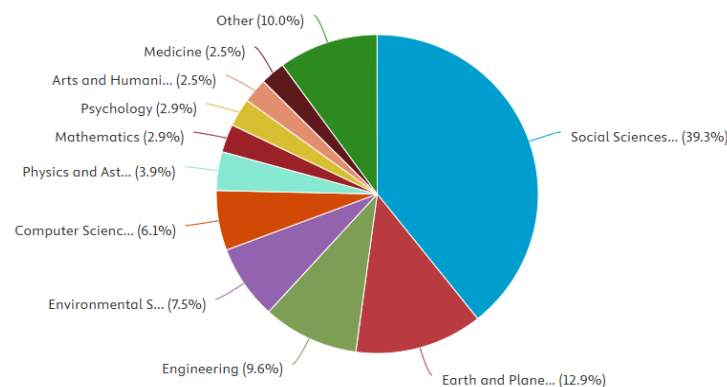


Figure 3. Subject Areas Most Frequently Discussed in Geo-STEM

Figure 3 presents the distribution of Geo-STEM and environmental literacy Research across subject areas. Social Sciences dominate the field, accounting for 39.3% of the publications, followed by Earth and Planetary Sciences (12.9%), Engineering (9.6%), and

Environmental Sciences (7.5%). This distribution demonstrates that Geo-STEM Research is not limited to technical or scientific applications but strongly emphasizes educational, social, and behavioral dimensions. The prominence of Social Sciences suggests that Geo-STEM is increasingly framed as a pedagogical approach to enhance learning processes and environmental awareness rather than solely as a technological innovation. The involvement of Computer Science, Physics, and Astronomy further reflects the interdisciplinary nature of Geo-STEM Research.

Country Contribution Analysis

To examine global Research participation and geographical distribution, the number of publications was analyzed by authors' country of affiliation.

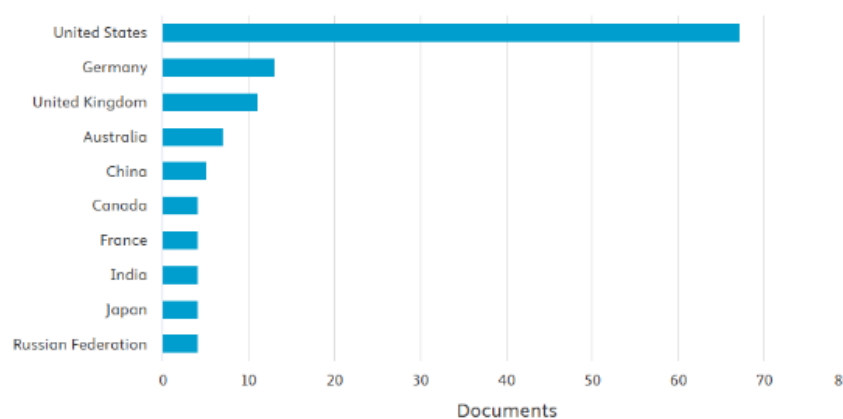


Figure 4. Contributions from Various Countries

Figure 4 shows that the United States leads global Research contributions with 67 publications, followed by Germany (13) and the United Kingdom (11). Other countries, including Australia, China, and Canada, also show active participation, albeit with lower publication counts. This distribution suggests that Research in Geo-STEM and environmental literacy remains concentrated in regions with advanced Research infrastructure. Nevertheless, increasing contributions from Asian countries indicate expanding interest in Geo-STEM integration within diverse educational contexts.

Keyword Co-occurrence and Thematic Clusters

To examine the intellectual structure of the research field, we performed a keyword co-occurrence analysis using VOSviewer to detect dominant themes, emerging topics, and relational patterns among frequently used keywords across the selected publications. The procedure produced visual maps that elucidate thematic clusters and their proximities, enabling identification of central research directions, peripheral topics, and cross-cutting linkages between Geo-STEM and environmental literacy in geography education. Cluster composition, node strength, and link density were interpreted to infer conceptual foci and research fronts, while overlay visualizations provided temporal insights into topic emergence and shifts, supporting robust synthesis of the literature and implications.

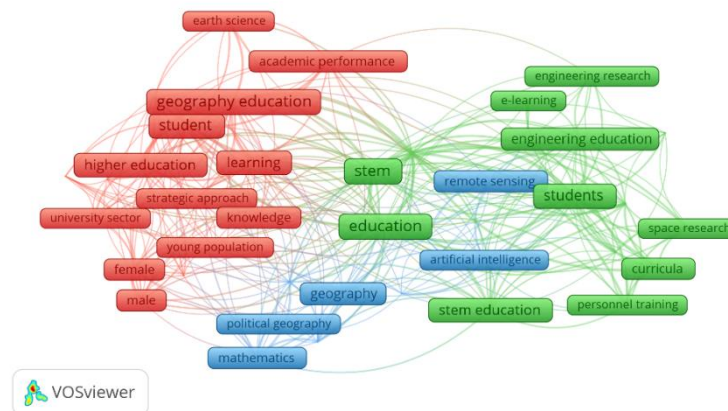


Figure 5. Keyword Co-occurrence Network of Geo-STEM and Environmental Literacy

Figure 5 presents the keyword co-occurrence network generated using VOSviewer, revealing three major thematic clusters that characterize the intellectual structure of Geo-STEM and environmental literacy Research. The red cluster is dominated by keywords such as *geography education*, *learning*, *students*, *knowledge*, and *academic performance*. This cluster reflects a strong focus on pedagogical strategies and learning outcomes within geography education, particularly at the secondary and higher education levels. The dominance of this cluster indicates that early and ongoing Research emphasizes instructional approaches aimed at improving students' conceptual understanding and academic achievement in environmental contexts.

The green cluster includes keywords such as *STEM education*, *engineering education*, *curriculum*, and *e-learning*. This cluster represents Research that focuses on interdisciplinary STEM integration and curriculum innovation, often supported by digital learning environments. The strong connections within this cluster suggest that Geo-STEM is increasingly positioned within broader educational reforms targeting 21st-century skills, including critical thinking, collaboration, and problem-solving. The blue cluster comprises keywords such as *remote sensing*, *artificial intelligence*, *geography*, and *mathematics*. This cluster highlights a technologically oriented Research direction, emphasizing the application of geospatial technologies, data analytics, and artificial intelligence in geography and environmental education. The presence of this cluster indicates a growing trend toward data-driven, technology-enhanced learning models in Geo-STEM Research.

Overlay Visualization: Evolution of Research Themes

This section presents an overlay visualization generated using VOSviewer to illustrate the temporal evolution of research themes within the selected publications. By mapping keywords according to their average publication year, the visualization highlights how specific topics have emerged, developed, and gained prominence over time. The color gradient indicates the progression of research interests, enabling the identification of earlier foundational themes as well as more recent and rapidly expanding areas. Consequently, this overlay map provides valuable insights into shifting research trends and the dynamic

received greater scholarly attention and are central to the field, while lower-density regions indicate emerging or less-explored themes. Therefore, this visualization provides a clear overview of the dominant research foci and helps identify potential gaps and opportunities for future studies related to Geo-STEM and environmental literacy in geography education.

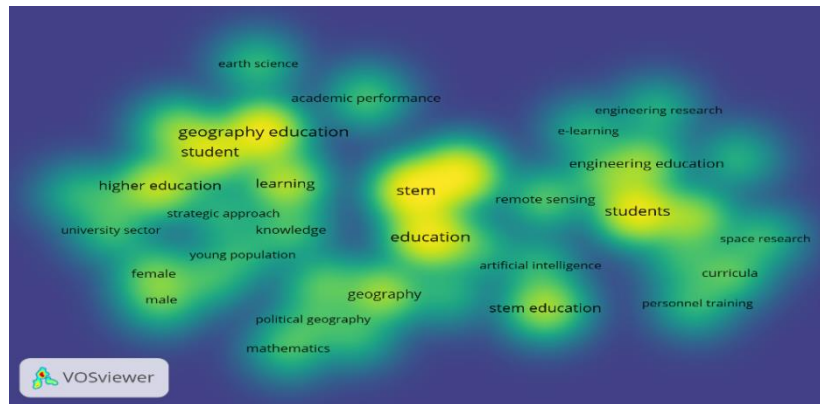


Figure 7. Density Visualization Analysis Based on VOSviewer

Figure 7 presents the density visualization of keyword co-occurrence generated using VOSviewer, illustrating the intensity and centrality of Research themes in Geo-STEM and environmental literacy. High-density areas (yellow) are dominated by keywords such as *STEM*, *education*, *students*, and *geography education*, indicating that current Research primarily focuses on instructional design and the integration of geospatial technology in learning. In contrast, low-density areas (blue), including *political geography*, *mathematics*, and *the university sector*, represent underexplored themes with potential for future Research development. This distribution suggests that while Geo-STEM Research has strongly emphasized pedagogical and technological integration, policy-oriented perspectives and higher-education-level applications remain limited. Overall, the density map confirms that global Geo-STEM Research is centered on education and digital learning, with emerging attention to artificial intelligence, remote sensing, and e-learning, thereby reinforcing the trends identified in the overlay visualization (Figure 8).

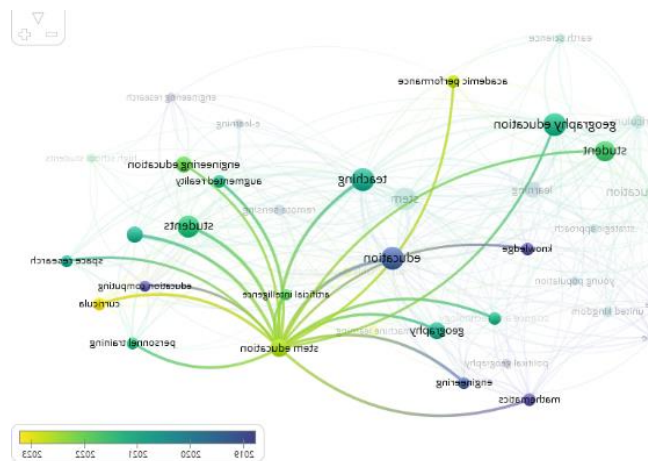


Figure 8. Results of Keyword Analysis Overlay Visualization

The pattern of this map shows the evolution of Research from traditional geography-based and basic STEM approaches (2018–2020) towards digital integration and AI in STEM learning (2021–2024). This direction indicates that the Geo-STEM field is moving towards innovative education, where geospatial data, project-based learning, and artificial intelligence are key elements to support sustainable learning. Thus, this overlay visualization confirms that the focus of global Research is now shifting towards innovative technologies and adaptive pedagogy to address the challenges of 21st-century education.

D. Discussion

This section examines the development of Geo-STEM and environmental literacy Research and the formation of its intellectual structure. The bibliometric results demonstrate a significant increase in publications after 2020, accompanied by the emergence of interconnected thematic clusters related to geography education, STEM-based pedagogy, and geospatial technologies. This trend indicates that Geo-STEM has evolved from a niche technological topic into an interdisciplinary educational approach that addresses sustainability-oriented learning goals.

The dominance of keywords such as geography education, STEM education, GIS, and environmental literacy indicates that current Research emphasizes the integration of spatial thinking, technology, and environmental awareness. This pattern aligns with studies highlighting the central role of geospatial technologies in strengthening interdisciplinary understanding and spatial competence in geography education (Kerski, 2020; Peretz et al., 2023). Egger (2019) further contextualizes this development by identifying introductory geoscience courses as critical entry points for STEM education Research, a finding that corresponds with the post-2020 growth of Geo-STEM scholarship.

The empirical evidence summarized in Table 3 provides concrete support for the bibliometric patterns identified in the Results section. The table shows that Geo-STEM Research is predominantly oriented toward pedagogical integration, geospatial technology utilization, and STEM-based curriculum innovation within geography and environmental education contexts. This empirical distribution directly reinforces the dominance of keywords such as *geography education*, *STEM*, *GIS*, and *learning* identified in the co-occurrence, overlay, and density visualizations. Notably, 18 of the 29 reviewed studies adopt instructional approaches such as inquiry-based, project-based, problem-based, and place-based STEM learning (e.g., Karvánková et al., 2025; Fadjarajani et al., 2024; Boz et al., 2024), indicating that Geo-STEM knowledge construction is primarily operationalized through active and student-centered learning models rather than purely technological applications.

In terms of instructional implementation, Geo-STEM in geography education is most frequently associated with inquiry-based and project-based learning supported by geospatial technologies such as GIS, remote sensing, and artificial intelligence. The results reveal that Geo-STEM integration is most frequently associated with inquiry-based and project-based learning, as well as the use of geospatial technologies such as GIS, remote

sensing, and artificial intelligence. These patterns indicate that Geo-STEM is predominantly implemented as an experiential and problem-oriented learning approach.

This implementation pattern explains why Geo-STEM is closely linked to improvements in environmental awareness and interdisciplinary problem-solving skills. Inquiry-based and project-based Geo-STEM learning enables students to investigate real-world environmental issues, particularly in urban contexts, such as land-use change, waste management, and climate-related risks. Gilbertz et al (2022) demonstrated that interdisciplinary sustainability and STEM modules in geography education significantly improved students' sustainability knowledge and critical thinking skills, regardless of whether delivered in-person or online. This finding is further strengthened by Morris (2025), who argues for a paradigm shift from investigation-centric to comprehensive inquiry-based instruction in science education, emphasizing that authentic problem-solving – core to Geo-STEM – better prepares students for complex environmental challenges. Taken together, these studies reveal a consistent trajectory from modular sustainability integration (Gilbertz et al., 2022) toward systemic inquiry-based transformation (Morris, 2025), converging on Geo-STEM as a practical framework for urban geography education.

Studies focusing on GIS-based learning (Jaeger, 2024; Neis et al., 2024), remote sensing applications (Hiby et al., 2024), and mobile or augmented reality technologies (Schmidt & Stumpe, 2025) illustrate that geospatial tools function primarily as cognitive instruments that enhance spatial reasoning and contextual understanding of environmental phenomena. Importantly, these studies indicate that Geo-STEM integration is rarely implemented as an isolated technological intervention. Instead, geospatial technologies are embedded in interdisciplinary STEM pedagogies that emphasize real-world problem-solving, particularly in environmental and urban contexts. This finding extends previous conclusions by Gilbertz et al (2022), Morris (2025), and Manning & LaDue (2025), showing that Geo-STEM functions as a pedagogical mechanism that connects spatial data analysis, scientific inquiry, and applied environmental literacy.

Technological innovation and pedagogical experimentation are well represented, but explicit empirical measurement of environmental literacy outcomes remains limited. Only a small subset of studies directly assesses changes in students' environmental attitudes, behaviors, or environmental literacy competencies, despite sustainability being a stated objective in many Geo-STEM initiatives. This gap confirms earlier concerns raised by Hermawan et al (2024) and Ramdani (2025), who argue that environmental education Research often emphasizes cognitive gains while underexamining affective and behavioral dimensions. The bibliometric patterns identified in this study corroborate this observation, as behavioral and curriculum-level implementation themes appear peripheral in keyword density and overlay analyses.

The increasing prominence of digital mapping, remote sensing, and artificial intelligence in recent Geo-STEM Research reflects a global shift toward data-driven education and innovative learning environments. This shift has been accelerated by post-pandemic digitalization and the global emphasis on sustainability in education policy

(Rachmadtullah et al., 2022; UNESCO, 2023). Consequently, Geo-STEM emerges as a response to both pedagogical limitations and societal needs, offering a learning framework that supports the development of environmental literacy in technologically and socially complex urban settings.

The observed Research patterns can be attributed to both structural and methodological factors. First, the widespread availability of geospatial platforms, open-access spatial data, and user-friendly GIS interfaces has significantly lowered technical barriers, encouraging educators to adopt Geo-STEM approaches. Second, global education policies emphasizing 21st-century skills, digital literacy, and sustainability have accelerated the integration of STEM and environmental education within geography curricula (Rachmadtullah et al., 2022; UNESCO, 2023).

However, the limited focus on environmental literacy assessment may stem from the complexity of measuring affective and behavioral outcomes, which often requires longitudinal designs and validated instruments. As a result, many studies prioritize short-term cognitive achievement and technological feasibility over long-term ecological behavior change. This methodological tendency explains why environmental literacy remains conceptually central yet empirically underrepresented in the Geo-STEM literature. The findings of this study largely support and extend previous Research while also revealing critical gaps. Consistent with Manning & La Due (2025), this study confirms that Geo-STEM enhances interdisciplinary learning and spatial competence. The foundational role of geoscience education in STEM Research, as emphasized by Egger (2019), reinforces the validity of our bibliometric findings that show Geo-STEM evolving from geoscience-based pedagogies into broader interdisciplinary frameworks."

However, this study also highlights a limitation in existing literature. At the same time, many studies emphasize cognitive and technical outcomes; relatively few address affective and behavioral dimensions of environmental literacy. Previous reviews by Hermawan et al (2024) and Ramdani (2025) report that environmental education often fails to translate knowledge gains into sustainable behavior. The bibliometric patterns identified in this study confirm that behavioral outcomes and curriculum-level implementation remain underrepresented themes. By integrating bibliometric analysis with qualitative synthesis, this study offers a more comprehensive and critical understanding of the Geo-STEM Research landscape than prior reviews that examine technology integration or environmental education separately. The combined evidence demonstrates that while Geo-STEM effectively supports interdisciplinary learning and spatial competence (Egger, 2019; Manning & LaDue, 2025), it has not yet fully realized its potential in fostering measurable environmental behavior change.

This synthesis highlights the need for future Geo-STEM Research to move beyond descriptive and exploratory designs toward theory-driven, empirically validated models that explicitly link pedagogy, technology, and environmental literacy outcomes. In this regard, the proposed Geo-STEM-Deep Learning-Environmental Literacy (GSDL) model

represents a conceptual advancement that addresses the gaps identified in both bibliometric patterns and the empirical literature.

Beyond confirming existing trends, this study contributes theoretically by identifying the absence of an integrative framework that simultaneously connects Geo-STEM, deep learning, and environmental literacy. This approach identifies introductory geoscience courses as essential platforms for building foundational STEM skills, suggesting that similar pedagogical designs should be prioritized in Geo-STEM curriculum development (Egger, 2019). Most previous studies focus on partial relationships, such as Geo-STEM and spatial skills (Nazareth et al., 2019) or environmental literacy and contextual learning (Davis et al., 2018; Xiong et al., 2025). In response, this study proposes the Geo-STEM–Deep Learning–Environmental Literacy (GSDL) conceptual model, which positions geospatial technology as a cognitive foundation, deep learning as a pedagogical process, and environmental literacy as an affective-behavioral outcome.

Practically, these findings have important implications for geography curriculum development, teacher professional capacity building, and education policy. The integration of Geo-STEM can support transformative geography education by fostering higher-order thinking, ecological awareness, and technology-enhanced learning practices, particularly in urban contexts. Accordingly, this study strengthens the empirical and conceptual basis for implementing Geo-STEM as a future-oriented approach to sustainable geography education (Lubishtani & Lubishtani, 2025; Manning & LaDue, 2025).

E. Implication

This study strengthens the theoretical understanding of Geo-STEM as an integrative framework in geography education. The bibliometric and thematic synthesis demonstrates that Geo-STEM is not merely a technological extension of STEM but a pedagogical approach that connects spatial thinking, learning processes, and environmental literacy within a sustainability-oriented paradigm. By identifying the lack of integrative theoretical models in previous studies, this Research positions Geo-STEM as a bridge between cognitive (geospatial knowledge), pedagogical (inquiry- and project-based learning), and affective-behavioral (environmental literacy) dimensions. Consequently, this study extends existing STEM and environmental literacy frameworks into a more holistic and interdisciplinary model relevant to contemporary geography education, particularly in urban and environmental contexts.

From a practical and policy perspective, the findings indicate that geography instruction should move beyond content transmission toward experiential and problem-oriented learning supported by geospatial technologies such as GIS, remote sensing, and digital mapping. The integration of Geo-STEM into geography curricula can enhance students' spatial reasoning, critical thinking, and environmental responsibility, primarily through thematic learning focused on urban sustainability issues. At the policy level, the results support the inclusion of Geo-STEM and environmental literacy as priority components in curriculum frameworks and digital education policies. Strengthening teacher

professional development, infrastructure, and access to geospatial technologies is essential to ensure equitable and effective implementation, particularly in urban schools facing complex socio-environmental challenges.

F. Limitation and Suggestion for Further Research

This study has several limitations. First, the SLR and bibliometric analysis relied exclusively on the Scopus database, which may limit coverage and introduce publication bias by excluding relevant studies indexed in other databases. Second, bibliometric results depend on the consistency and completeness of metadata, which may affect keyword clustering and thematic interpretation. Third, the study is based on secondary data and lacks empirical validation, so conclusions regarding the effectiveness of Geo-STEM integration should be interpreted as indicative rather than causal.

Future Research should address these limitations by conducting experimental or quasi-experimental studies to examine the causal impact of Geo-STEM learning on environmental literacy and spatial thinking. Further studies are also needed to develop and validate standardized instruments for measuring Geo-STEM competencies and ecoliteracy outcomes. In addition, Research focusing on teacher readiness, infrastructure availability, and institutional support – particularly in urban schools – would provide critical insights for sustainable and equitable Geo-STEM implementation.

G. Conclusion

This study concludes that Research on Geo-STEM and environmental literacy has increased significantly over the past decade, particularly after 2020, reflecting a growing global focus on sustainability-oriented and technology-enhanced geography education. The bibliometric analysis identified three dominant thematic clusters: geography education and learning outcomes, STEM-based curriculum and pedagogy, and geospatial technologies such as GIS, remote sensing, and artificial intelligence. Despite this growth, the study reveals a clear Research gap: the limited integration of Geo-STEM with the behavioral dimensions of environmental literacy and deep learning frameworks. To address this gap, this study proposes an integrative Geo-STEM-Deep Learning-Environmental Literacy model that conceptually links geospatial technology, pedagogical transformation, and ecological behavior. This model provides a coherent framework for advancing geography education toward meaningful and transformative learning. Overall, the findings offer clear recommendations for curriculum development, teacher capacity building, and future empirical Research to support sustainable geography education in urban contexts.

Acknowledgment

The authors acknowledge Universitas Pendidikan Indonesia for institutional support. This study received no external funding.

References



- Amoah, A., & Addoah, T. (2021). Does Environmental Knowledge Drive Pro-Environmental Behaviour in Developing Countries? Evidence from Households in Ghana. *Environment, Development and Sustainability*, 23(2), 2719–2738. <https://doi.org/10.1007/s10668-020-00698-x>
- Arfanuzzaman, M., & Dahiya, B. (2019). Sustainable Urbanization in Southeast Asia and Beyond: Challenges of Population Growth, Land Use Change, and Environmental Health. *Growth and Change*, 50(2), 725–744. <https://doi.org/10.1111/grow.12297>
- Cox, H., Kelly, K., & Yetter, L. (2014). Using Remote Sensing and Geospatial Technology for Climate Change Education. *Journal of Geoscience Education*, 62(4), 609–620. <https://doi.org/10.5408/13-040.1>
- Davis, L. F., Ramirez-Andreotta, M. D., McLain, J. E. T., Kilungo, A., Abrell, L., & Buxner, S. (2018). Increasing Environmental Health Literacy Through Contextual Learning in Communities at Risk. *International Journal of Environmental Research and Public Health*, 15(10), 2203. <https://doi.org/10.3390/ijerph15102203>
- Edeigba, B. A., Ashinze, U. K., Umoh, A. A., Biu, P. W., & Daraojimba, A. I. (2024). Urban Green Spaces and Their Impact on Environmental Health: A Global Review. *World Journal of Advanced Research and Reviews*, 21(2), 917–927. <https://doi.org/10.30574/wjarr.2024.21.2.0518>
- Egger, A. E. (2019). Introductory Geoscience Courses and STEM Education Research. *Journal of Geoscience Education*, 67(3), 193–194. <https://doi.org/10.1080/10899995.2019.1633876>
- Fullan, M., Quinn, J., & McEachen, J. (2017). *Deep Learning: Engage the World Change the World*. Corwin Press.
- Gibson, L. M., Busch, K. C., Stevenson, K. T., Cutts, B. B., DeMattia, E. A., Aguilar, O. M., Ardoin, N. M., Carrier, S. J., Clark, C. R., & Cooper, C. B. (2022). What Is Community-Level Environmental Literacy, and How Can We Measure It? A Report of a Convening to Conceptualize and Operationalize CLEL. *Environmental Education Research*, 28(10), 1423–1451. <https://doi.org/10.1080/13504622.2022.2067325>
- Gilbertz, S., Wood, B., Craig, C., Karabas, I., Petrun Sayers, E., & McCormick, B. (2022). Integrating and Evaluating Interdisciplinary Sustainability and STEM Curriculum in Geographical Education: A Case of Three Teaching Modalities. *Journal of Geography*, 121(2), 77–85. <https://doi.org/10.1080/00221341.2022.2059099>
- Hermawan, I. M. S., Diarta, I. M., & Dharmayanti, P. A. P. (2024). Profile, Challenge, and Opportunity of Environmental Literacy Research in Indonesia: A Systematic Literature Review. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(2), 652–665. <https://doi.org/10.22219/jpbi.v10i2.33953>
- Hiby, R., Lindner, C., Rienow, A., & Daali, S. (2024, October 14–18). The Earth-Moon System











- with Remote Sensing in Education - Implementing Lunar and Cis-Lunar Topics into the School Curriculum [Paper presentation]. 75th International Astronautical Congress (IAC), Milan, Italy.
- Jaeger, A. J. (2024). Google Earth as a Tool for Supporting Geospatial Thinking. *Land*, 13(12), 2218. <https://doi.org/10.3390/land13122218>
- Kerski, J. J. (2022). Online, Engaged Instruction in Geography and GIS Using IoT Feeds, Web Mapping Services, and Field Tools Within a Spatial Thinking Framework. *The Geography Teacher*, 19(3), 93–101. <https://doi.org/10.1080/19338341.2022.2070520>
- Lange, F. (2024). What Is Measured in Pro-Environmental Behavior Research? *Journal of Environmental Psychology*, 98, 102381. <https://doi.org/10.1016/j.jenvp.2024.102381>
- Lubishtani, F. B., & Lubishtani, M. (2025). Advancing Geodesy Education: Innovative Pedagogical Approaches and Integration Into STEM Curricula. *STEM Education*, 5(2), 229–249. <https://doi.org/10.3934/steme.2025012>
- Manning, C. L. B., & LaDue, N. D. (2025). Geo-STEM Learning Ecosystems: A Transdisciplinary Theory-Based Framework to Establish and Engage Communities in the Geosciences. *Journal of Geoscience Education*, 73(2), 172–186. <https://doi.org/10.1080/10899995.2024.2351028>
- Morris, D. L. (2025). Rethinking Science Education Practices: Shifting from Investigation-Centric to Comprehensive Inquiry-Based Instruction. *Education Sciences*, 15(1), 73. <https://doi.org/10.3390/educsci15010073>
- Mukherjee, S., & Bairwa, H. (2025). Environmental Issues Arising from Urbanization: A Study on the Ecological Consequences of Rapid Urban Growth. *Journal of Humanities and Education Development*, 7(3), 15–22. <https://doi.org/10.22161/jhed.7.3.3>
- Nazareth, A., Newcombe, N. S., Shipley, T. F., Velazquez, M., & Weisberg, S. M. (2019). Beyond Small-Scale Spatial Skills: Navigation Skills and Geoscience Education. *Cognitive Research: Principles and Implications*, 4, Article 27. <https://doi.org/10.1186/s41235-019-0166-8>
- Neis, P., Cubela, D., & Rossner, A. (2024). Innovative Teaching Methods in GIScience Using the Example of Crime Mapping with ATM Explosions [Innovative Lehrmethoden in der GIScience am Beispiel von Crime Mapping mit Geldautomatensprengungen]. *gis.Science*, 2024(3), 88–96. <https://doi.org/10.14627/gis.Science.2024.3.1>
- Otero, L. C., Catala, A., Morante, C. F., Taboada, M., Cebreiro, B., & Barro, S. (2023). AI Literacy in K-12: A Systematic Literature Review. *International Journal of STEM Education*, 10, Article 1. <https://doi.org/10.1186/s40594-023-00418-7>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E.,

- McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- Peretz, R., Dori, D., & Dori, Y. J. (2023). Investigating Chemistry Teachers' Assessment Knowledge Via a Rubric for Self-Developed Tasks in a Food and Sustainability Context. *Education Sciences*, 13(3), 308. <https://doi.org/10.3390/educsci13030308>
- Rachmadtullah, R., Aliyyah, R. R., Samsudin, A., Syaodih, E., Nurtanto, M., & Tambunan, A. R. S. (2022). Multimedia-Based Mobile Learning in Social Studies: Improving Student Learning Outcomes in Elementary Schools. *International Journal of Interactive Mobile Technologies (ijIM)*, 16(6), 39–49. <https://doi.org/10.3991/ijim.v16i06.27306>
- Ramdani, A. (2025). Examining the Global Trends of Environmental Literacy: A Systematic Literature Review and Bibliometric Analysis. *International Journal of Current Science Research and Review*, 8(9), 4592–4607. <https://doi.org/10.47191/ijcsrr/V8-i9-14>
- Santoso, M., Lestiani, D. D., Kurniawati, S., Damastuti, E., Kusmartini, I., Atmodjo, D. P. D., Sari, D. K., Hopke, P. K., Mukhtar, R., & Muhtarom, T. (2020). Assessment of Urban Air Quality in Indonesia. *Aerosol and Air Quality Research*, 20(10), 2142–2158. <https://doi.org/10.4209/aaqr.2019.09.0451>
- Schmidt, R., & Stumpe, B. (2025). Systematic Review of Mobile Augmented Reality Applications in Geography Education. *Review of Education*, 13(1), e370042. <https://doi.org/10.1002/rev3.70042>
- UNESCO. (2023). *Global Education Monitoring Report 2023: Technology in Education – A Tool on Whose Terms?* UNESCO.
- Xiong, Z., Song, Y., & Zhu, R. (2025). Pedagogical Strategies for Teaching Environmental Literacy in Secondary School Education: A Systematic Review. *Sustainability*, 17(20), 9104. <https://doi.org/10.3390/su17209104>

Author's Biography



Abdul Mufahir.    Was born in South Tangerang City on October 6, 1996, he is currently pursuing a master's degree in Geography Education at Universitas Pendidikan Indonesia (UPI). He earned his bachelor's degree in Social Sciences Education from Universitas Islam Negeri (UIN) Syarif Hidayatullah Jakarta, graduating in 2020.
Email: abdulmufahir@upi.edu

	<p>Dr. Bagja Waluya.     Is a permanent lecturer in the Geography Education Program at Universitas Pendidikan Indonesia (UPI), where he earned his Bachelor's (1999), Master's (2013), and Doctoral (2022) degrees. Committed to advancing geography pedagogy, his 2024 research focuses on developing an ADDIE-based microteaching e-module using the SIGIL application. Dr. Waluya is also a prolific author of educational textbooks in geography and sociology, contributing significantly to curriculum development at both secondary and tertiary levels. Email: bagjawaluya@upi.edu</p>
	<p>Annisa Joviani Astari, M.I.L., M.Sc., Ph.D.     Is an Assistant Professor in the SaIG and SPIG programs at Universitas Pendidikan Indonesia. She holds a Ph.D. in Governance for Sustainable Development (University of Twente, 2019), a Master's in Environmental Science (Universitas Padjadjaran), and an M.Sc. in Environmental and Energy Management. Her research focuses on sustainability governance, ISPO palm oil policy, GIS applications, river ecosystem services, eco-anxiety, and sustainable batik industries. Email: annisa.astari@upi.edu</p>