

AI in Climate Change Education: A Systematic Review of Trends, Knowledge Structures, and Future Directions

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Abstract: Artificial intelligence (AI), including generative AI, machine learning, and learning analytics, is increasingly being integrated into climate change education (CCE) practice and efforts to improve climate literacy. This study aims to map the knowledge structure, research trends, and future directions at the intersection of AI and climate change education through a systematic literature review (SLR) approach based on the PRISMA 2020 protocol. The search was conducted in the Scopus database on 22 June 2026 using a combination of the terms “climate change education”, “climate literacy”, and similar terms together with “artificial intelligence”, “machine learning”, “generative AI”, “ChatGPT”, “large language model”, and “learning analytics”. From 38 initial documents, 16 English-language journal articles met the inclusion criteria and were analyzed thematically. The results reveal six main knowledge clusters: (1) generative AI and climate literacy, (2) misinformation and science communication, (3) immersive learning based on virtual reality, (4) learning engagement and learning analytics, (5) machine-learning-based awareness assessment, and (6) sustainability, justice, and policy. Publication trends show a sharp surge in 2025–2026, in line with the widespread adoption of ChatGPT and other large language models after 2023, with the most-cited article addressing the potential and bias-related risks of generative AI for climate literacy. This review identifies several research gaps, particularly regarding the evaluation of long-term learning impacts, bias audits of AI-generated content, the integration of conversational AI with immersive technologies, and the representation of vocational education contexts and developing countries, and proposes a research agenda to strengthen the role of AI in responsible climate change education.

Keywords: artificial intelligence, climate change education, climate literacy, generative AI, systematic literature review, PRISMA.

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Introduction

Climate change is one of the most pressing global challenges of the 21st century, and education is regarded as a key instrument for building societal awareness, literacy, and adaptive capacity in facing it (Godfrey & Tunhuma, 2020). Climate change education (CCE) and climate literacy have become rapidly growing research and policy agendas (Kundariati et al., 2025b), in line with global initiatives such as the Sustainable Development Goals (SDGs) and education-for-sustainable-development strategies (Lofts et al., 2016). Through education, learners not only gain scientific understanding of the causes, impacts, mitigation, and adaptation of climate change, but also develop critical thinking skills, evidence-based decision-making, and the ability to participate in collective action that supports environmental sustainability (Kundariati et al., 2025a). Consequently, various countries have begun integrating climate change issues into formal curricula to shape a generation with the knowledge, attitudes, and pro-environmental behaviors needed to face future climate challenges (UNESCO, 2021).

Alongside the development of digital technology, the use of artificial intelligence (AI) in education is increasingly gaining attention as a means to improve learning quality and support the achievement of sustainable education goals (Vieriu & Petrea, 2025). AI offers various opportunities, such as personalized learning, real-time feedback, analysis of learners' needs, and broader access to relevant and contextual learning resources (Oyebola Olusola Ayeni et al., 2024). In the context of climate change education, AI has the potential to help learners understand complex climate phenomena through simulation, data visualization, predictive modeling, and exploration of various environmental scenarios that are difficult to observe directly (Mamadiyarov et al., 2026). In addition, AI can support the development of 21st-century skills, including problem-solving, systems thinking, and data-driven decision-making, which are essential for addressing the multidimensional issue of climate change.

Although interest in this topic is growing rapidly, systematic efforts to map the knowledge structure and research trends specifically at the intersection of AI and climate change education remain limited. Previous reviews have generally addressed AI in education in general, or climate change education in general, without focusing on the intersection of the two fields. This gap forms the basis for the present study. This study aims to answer three research questions through a systematic literature review (SLR) approach based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol: (1) what is the knowledge structure of the literature integrating AI

with climate change education/literacy? (2) how have research trends in this field developed in terms of publication volume, citation impact, methodological approaches, and disciplinary/geographic distribution? (3) what future research directions can be identified from gaps in the existing literature? By answering these three questions, this review is expected to provide a conceptual roadmap for researchers, educators, and policymakers interested in developing responsible, evidence-based AI-driven climate change education practicest.

Methods

This study used a systematic literature review design following the PRISMA 2020 protocol, which emphasizes reporting transparency at every stage of identification, screening, eligibility assessment, and inclusion of documents. The literature search was conducted in the Scopus database on 22 June 2026 using the following Boolean search combination, which combined a climate education/literacy concept block with an artificial intelligence concept block:

("climate change education" OR "climate education" OR "education for climate change" OR "climate literacy") AND ("artificial intelligence" OR AI OR "machine learning" OR "deep learning" OR "generative AI" OR ChatGPT OR "large language model" OR "learning analytics")

The initial search yielded 38 documents without additional filters. The inclusion criteria applied were: (a) document type of journal article, and (b) publication language of English. After applying both filters, 16 articles were obtained that formed the final corpus for analysis. A total of 22 documents were excluded at the screening/eligibility stage because they were non-article document types (e.g., conference papers, book chapters, or editorials) or were published in a language other than English. This review did not add documents through manual citation searching (snowballing) or additional databases, so the analysis is based entirely on the Scopus search results.

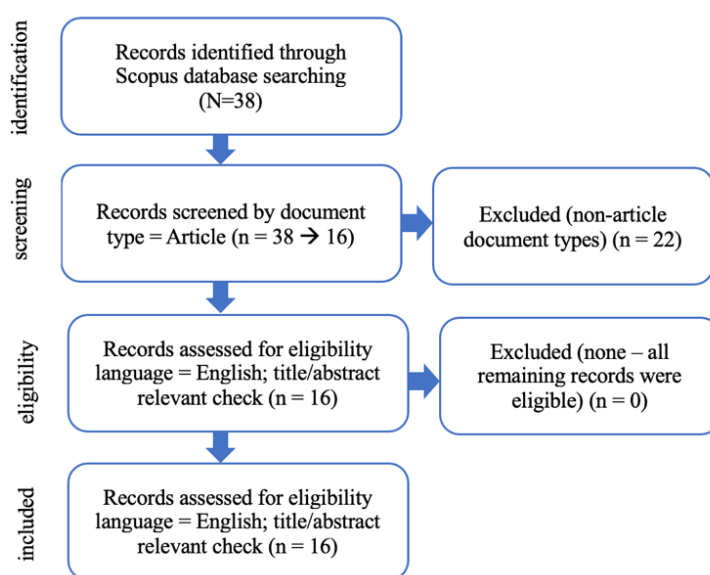


Figure 1. PRISMA Framework

Given the relatively small corpus size (n = 16), thematic analysis of author keywords and abstract content was carried out manually to identify conceptual clusters, rather than using software-assisted bibliometric analysis (e.g., VOSviewer or Bibliometrix), which is more suitable for larger-scale corpora. Trend analysis was carried out by tabulating publication year, number of citations (as recorded in Scopus), research method type, and journal/publication source).

Results

Knowledge Structure

Thematic analysis of the author keywords from the 16 articles produced six overlapping knowledge clusters, as summarized in Table 2.

Table 2. CCE-AI Knowledge Clusters

Cluster	Representative Keywords	Main Focus
Generative AI & Literacy	Generative AI, ChatGPT, climate literacy, finance literacy, large language models	How generative AI informs, misleads, or builds climate understanding (Atkins et al., 2024; Raja et al., 2025; Schäfer et al., 2026)
Misinformation & Science Communication	climate change denial, disinformation, misinformation, climate scepticism, science communication	AI's dual role in spreading vs. countering false climate narratives (Heidari et al., 2026; Hornsey et al., 2025; Nguyen et al., 2025; Schäfer et al., 2026)
Immersive & Experiential Learning	virtual reality, 3D asset management, immersive learning, experiential learning, engineering fiction	Technology-based pedagogy for abstract climate concepts (Carmona-Galindo et al., 2025; Miranto et al., 2025; Reynante et al., 2024)
Engagement & Learning Analytics	situational engagement, optimal learning moments, online/distance learning, active learning, galvanic sensors	Data-based measurement and optimization of learning engagement (Morrison et al., 2020; Vilhunen et al., 2025)
ML-Based Awareness Assessment	machine learning, unsupervised clustering, environmental awareness	Use of ML to classify climate knowledge/behavior (Karaelmas et al., 2025)
Sustainability, Justice & Policy	SDGs, intersectional climate justice, smart city, curriculum, public health, global citizenship	Embedding AI-based education within broader sustainability/justice agendas (Çiçek & Özoğlu, 2026; Delia L. Olaybal et al., 2025; Nguyen et al., 2025; Obracht-Prondzyńska et al., 2022)

In terms of disciplinary distribution, this research corpus spans a very diverse range of fields for a set of 16 articles: general sustainability and environmental journals (Sustainability, Climatic Change, Communications Earth and Environment, Nature Climate Change), education and learning technology journals (Education Sciences, Learning Media and Technology, Internet and Higher Education, European Journal of Geography, Environment and Social Psychology), engineering/computing journals (Bulletin of Electrical Engineering and Informatics), public health/nursing journals (Journal of Professional Nursing), finance journals (Finance Research Letters), internet studies journals (First Monday), psychology journals (Journal of Environmental Psychology), and interdisciplinary review journals (WIREs Climate Change). This diversity indicates that AI-based climate change education has not been consolidated within a single discipline, but is being studied in parallel by educators, VR/computer engineers, environmental psychologists, health-profession educators, and finance researchers alike.

The identified application domains include: general science/geography education (correcting misinformation, curriculum analysis), higher education (student awareness, online learning engagement), professional/vocational education (nursing curricula for climate-impacted health practice), public engagement and communication (ChatGPT/GenAI for skepticism and climate literacy among the general public), immersive technology pedagogy (VR/3D simulation for ecology and energy-system learning), and smart-city and policy-related education (AI-based citizen awareness tools, e.g., Greecoin). One study (on retail investor literacy) lies in a more peripheral domain at the intersection of GenAI with climate and financial literacy outside the context of formal education.

Research Trends

The distribution of publications by year is shown in Figure 2.

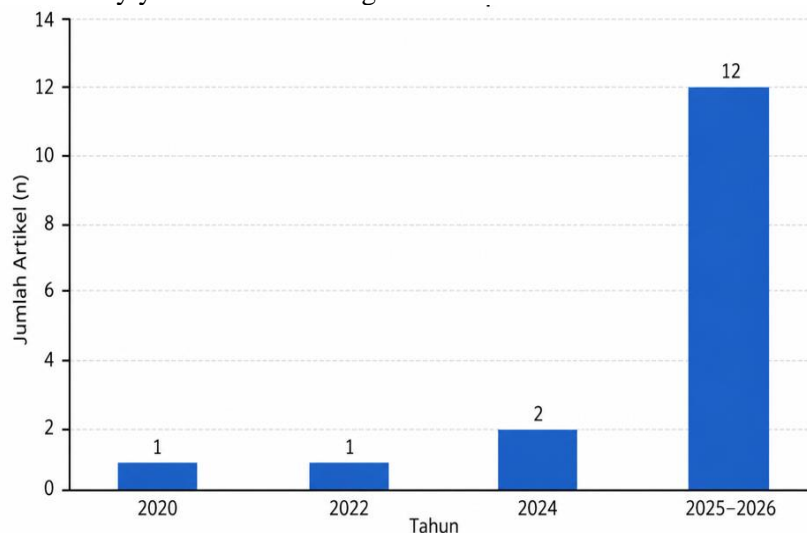


Figure 2. Distribution of AI and Climate Change Education Publications by Year

This field was relatively inactive before 2024 (only one article in 2020 and one in 2022), then accelerated sharply starting in 2024, with 12 of the 16 articles (75%) published in 2025–2026. This pattern is consistent with the widespread public adoption of generative AI (ChatGPT and similar models) after 2023, which appears to have driven a new wave of empirical and conceptual research specifically applying generative AI to climate education and literacy. In terms of citation impact, the most-cited article in this corpus is Atkins et al. (2024), published in *Communications Earth and Environment* with 49 citations, discussing the potential of generative AI for climate literacy alongside the risk of bias and inaccuracy, indicating this issue as a current major concern in the field. The second most-cited article is Obracht-Prondzyńska et al. (2022) with 25 citations, on AI solutions for smart-city-based climate awareness. Some articles published in 2025–2026 have not yet recorded citations, as is expected for very recent publications.

In terms of methods, four main methodological approaches were identified in the corpus of 16 articles, as summarized in Table 3. True mixed-methods or longitudinal designs remain rare, and almost no studies report classroom-scale randomized/controlled evaluations of the impact of AI tools on learning outcomes.

Table 3. Methodological Approaches of AI and Climate Change Education Publications

Methodological Approach	Description	n	Articles (Citations)
(1) Empirical/experimental testing of AI output	Prompt-based testing of ChatGPT/GenAI to assess bias, accuracy, or persuasive framing on climate topics	5	(Atkins et al., 2024; Boni, 2025; Hornsey et al., 2025; Nguyen et al., 2025; Raja et al., 2025)
(2) Quantitative/ML & sensor-based	Surveys analyzed with unsupervised clustering (k-means), or NLP/physiological sensor data to classify levels of awareness or engagement	5	(Delia L. Olaybal et al., 2025; Karaelmas et al., 2025; Morrison et al., 2020; Reynante et al., 2024; Vilhunen et al., 2025)
(3) Systematic/narrative literature review	Synthesizing prior research on misinformation in geography education, nursing curricula, or climate communication in general	3	(Çiçek & Özoğlu, 2026; Heidari et al., 2026; Schäfer et al., 2026)
(4) Design & applied technology	Development and performance evaluation of VR/3D simulation platforms and AI-based civic/smart-city tools	3	(Carmona-Galindo et al., 2025; Miranto et al., 2025; Obracht-Prondzyńska et al., 2022)
Total		16	

Note: Three of the 16 articles (19%) are literature reviews (category 3), while the other 13 articles (81%) are primary/empirical studies (categories 1, 2, and 4), indicating that this field is still dominated by early, small-scale studies and has not yet been extensively synthesized through large-scale systematic reviews.

In terms of corresponding-author affiliation, this corpus spans several countries including Indonesia, Poland, Turkey, and the United States, with co-author contributions from European and Asia-Pacific universities. Although the sample size is too small for strong geographic claims, this pattern indicates an emerging international research community, without dominance from any single country. The geographic distribution of publications based on corresponding-author affiliation is shown in Figure 1 and Table 5.

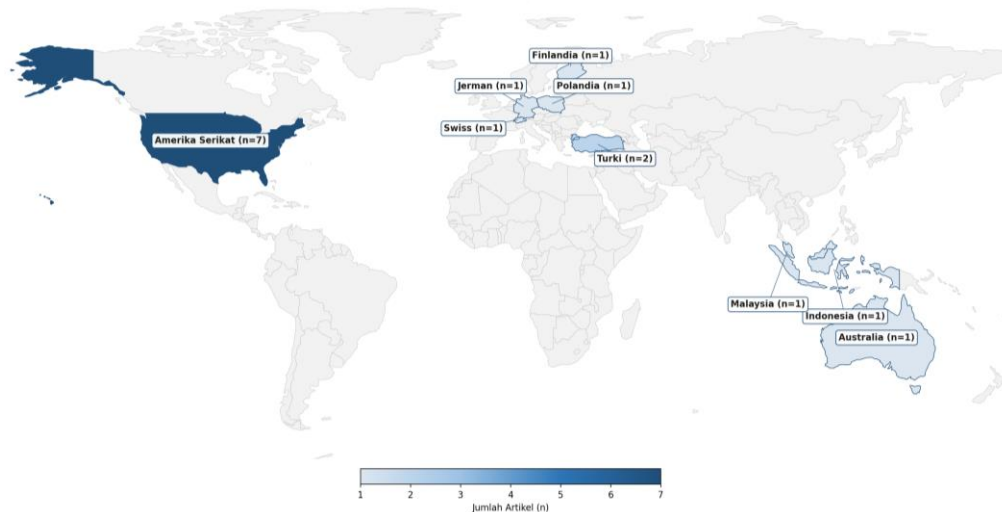


Figure 3. Geographic Distribution of AI and Climate Change Education Publications by Corresponding-Author Affiliation (n = 16 articles)

Table 5. Geographic Distribution of AI and Climate Change Education Publications by Corresponding-Author

Country	n	Articles (Citations)
United States	7	(Atkins et al., 2024; Boni, 2025; Carmona-Galindo et al., 2025; Morrison et al., 2020; Nguyen et al., 2025; Raja et al., 2025; Reynante et al., 2024)
Turkey	2	(Çiçek & Özoğlu, 2026; Karaelmas et al., 2025)
Indonesia	1	(Miranto et al., 2025)
Poland	1	(Obracht-Prondzyńska et al., 2022)
Australia	1	(Hornsey et al., 2025)
Germany	1	(Heidari et al., 2026)
Malaysia	1	(Delia L. Olaybal et al., 2025)
Finland	1	(Vilhunen et al., 2025)
Switzerland	1	(Schäfer et al., 2026)
Total	16	

Note: The United States dominates this corpus with 7 of the 16 articles (44%), followed by Turkey with 2 articles (13%), while seven other countries (Indonesia, Poland, Australia, Germany, Malaysia, Finland, and Switzerland) each contribute 1 article (6%). This pattern confirms the dominance of research from North America and Europe, with limited representation from Southeast Asia (Indonesia, Malaysia) and no representation from Africa or Latin America in the analyzed corpus.

Discussion

Based on the synthesis of the knowledge structure and trends above, the following research gaps and priorities can be identified for AI-based climate change education.

Research Gaps

The first prominent gap is the still very limited evaluation of learning outcomes. Most studies in this corpus examine the capabilities of AI tools, output quality, or short-term learner engagement, as seen in the exploratory study of ChatGPT output by Raja et al. (2025) and the situational engagement study by Vilhunen et al. (2025), but no study has longitudinally measured durable learning achievement, behavioral change, or long-term retention of climate literacy resulting from AI-assisted learning. Even the galvanic-sensor-based engagement study by Morrison et al. (2020), one of the earliest and most methodologically detailed studies in this corpus, remains focused on measuring engagement during the learning session itself, rather than on learning impacts that persist afterward. The second gap relates to bias, accuracy, and inclusivity of generative AI content. Atkins et al. (2024) explicitly found that generative AI tools can enhance climate literacy, but their output still needs to be checked because it is prone to bias and inaccuracy. This finding is reinforced by Nguyen et al. (2025), who showed that generative AI risks producing inequitable representations of intersectional climate justice perspectives, and by Boni (2025), who documented how retail investors' interactions with GenAI on climate and finance literacy issues can be affected by model limitations and bias. Systematic audit frameworks specifically designed to assess bias in generative AI content on climate issues, as far as can be identified in this corpus, remain inadequately developed.

Third, there is a disconnect between misinformation research and AI tool design. Heidari et al. (2026) and Hornsey et al. (2025) respectively examine climate misinformation/denial in geography education and climate skepticism in general, while studies on generative AI capabilities (Atkins et al., 2024; Raja et al., 2025) proceed relatively independently without directly testing whether such AI tools can be designed to counter, rather than reinforce, climate disinformation. Hornsey et al. (2025) do begin to bridge these two tracks by examining the potential and limitations of GenAI for reducing climate skepticism, but such studies remain the exception rather than the norm compared with the mainstream of misinformation research and AI capability research, which still proceed separately. Fourth, the use of large-scale learning analytics remains minimal. Only Morrison et al. (2020) and Vilhunen et al. (2025) directly use physiological sensor data or situational engagement analytics, and both remain small-scale and limited to a single institution. Larger-scale, multi-institutional learning analytics research in climate change education that could integrate data from various cultural and institutional contexts has not been found in this corpus. Fifth, coverage of professional and vocational education remains rarely examined. Apart from the systematic review of nursing curricula by Çiçek and Özoğlu (2026), climate change education in other professional pathways such as engineering, medicine more broadly, or teacher training is not adequately represented in this corpus, which mostly focuses on general higher education contexts (Karaelmas et al., 2025; Vilhunen et al., 2025) or primary-secondary education (Carmona-Galindo et al., 2025; Reynante et al., 2024).

Sixth, integration between immersive technology and AI remains loose. The study by Miranto et al. (2025) on the performance of 3D assets in virtual reality simulations and the study by Carmona-Galindo et al. (2025) on VR-based experiential learning both focus on technical aspects (rendering performance, delivery of immersive content) without

genuinely integrating conversational AI capabilities into those VR environments; such integration is only mentioned as a future research direction, not something that has been implemented and tested. Seventh, there is a significant geographic and equity gap. Studies in this corpus are dominated by European, North American, and some Asian contexts (e.g., Karaelmas et al., 2025 in Turkey; Obracht-Prondzyńska et al., 2022 in Poland), while studies on AI-based climate education in low-resource education contexts or Global South countries remain rare, even though vulnerability to the impacts of climate change is in fact concentrated in those regions, as emphasized in the climate communication review by Schäfer et al. (2026).

Proposed Research Agenda

In response to the various existing gaps, future research in the field of AI and climate change education needs to prioritize the development and validation of bias and accuracy audit protocols specifically designed to assess climate-change-themed generative AI output. The findings of Atkins et al. (2024) and Nguyen et al. (2025) regarding potential bias in generative AI content point to the need for standardized benchmarks that go beyond the ad hoc prompt testing conducted by Raja et al. (2025) and Boni (2025), toward evaluation frameworks that can be replicated across models and educational contexts.

Second, future research needs to design and evaluate AI tools specifically aimed at countering climate misinformation in educational contexts, with pre/post and longitudinal outcome measurement. Initial steps in this direction have been pioneered by Hornsey et al. (2025) in the context of reducing climate skepticism, but they need to be expanded by drawing on the misinformation characteristics mapped by Heidari et al. (2026) in geography education, so that designed AI interventions genuinely target empirically identified disinformation patterns. Third, learning-analytics-based research needs to be expanded using larger multi-site samples and triangulation of physiological, behavioral, and self-report data sources. This approach can be built upon the methodological foundations developed by Morrison et al. (2020) through galvanic sensors and by Vilhunen et al. (2025) through online situational engagement measurement, but needs to be replicated at a broader institutional scale and across cultures.

Fourth, the integration of conversational AI into immersive climate learning environments (VR/AR) needs to be examined more deeply, moving from technical feasibility studies such as that conducted by Miranto et al. (2025) toward pedagogical effectiveness studies that test the combined impact of VR immersion and conversational AI interaction on the understanding of abstract climate concepts, in line with the experiential pedagogical needs identified by Carmona-Galindo et al. (2025) and Reynante et al. (2024). Fifth, AI-based climate education research needs to be extended to professional and vocational training pathways, including engineering, health, and teacher education, beyond the single nursing curriculum example identified in the review by Çiçek and Özoğlu (2026). This expansion is important given that professionals across various sectors will directly face the impacts of climate change in their work practice.

Sixth, equity-oriented and contextual studies in Global South countries need to be prioritized, examining access, infrastructure, and culturally responsive AI-climate curricula. This priority is in line with the intersectional climate justice framework raised by Nguyen et al. (2025) and the SDG-based action agenda proposed by Olaybal et al. (2025), both of which emphasize the importance of representing groups and regions most vulnerable to the impacts of climate change. Seventh, cross-disciplinary collaboration that explicitly connects AI/ML researchers, climate scientists, and education/learning science researchers needs to be built more structurally. As shown by the diversity of publishing disciplines in this corpus ranging from policy and smart-city journals (Obracht-Prondzyńska et al., 2022) to environmental psychology journals (Reynante et al., 2024) and interdisciplinary climate review journals (Schäfer et al., 2026) research in this field currently still tends to originate from a single disciplinary perspective; more structured collaboration could accelerate knowledge synthesis and practical application in the field.

Research Limitations

This review is based on a single, deliberately limited Scopus data export (16 English-language journal articles after filtering by document type/language from an initial 38 documents) and does not cover conference papers, book chapters, gray literature, or studies in languages other than English, nor does it cover other databases (e.g., Web of Science, ERIC, or IEEE Xplore). Thematic clustering was performed manually given the small corpus size, rather than through software-assisted bibliometric co-word analysis (e.g., VOSviewer or Bibliometrix), which is more recommended for larger-scale reviews in future research. Conclusions regarding trends, particularly the publication surge in 2025, should be interpreted with caution given the small sample size and the potential indexing lag for the most recent 2026 records).

Conclusion

The intersection of artificial intelligence and climate change education is a still-small but rapidly growing field, with more than three-quarters of the identified literature published in the last two years of this data range. The knowledge structure of this field is currently organized around six interrelated themes: generative AI and literacy, misinformation and science communication, immersive and experiential learning, engagement and learning analytics, ML-based awareness assessment, and the framing of sustainability/justice/policy drawn from a striking diversity of disciplines. The short-term direction of this field points toward auditing generative AI content for climate-issue-specific bias, deeper integration between conversational AI and immersive technology, expansion of learning analytics infrastructure, and a stronger research focus on equity and Global South countries. As the diffusion of generative AI tools into classrooms and public climate discourse continues to expand, systematic and outcome-oriented research bridging AI capability with pedagogical effectiveness will be crucial to ensure that this technology strengthens, rather than weakens, climate literacy)

AI Declaration

The authors declare that Artificial Intelligence (AI) tools were used in the preparation of this manuscript. Specifically, ChatGPT was utilized to assist in summarizing and synthesizing information from the reviewed literature during the screening and analysis stages of the systematic review. All AI-generated outputs were critically evaluated, verified, and revised by the authors to ensure accuracy, consistency, and alignment with the original sources. The authors take full responsibility for the content, interpretations, and conclusions presented in this manuscript.

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