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PAPER

Responsible Generative Artificial Intelligence for Sustainable Pedagogy Systems: A Conceptual Framework for the Global South

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ABSTRACT

This study examines the growth and intellectual structure of scholarly literature on responsible generative artificial intelligence (GAI) in pedagogy and proposes a context-sensitive conceptual framework for responsible GAI adoption in the Global South. Using bibliometric analysis and systematic review, the study analyzes publications published between 2022 and 2025 extracted from the Dimensions AI database. The bibliometric findings indicate a rapid expansion of the field, with an annual publication growth rate of 18.92%, reflecting increasing academic interest in GAI-enabled pedagogy. Medical education journals dominate the research landscape, with *BMC Medical Education* (22 articles; 227 citations) and *JMIR Medical Education* (13 articles; 355 citations) emerging as the most productive sources, while *Scientific Reports* exhibits the highest citation impact (8 articles; 628 citations). In terms of geographical contribution, the United States (40 articles), China (35 articles), and Australia (16 articles) lead in research output, whereas selected Global South countries, particularly the United Arab Emirates (497 citations), demonstrate high scholarly influence despite lower publication volume. Thematic analysis reveals a strong focus on artificial intelligence, generative AI, medical education, and language teaching, alongside emerging but underdeveloped themes related to ethics, governance, and sustainability. Insights from the systematic review identify ethical awareness, trust, institutional support, infrastructural readiness, and AI competence as key determinants shaping adoption. Accordingly, synthesizing these findings, the study advances an extended TAM that conceptualizes responsible GAI adoption within pedagogical systems of the Global South.

KEYWORDS

generative artificial intelligence (GAI), sustainable pedagogy, global south, technology acceptance model (TAM), Society 5.0, Society 6.0

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1 INTRODUCTION

The intellectual origins of artificial intelligence (AI) can be traced to the mid-twentieth century [1, 2]. However, its educational significance has intensified only in recent years due to rapid advances in computing power, the availability of big data, cloud infrastructures, and machine learning algorithms [3, 4, 5]. These developments, often associated with the broader vision of "*Society 6.0*," have enabled the emergence of generative artificial intelligence (GAI), systems capable of producing human-like text, images, code, and analytical outputs [6, 7]. Unlike earlier educational technologies that primarily supported automation or content delivery, GAI actively participates in knowledge creation and meaning-making processes, thereby reshaping pedagogical practices, assessment models, and academic labor across education systems [8].

At the global level, AI is increasingly positioned as a strategic enabler of sustainable education [9]. The United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Organization for Economic Co-operation and Development (OECD) emphasize the potential of GAI to support inclusive access, personalized learning pathways, teacher support, and scalable educational provision, aligning closely with Sustainable Development Goal 4 (SDG4), which seeks to ensure inclusive, equitable, and quality education for all [10, 11]. Scholarly work suggests that AI-driven personalization, adaptive learning systems, and automated feedback mechanisms can help address persistent challenges such as overcrowded classrooms, teacher shortages, and uneven learning outcomes [5, 7]. However, the literature also cautions that the realization of these benefits depends heavily on governance structures, institutional capacity, and ethical safeguards [1, 10, 12].

A substantial proportion of the empirical literature on GAI in pedagogy has emerged from the medical and health sciences, where technology-enhanced learning has long been embedded within professional training [13, 14]. Alkhaaldi et al. [8], examining 325 medical students in the United Arab Emirates, found that 63.4% of respondents use AI tools to explore new medical topics and support research activities. These findings are consistent with broader European evidence, where Weidener and Fischer [3] reported that although only 38.8% of 487 students from Germany, Austria, and Switzerland had prior experience with AI-based chat applications such as ChatGPT, interest and anticipated future use were growing rapidly. Medical education studies consistently highlight AI's perceived value for diagnostic support, research efficiency, and clinical decision-making [15, 16, 17]. However, these studies also reveal persistent challenges related to uneven access, limited formal training, and ethical uncertainty, suggesting that technological adoption alone does not ensure responsible or sustainable integration [15, 18].

Beyond the medical domain, scholarly attention has increasingly shifted toward higher education contexts, where GAI is transforming teaching, learning, and assessment practices [9, 16]. In China, Zhou et al. [2] investigated 456 academic physicians engaged in teaching roles and found that the most common uses of GAI included querying teaching content (79.5%) and generating teaching materials (65.6%). Similar patterns have been documented across universities in Asia, Europe, and North America, where GAI is used for lesson planning, assessment design, feedback generation, and academic writing support [19, 20, 21]. From a student perspective,

Tung and Dong [22] found strong support for AI education among Malaysian university students, with 71% believing that AI-related learning can enhance career prospects and 69.44% advocating that AI education should be made available to all students. Comparable findings from Indonesia, India, Vietnam, and Bangladesh emphasize the perceived role of AI in enhancing employability, digital competencies, and global competitiveness [23, 24]. At the same time, critical scholars warn that without appropriate ethical safeguards, generative AI may reinforce academic dishonesty, learner dependency, epistemic bias, and unequal learning outcomes [7, 8].

Parallel strands of literature examine the impact of GAI on academic research practices and supervision. Ujkani et al. [2] and Zhou et al. [18] reported limited familiarity with GAI tools for data analysis among research supervisors, coupled with growing recognition of their future relevance. Studies from South Africa similarly note cautious optimism among academics, alongside concerns related to data integrity, authorship, transparency, and widening skill gaps [25, 26]. Conceptual analyses argue that while GAI has the potential to enhance creativity and productivity, its educational application remains constrained by limited institutional readiness and conceptual clarity [27, 28, 29].

The global diffusion of large language models (LLMs) has further intensified debates surrounding GAI in education [2]. As the most widely adopted GAI chatbot to date, ChatGPT enables the production of original content and immediate responses, reshaping learning, assessment, and research practices at scale [15]. Importantly, ChatGPT has become a broadly accessible global tool, experiencing especially rapid adoption in low- and middle-income countries [24, 25]. According to the National Bureau of Economic Research (NBER), ChatGPT has been adopted by approximately 10% of the world's adult population, reflecting its unprecedented reach and influence [30]. Studies from the Global South, including Nepal, India, Kenya, Ghana, and Bangladesh, highlight both the democratizing potential of such LLMs in expanding access to learning support and the associated risks related to plagiarism, data privacy, linguistic bias, and infrastructural inequality [24, 26, 31]. However, ethical challenges are particularly acute in Global South contexts, where weak regulatory frameworks, digital divides, and limited AI literacy can amplify existing educational inequalities and governance gaps [23, 25, 26].

Within this evolving body of scholarship, the concept of responsible GAI for sustainable pedagogy systems has gained increasing relevance [32]. Responsible GAI refers to the ethical, transparent, accountable, and inclusive deployment of generative technologies, emphasizing fairness, accountability, data protection, and human oversight [33, 34]. Sustainable pedagogy systems, in turn, prioritize long-term educational quality, inclusivity, cultural relevance, and institutional resilience [35, 36]. The literature suggests that aligning responsible GAI with sustainable pedagogy offers a pathway for advancing SDG4 by enhancing equitable access to learning, supporting teachers, promoting lifelong learning, and mitigating structural barriers in resource-constrained contexts [10, 11]. However, achieving this alignment requires integrated governance frameworks, pedagogical redesign, and context-sensitive implementation strategies that reflect the socio-economic realities of the Global South [24, 29]. In this context, the present study has two primary objectives: (i) to examine the growth and trends of scholarly literature on GAI in pedagogy, and (ii) to develop a conceptual framework for the implementation of responsible GAI that supports sustainable pedagogical systems in the Global South.

2 METHODOLOGY

To achieve the study's objectives, a mixed-method approach combining bibliometric analysis and systematic review was employed. Bibliometric analysis is a quantitative technique used to evaluate and map scholarly literature by examining bibliographic data such as authors, keywords, citations, and publication sources over time [37, 38]. This method was selected because it facilitates the identification of research trends, intellectual structures, and thematic evolution through scientific mapping and network analysis, thereby addressing the first research objective. To complement the quantitative insights derived from the bibliometric analysis, a systematic review was conducted to provide a rigorous qualitative synthesis of key theories and empirical findings in the existing literature. A systematic review is a structured and transparent approach to identifying, evaluating, and synthesizing prior research to address a clearly defined research question [39, 40]. In this study, the systematic review serves as the foundation for developing a conceptual framework for the adoption of GAI in sustainable pedagogical systems of the Global South, thereby fulfilling the second research objective.

For the bibliometric analysis, this study followed a four-step data selection process consisting of Identification, Screening, Eligibility, and Selection (see Figure 1). In the identification phase, data were retrieved from the Dimensions AI database, a comprehensive, AI-powered, and freely accessible research platform developed by Digital Science that integrates over 159 million publications across multiple disciplines. This database was selected to ensure both affordability and the quality of research data. During this phase, the search string was applied: *("responsible AI" OR "ethical AI" OR "trustworthy AI" OR "ChatGPT" OR "accountable AI" OR "human-centered AI" OR "sustainable AI" OR "AI ethics" OR "AI governance") AND ("sustainable learning" OR "teaching" OR "education for sustainability" OR "green education" OR "eco-education" OR "environmental education" OR "education for sustainable development" OR "climate education" OR "SDG education" OR "green pedagogy" OR "eco-training")*, yielding 102,051 publications. In the screening phase, records were filtered based on title and abstract relevance, resulting in 5,189 publications. During the eligibility phase, further refinements were applied by limiting the data to the last five years (2022–2026), journal articles only, open-access publications, and subject fields including *Education, Artificial Intelligence, and Information and Computing Science*, which reduced the dataset to 1,273 publications. In the final selection phase, 486 publications were retained after manually filtering for English-language documents using MS Excel. The selected publications were subsequently analyzed using Biblioshiny (R) and VOSviewer, chosen for their strengths in comprehensive bibliometric analysis and network visualization, respectively [37].

For the systematic review, the article selection process followed the same four-step procedure (see Figure 2). In the identification phase, articles were drawn from the 487 publications identified through the preceding bibliometric analysis, after which titles were manually screened for relevance, resulting in 232 documents. During the screening phase, abstracts were reviewed to further refine the dataset, narrowing it to 73 articles. In the eligibility phase, inclusion criteria were applied to retain studies that explicitly addressed GAI, responsible or ethical AI, ChatGPT in education, and issues related to sustainable pedagogy, sustainable education, or learning, yielding

33 articles. In the final selection phase, only studies published from 2023 onward were included, resulting in a final corpus of 25 articles. This systematic and rigorous selection process ensured that the reviewed literature was both current and highly relevant to the study's focus on generative AI and its implications for sustainable pedagogical systems.

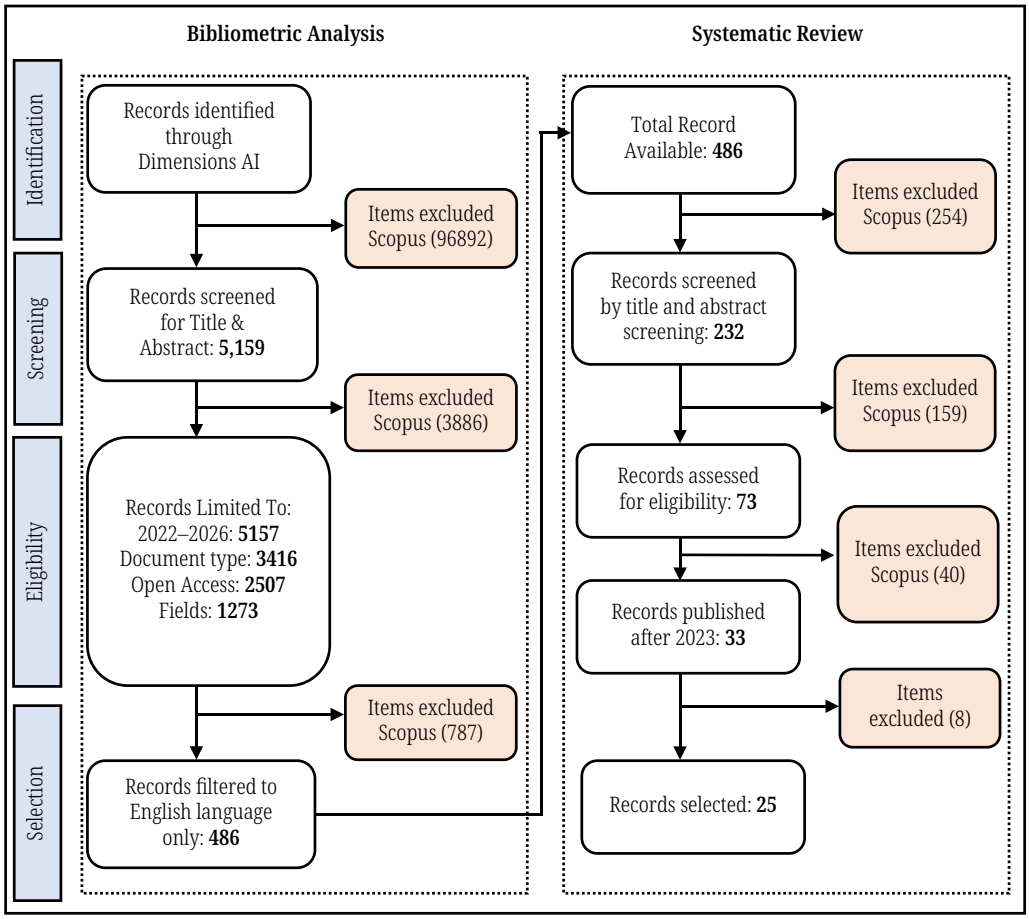

Fig. 1. PRISMA flowchart showing data selection process

3 RESULTS

3.1 Bibliometric analysis

According to Basnet et al. [37] and Xiao et al. [41], bibliometric analysis is broadly categorized into two main approaches: (i) performance analysis and (ii) science mapping. Performance analysis focuses on assessing research productivity and impact by examining indicators such as publication output, citation counts, influential authors, leading journals, and contributing countries [38, 42]. In contrast, science mapping investigates the intellectual and conceptual structure of a research field by analyzing relationships among authors, documents, and keywords through co-authorship, co-citation, and keyword co-occurrence networks, thereby uncovering thematic patterns and the evolution of knowledge [18, 43]. Accordingly, this study adopts a comprehensive bibliometric approach that integrates both performance

analysis and science mapping to provide a holistic examination of the research landscape.

Performance analysis. The performance analysis of this study includes a dataset summary, annual scientific production, the lifecycle of scientific production, the most relevant sources and their impact, most relevant countries and their impact, and the most globally cited documents.

Dataset summary. The dataset analyzed in this study comprises 486 journal articles published between 2022 and 2026 (refer to Table 1), reflecting the recent and rapidly expanding body of research on Responsible GAI in Sustainable Pedagogy. These articles were drawn from 321 distinct sources, demonstrating the multidisciplinary nature of the field. The annual publication growth rate of 18.92% indicates increasing scholarly attention, while the average document age of 1.71 years underscores the contemporary relevance of the literature. On average, each document received 19.67 citations, suggesting a notable research impact. The dataset includes 218 Author Keywords and 218 Keywords Plus, highlighting thematic diversity and consistency. A total of 2,054 authors contributed to the publications, with an average of 4.65 co-authors per document, indicating strong collaborative practices. However, international co-authorship remains limited at 9.05%. All included documents are peer-reviewed journal articles, ensuring academic rigor and consistency.

Table 1. Summary of the dataset extracted

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2022:2026
Sources (Journals, Books, etc.)	321
Documents	486
Annual Growth Rate %	18.92
Document Average Age	1.71
Average citations per doc	19.67
DOCUMENT CONTENTS	
Keywords Plus (ID)	218
Author's Keywords (DE)	218
AUTHORS	
Authors	2054
Authors of single-authored docs	120
AUTHORS COLLABORATION	
Single-authored docs	123
Co-authors per doc	4.65
International co-authorships %	9.053
DOCUMENT TYPES	
Article	486

Annual scientific production. Annual scientific production denotes the volume of scholarly publications generated within a given year [43]. The analysis reveals a clear and consistent upward trend in research output on Responsible GAI in sustainable pedagogy over the past five years (Figure 2). Scholarly publications increased markedly from only 2 articles in 2022 to 80 in 2023, followed by substantial growth in 2024 with 182 articles and a peak of 218 articles in 2025. Notably, 4 articles were already published in January 2026 at the time of data extraction (13 January 2026), indicating continued momentum. Therefore, this rising trajectory reflects the rapidly growing academic interest and the increasing relevance of GAI in advancing sustainable pedagogical systems, as found by Ujkani et al. [18].

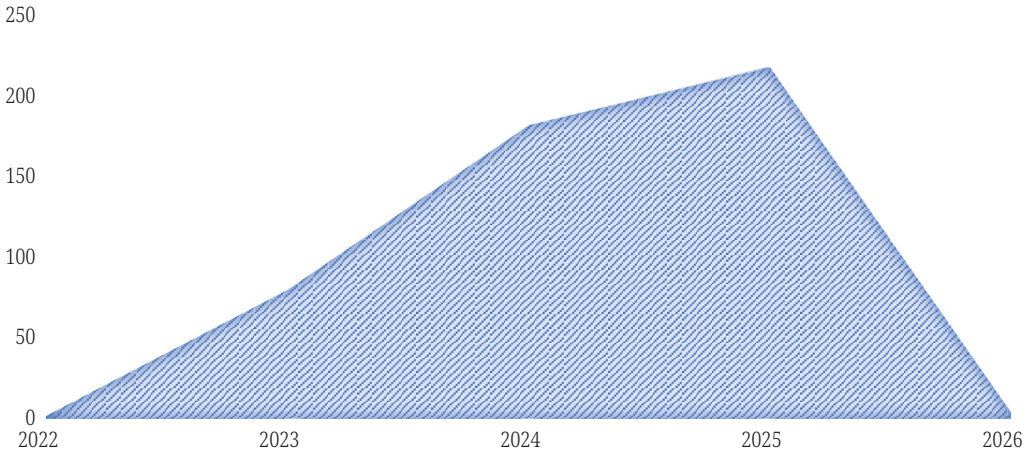

Fig. 2. Annual scientific production

Life cycle of scientific production

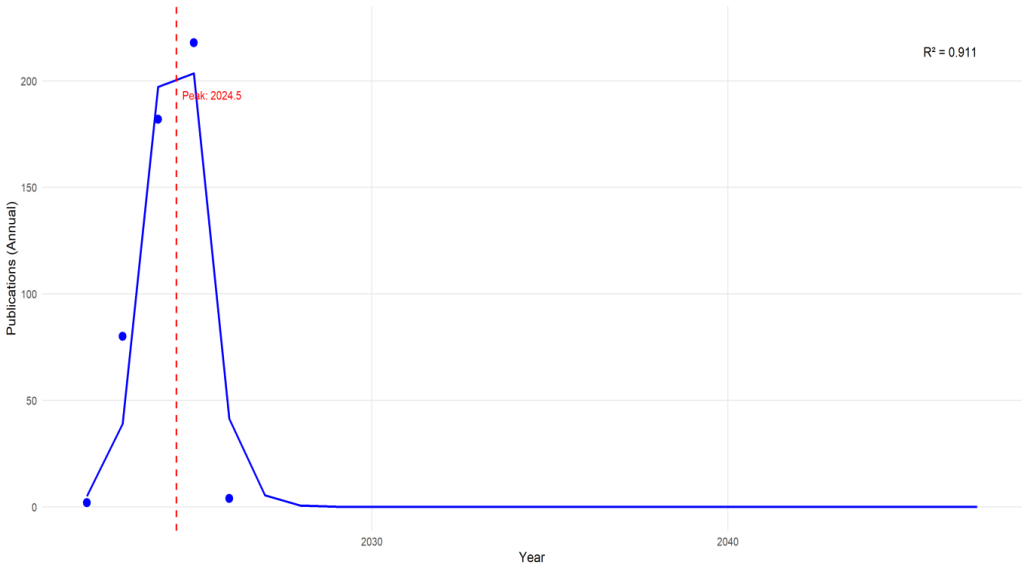

Fig. 3. Life cycle of scientific production

The lifecycle of scientific production refers to the temporal pattern through which a research field evolves, typically progressing from emergence and rapid growth to saturation and consolidation [40]. As depicted in Figure 3, the lifecycle model applied in this study indicates that the field has entered a saturation phase (K = 494), suggesting that publication output is approaching its theoretical upper limit. The model identifies 2025 as the peak year, with 262 publications, marking the point at which growth begins to stabilize. The estimated growth duration (Δ_t = 2.1 years) reflects a rapid expansion phase, highlighting the accelerated scholarly response to responsible GAI in pedagogy. The model demonstrates a strong fit, as indicated by a high R^2 value of 0.911, meaning that over 91.1% of the variance in publication output is explained by the lifecycle model. Additionally, the relatively low root mean square error (RMSE) value of 26.57 indicates minimal deviation between observed and predicted values, confirming the robustness and reliability of the lifecycle analysis.

Most relevant sources and impact

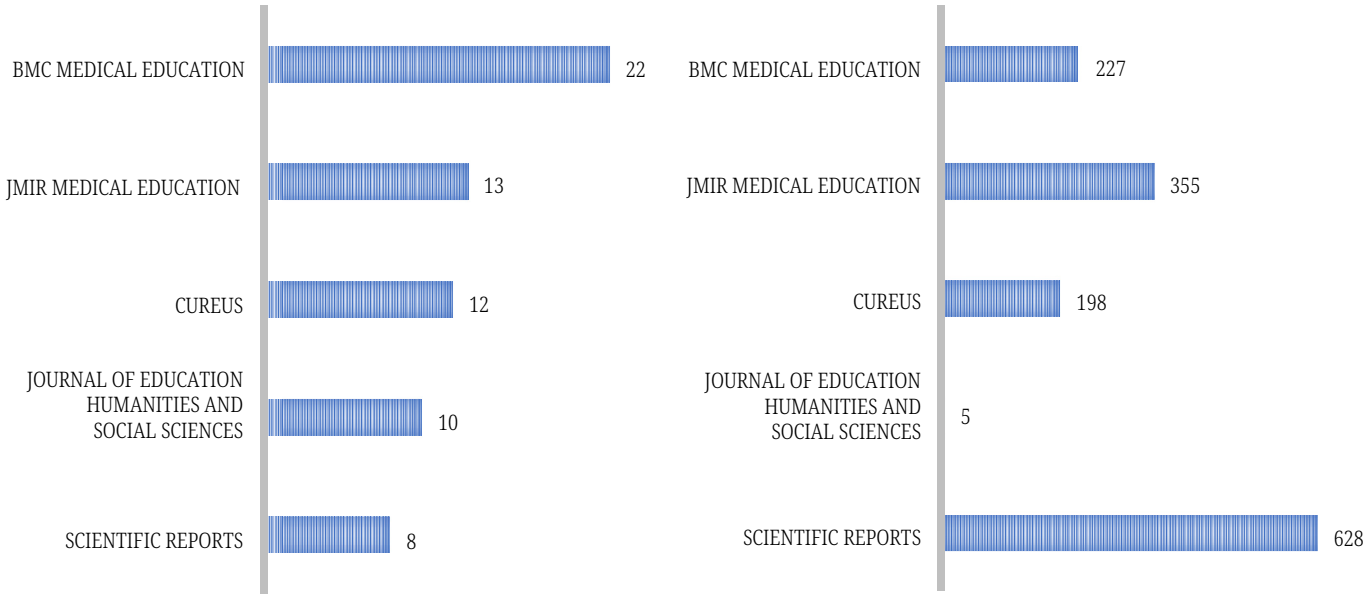

Fig. 4. Most relevant sources and their impact

Most relevant sources are journals with the highest publication counts and citation impact, while sources' local impact reflects their influence within a field based on total citations [38, 41]. Figure 4 illustrates the top five sources, with the left chart presenting publication volume and the right panel showing total citation-based impact. The results indicate that journals within the healthcare sector dominate publication output, with *BMC Medical Education* (22 articles) and *JMIR Medical Education* (13 articles) leading in productivity. However, higher publication volume does not necessarily translate into greater scholarly impact. For instance, *Scientific Reports* published fewer articles (8) yet received the highest number of citations (628), and *Cureus* with 12 articles and 198 citations, highlighting its strong visibility and cross-disciplinary influence. Conversely, Journal of Education Humanities and Social Sciences (articles = 10, TC = 5) shows moderate productivity but minimal citation impact. The findings suggest that while medical education journals are more active in publishing GAI-related research [18, 43], impact is unevenly distributed and influenced by journal scope, audience, and citation reach rather than volume alone.

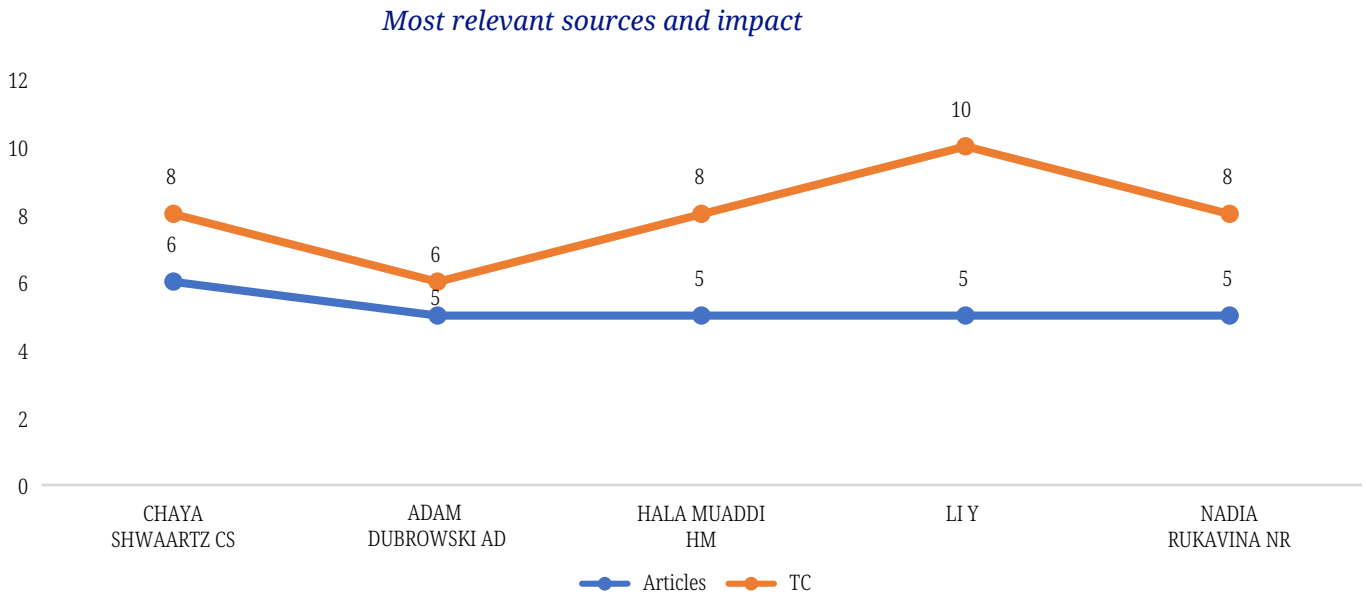

Fig. 5. Most relevant sources and their impact

Most relevant authors are those who contribute the highest number of publications, reflecting their productivity and active engagement within a research field [37, 42]. Figure 5 presents the top five most relevant authors based on the number of articles published and the total citations (TC) received. The findings show that Chaya Shwaartz CS leads in terms of productivity with six publications, although the associated citation count remains modest. Several authors, including *Adam Dubrowski AD, Hala Muaddi HM, Li Y*, and *Nadia Rukavina NR*, each contributed five articles, indicating a relatively even distribution of scholarly output among leading contributors. Notably, *Li Y* received the highest number of total citations (TC = 10) despite not having the highest publication count, suggesting greater research visibility or influence. Overall, the results indicate that higher productivity does not necessarily correspond to higher citation impact, highlighting differences between publication activity and scholarly influence within the field [44].

Most relevant countries. Most relevant countries are those producing the highest scholarly output on a specific topic or field [42]. Figure 6 presents the leading countries based on publication volume. The United States leads with 40 publications, followed by China with 35, indicating strong institutional capacity and policy-driven interest in responsible GAI applications in education. Australia (16) and Germany (13) also show substantial contributions, aligning with their emphasis on ethical AI frameworks and sustainability-oriented educational reforms. Notably, several countries from the Global South and emerging economies, such as Saudi Arabia (9), Malaysia (7), and India (5), are increasingly contributing to the discourse, suggesting growing awareness of the role of responsible GAI in addressing educational sustainability challenges. However, the overall distribution highlights a concentration of research in technologically advanced nations, while contributions from many Global South regions remain limited [28, 29]. This imbalance reinforces the relevance of the study's focus on developing context-sensitive frameworks to support responsible GAI adoption in sustainable pedagogical systems globally.

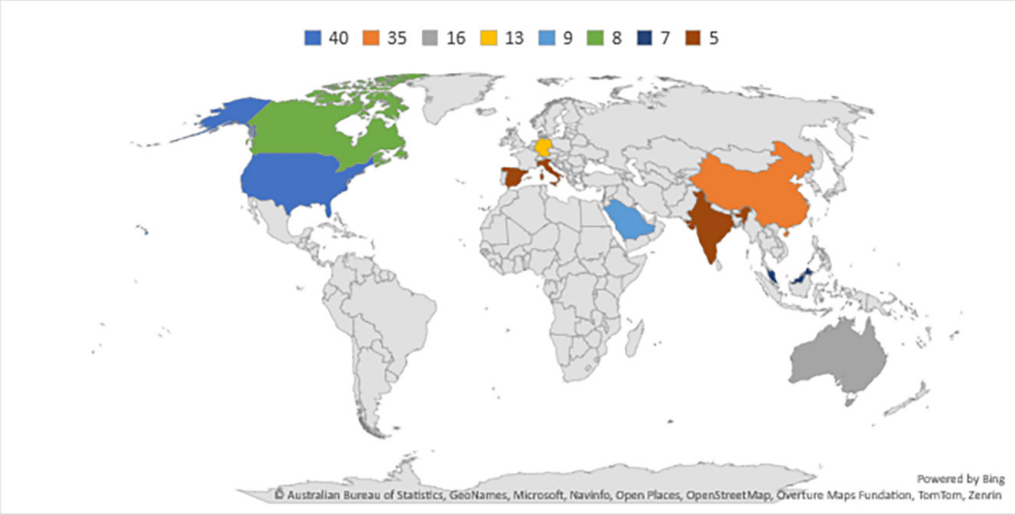

Fig. 6. Most relevant countries

Most cited countries. Most cited countries are those whose scholarly publications receive the highest total citations, reflecting greater research influence and academic visibility within a field [37]. Table 2 presents the leading countries based on total citations and average citations per article in studies on responsible GAI for sustainable pedagogy. The United States ranks first with 1,142 total citations, demonstrating its extensive scholarly influence and sustained engagement in this study area. Germany follows with 720 citations and a comparatively high average citation rate (55.4), indicating strong impact per publication despite a lower volume of output. Notably, countries often associated with the Global South, such as the United Arab Emirates and Jordan, record substantial total citations (497 and 445, respectively), suggesting that a limited number of highly impactful, context-specific studies can significantly shape scholarly discourse. In contrast, China exhibits high research productivity (35) but relatively lower average citations (17.1), highlighting a divergence between output and influence (see Figure 5). Therefore, when compared with the most relevant countries section, these findings underscore a clear distinction between research productivity and research impact, reinforcing that contextual depth, particularly from emerging and Global South contexts, plays a critical role in advancing the discourse on responsible GAI and sustainable pedagogical systems [29, 44].

Table 2. Most cited countries

Country	TC	Average Article Citations
USA	1142	28.6
Germany	720	55.4
China	599	17.1
United Arab Emirates	497	248.5
Jordan	345	115
Australia	273	17.1
Austria	267	66.8
Spain	236	47.2
Estonia	188	188
Malaysia	161	23

Most cited documents

Table 3. Most cited global documents

Documents	TC	TC per Year	Normalized TC
BAİDOO-ANU D, 2023, *Journal of AI*	1271	317.7	18.06
HALAWEH M, 2023, *Contemporary Educational Technology*	496	124	7.05
WARDAT Y, 2023, *Eurasia Journal of Mathematics Science and Technology Education*	334	83.5	4.75
ZHANG H, 2022, *International Journal of AI in Education*	283	56.6	1.78
HERBOLD S, 2023, *Scientific Reports*	280	70	3.98

Most globally cited documents are publications receiving the highest citations across the entire scholarly database [42]. Table 3 presents the most globally cited documents in research on responsible GAI and sustainable pedagogy, highlighting studies with substantial academic influence. The leading document by Baidoo-Anu (2023) in the *Journal of AI* records the highest total citations (1,271), along with the strongest annual citation rate (317.7) and normalized impact (18.06), indicating exceptional global visibility. This is followed by Halaweh (2023) in *Contemporary Educational Technology*, which demonstrates significant influence with 496 total citations. Studies by Wardat (2023) and Zhang (2022) further reflect strong scholarly engagement, particularly in AI-enabled education contexts. Notably, Herbold (2023) in *Scientific Reports* also shows high citation performance, underscoring the role of interdisciplinary journals in amplifying research impact. These highly cited documents represent foundational and influential contributions shaping current debates on responsible GAI adoption and sustainability-oriented pedagogical practices globally.

Science mapping. The science mapping component of this study comprises co-authorship analysis, citation analysis, co-citation analysis, tree map analysis, trending topic analysis, and thematic map analysis.

Co-authorship analysis. Co-authorship analysis examines collaboration patterns among researchers based on jointly published scholarly works, revealing the structure and intensity of research partnerships [37, 43]. Figure 7 illustrates the co-authorship network at the country level for research on responsible GAI in sustainable education, constructed using countries with a minimum threshold of one document and one citation. The findings indicate that the United States occupies a central position in the collaboration network, leading with 40 documents, 1,142 citations, and the highest total link strength (26), reflecting strong international research connectivity. China follows with 35 documents and 599 citations, though its lower link strength (12) suggests comparatively limited collaborative intensity. Australia demonstrates balanced performance with moderate productivity (16 documents), strong citation impact (273), and high collaboration strength (14). Similarly, Germany, despite fewer publications (13), records substantial citation impact (720) but lower collaboration link strength (8). Hence, the network reveals uneven collaboration patterns, with a concentration of collaborative influence among developed countries, highlighting opportunities to strengthen cross-regional partnerships, particularly involving Global South contexts.

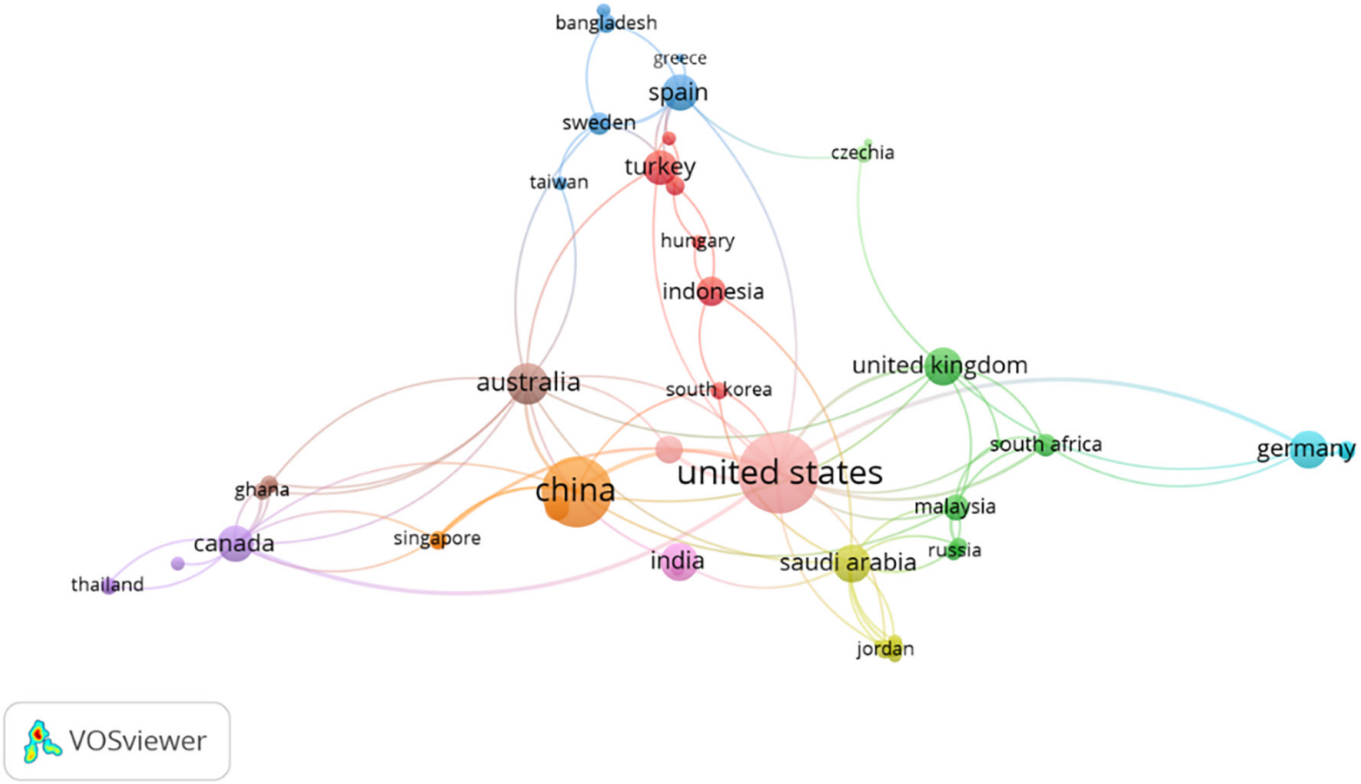

Fig. 7. Co-authorship analysis based on countries

Citation analysis

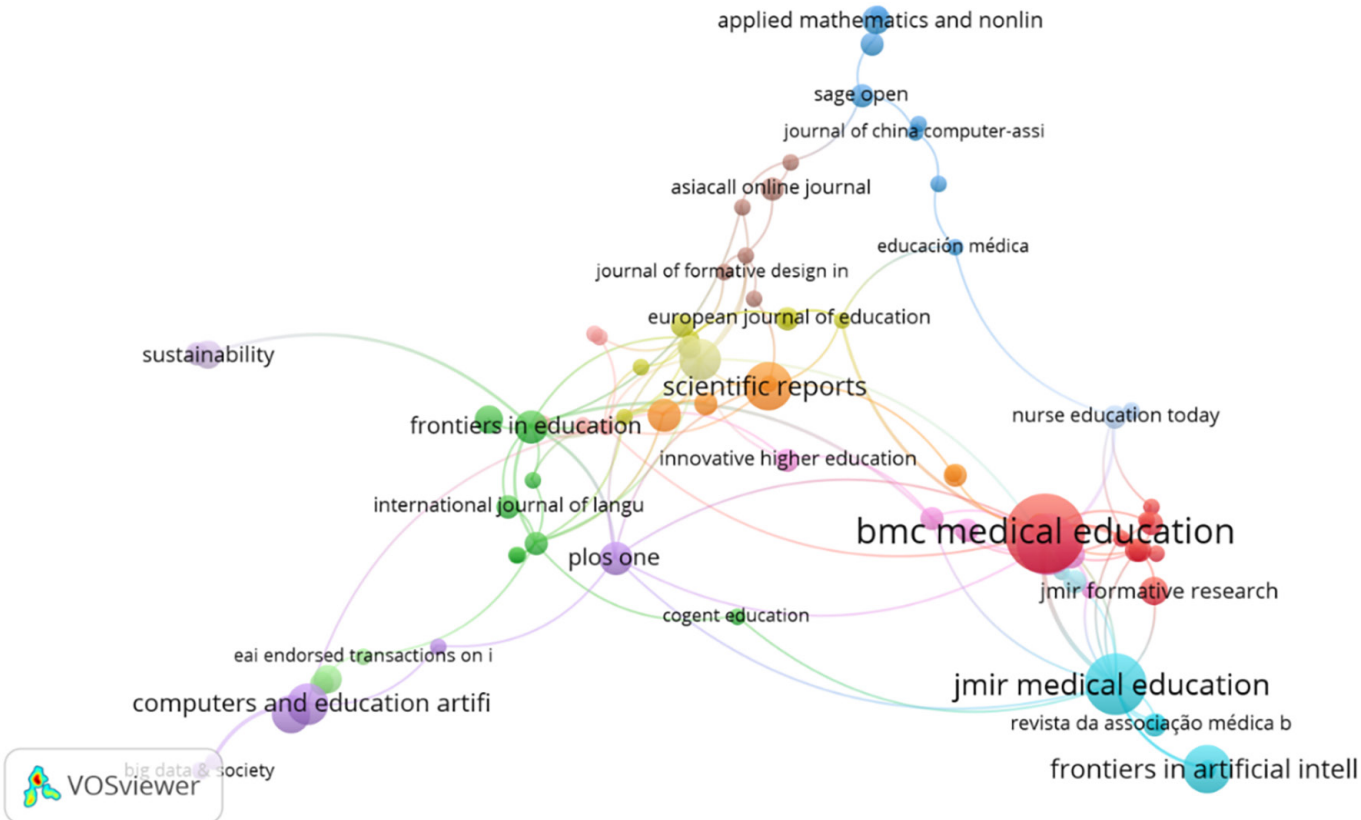

Fig. 8. Citation analysis based on sources

Citation analysis examines the influence of scholarly sources by analyzing citation relationships within a research field [18, 38]. Figure 8 presents the citation network based on sources with a minimum threshold of one document and one citation in studies on responsible generative AI for sustainable pedagogy. The findings reveal that BMC Medical Education leads the network with 22 documents, 227 citations, and the highest total link strength (20), indicating both high productivity and strong citation connectivity. This is followed by JMIR Medical Education, which, despite fewer publications (13), records higher citations (355) and a substantial link strength (18), reflecting strong scholarly influence. Frontiers in Education also emerges as an important contributor with 4 documents, 209 citations, and a link strength of 16. Notably, Scientific Reports shows high citation impact (628 citations) despite moderate publication output, though with comparatively lower link strength (12). Other sources, including *PLoS One*, *Sustainability*, *Education Sciences*, and *Cureus*, also contribute meaningfully to the citation network. Overall, the strong citation interlinkages among medical education journals align with the findings of Srivastava [27] and Verma et al. [29] and highlight opportunities to extend responsible GAI adoption across diverse disciplines, particularly within Global South contexts.

Co-citation analysis

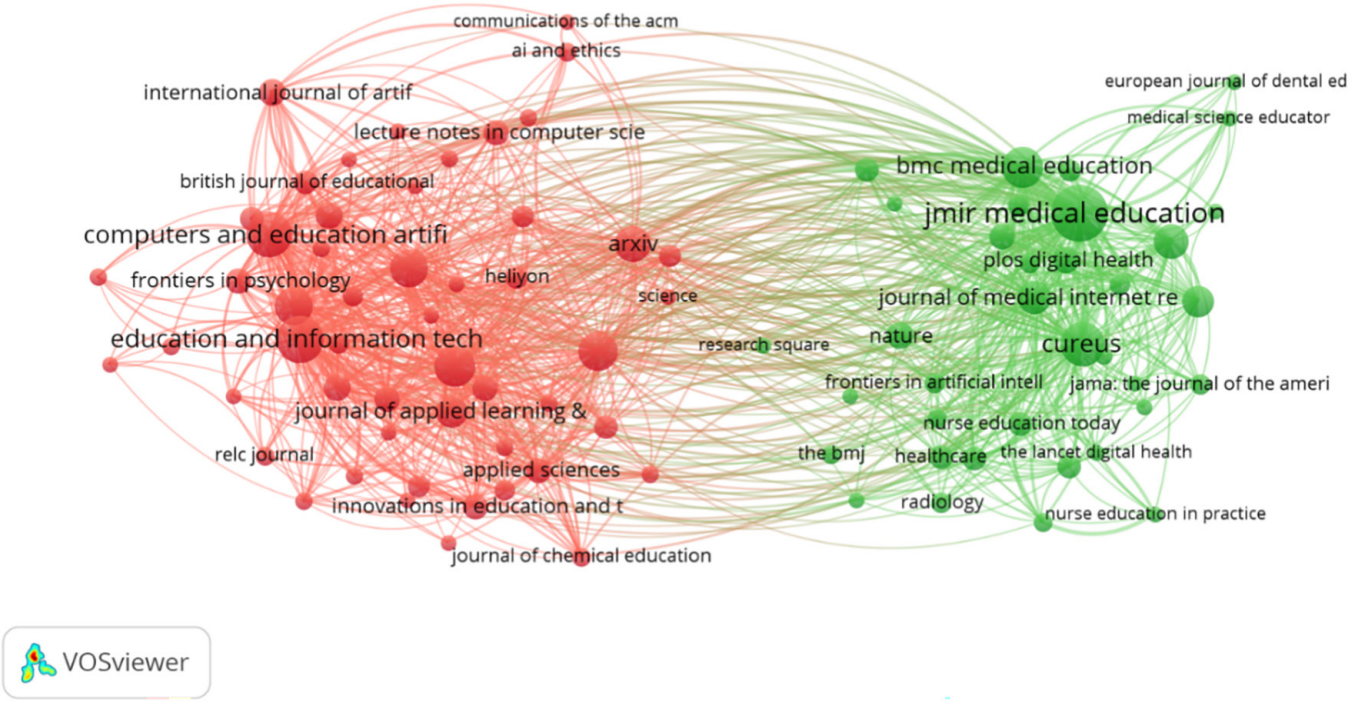

Fig. 9. Co-citation analysis based on cited sources

Co-citation analysis examines how frequently two sources are cited together, revealing the intellectual structure of a research field [37]. Based on cited sources with a minimum threshold of 20 citations, Figure 9 illustrates a co-citation network clustered into two dominant groups, represented in green and red. The green cluster is primarily anchored in medical and health-related education journals, led by *JMIR Medical Education* (258 citations; total link strength 5,952) and *BMC Medical Education* (144 citations; link strength 2,895), along with *Cureus* (165 citations; 4,152). This cluster reflects the strong influence of medical education in shaping responsible

GAI discourse. In contrast, the red cluster centers on education technology and AI-focused journals, including *Education and Information Technologies* (188 citations; 4,791) and *Computers and Education: AI* (174 citations; 3,747), highlighting pedagogical and technological foundations. The dense interconnections between clusters indicate growing cross-disciplinary integration, suggesting that responsible GAI research is increasingly bridging medical, educational, and technological domains to support sustainable pedagogy.

Tree map analysis. Tree-map analysis visualizes the prominence of keywords based on their frequency of occurrence [41, 42]. Figure 10 presents the tree-map analysis of author keywords, highlighting dominant research themes in responsible generative AI for sustainable pedagogy. The most prominent term is "artificial intelligence" (311 occurrences; 10%), confirming its central role in the literature. Closely related terms such as "intelligence AI" (156; 5%) and "AI tools" (124; 4%) indicate strong attention to applied AI technologies in educational settings. The frequent appearance of "medical education" (130; 4%) underscores the leading role of the health education domain, while pedagogical themes such as "language teaching" (96; 3%), "AI ethics" (94; 3%), and "generative AI" (78; 3%) reflect growing concern for responsible and ethical integration. Keywords including "critical thinking," "academic integrity," "AI literacy," and "responsible AI" further emphasize sustainability-oriented learning outcomes. This distribution reveals not only convergence but also a thematic imbalance, with technological and medical education keywords dominating ethical and sustainability-oriented terms. This suggests that while responsible GAI is increasingly discussed, its integration into broader, context-sensitive sustainable pedagogy, particularly beyond health and language domains, remains underdeveloped and warrants deeper scholarly attention [27, 29].

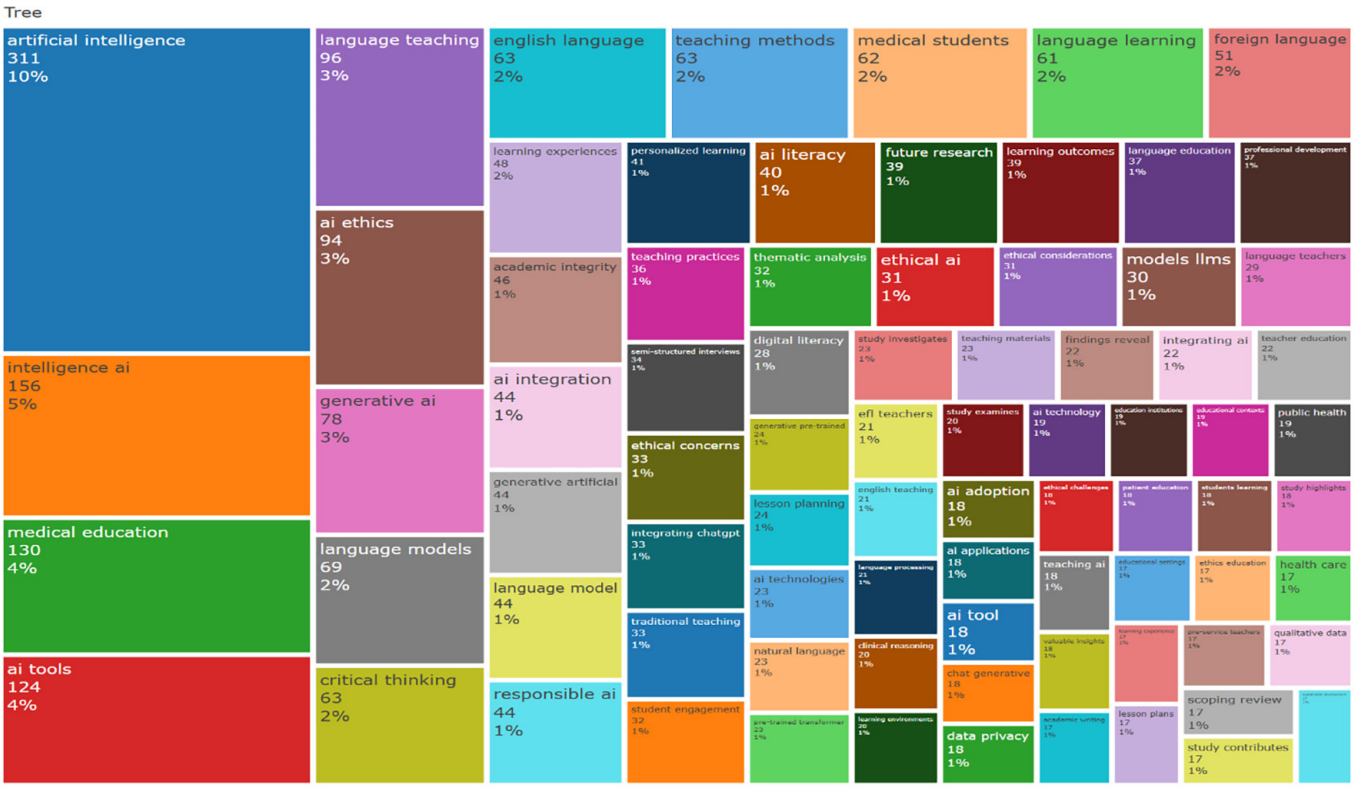

Fig. 10. Tree-map analysis

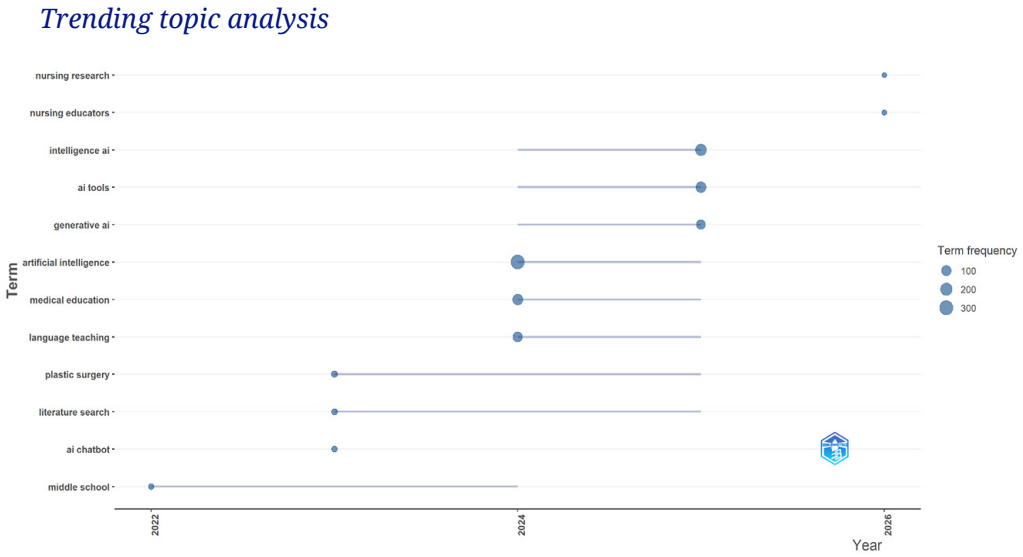

Fig. 11. Trending topic analysis

Trend topic analysis identifies the temporal evolution of dominant research themes by examining keyword frequency across time [44]. Figure 11 illustrates the progression of key topics in research on responsible GAI for sustainable pedagogy over the study period. Early-stage research in 2022 focused on foundational and context-specific themes such as middle school education, indicating exploratory adoption of AI in basic educational settings. In 2023, the emergence of applied themes including AI chatbots, literature search, and domain-specific areas such as plastic surgery reflects growing experimentation with generative AI tools in specialized educational and professional contexts. The year 2024 marks a significant shift, with AI (311 occurrences), intelligence AI, AI tools, generative AI, medical education, and language teaching dominating the discourse, signaling rapid expansion and consolidation of AI-driven pedagogy. Most recently, in 2026, the appearance of topics such as nursing educators and nursing research suggests increasing attention to professional capacity building and discipline-specific sustainability, highlighting a move toward responsible and practice-oriented GAI integration.

Thematic map analysis. A thematic map is a bibliometric visualization technique that helps identify and interpret key research themes according to their relevance and developmental maturity within a scholarly domain [42]. It is organized along two dimensions: centrality, which reflects a theme's importance and connectedness within the research network, and density, which indicates the internal development and conceptual coherence of a theme [44]. Based on these dimensions, themes are categorized into four quadrants: motor themes (high centrality and density), niche themes (low centrality, high density), emerging or declining themes (low centrality and density), and basic and transversal themes (high centrality, low density) [38, 41].

The thematic configuration reveals an evolving yet underdeveloped research domain on responsible GAI in sustainable pedagogy (see Figure 12). The absence of motor themes suggests that the field has not yet consolidated mature, highly influential research streams capable of steering scholarly discourse, a pattern often observed in emerging technological domains [44]. Niche themes, including *virtual teaching assistants, generative AI tools, developing teaching materials, enhancing teaching*

effectiveness, and pre-trained transformer–ChatGPT, demonstrate high internal coherence but weak external connectivity. This indicates that existing studies remain application-oriented and fragmented, focusing on functional experimentation rather than system-wide pedagogical integration [23, 24].

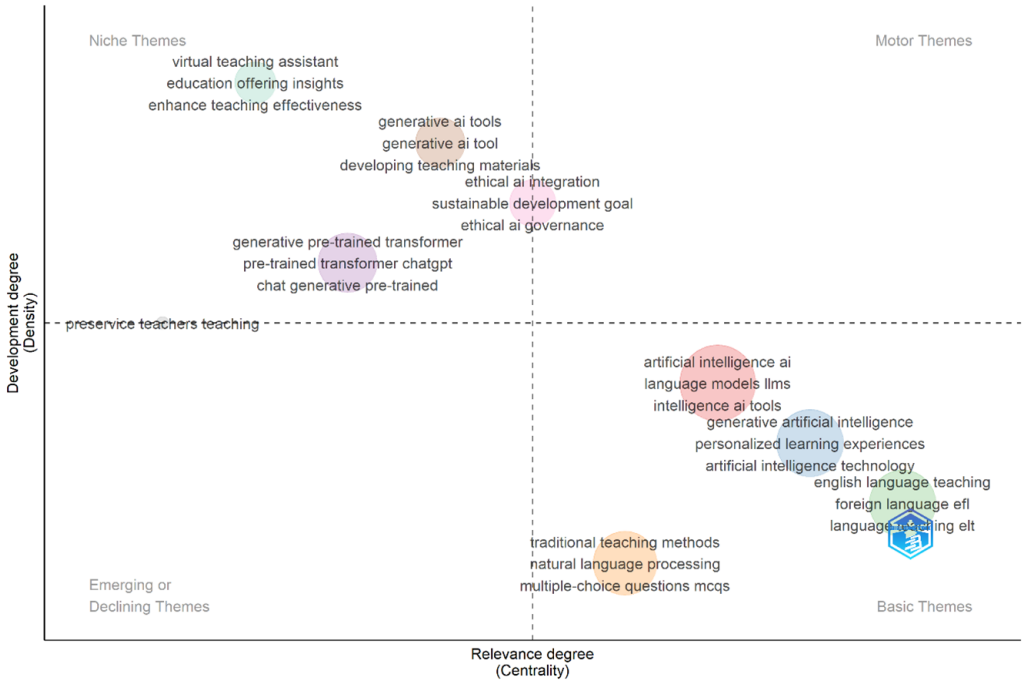

Fig. 12. Thematic map

The dominance of basic themes such as *artificial intelligence, large language models, generative AI, personalized learning experiences, AI technology, and language teaching* highlights their foundational role but limited conceptual refinement. Similar patterns have been noted by Hradilová [20], who argue that AI-in-education research often emphasizes technological potential over pedagogical theory. Importantly, lingering themes positioned between quadrants provide normative and transitional insights. *Ethical AI integration, alignment with SDGs, and ethical AI governance* occupy the space between motor and niche themes, reflecting growing ethical awareness without full mainstream adoption [19, 21]. *Preserving teachers' teaching* roles bridges niche and emerging areas, echoing concerns about professional displacement [17]. Meanwhile, *traditional teaching methods and MCQ*-based assessment lie between emerging and basic themes, signaling an ongoing recalibration between conventional pedagogy and GAI. These findings therefore underscore the urgency of centering ethics in responsible GAI-driven pedagogy, particularly in the Global South.

3.2 Systematic review

The bibliometric findings indicate a maturing yet still evolving research landscape in which responsible GAI is increasingly associated with ethics, pedagogy, and educational sustainability [9, 45], while several core themes remain insufficiently developed at the conceptual level. Although the bibliometric analysis

effectively captures scholarly trends in GAI-enabled pedagogy, thereby addressing the first objective of the study, it offers limited insight into how responsible GAI is operationalized and governed across varied educational and socioeconomic contexts, particularly within the Global South, which constitutes the study's second objective. Consequently, the discussion now transitions to a systematic review of the literature to critically explore implementation practices of responsible GAI in education.

Ethical foundation of responsible GAI in education. The integration of GAI into educational environments has intensified long-standing ethical debates concerning autonomy, fairness, epistemic integrity, and accountability (Table 4). Foundational scholarship on responsible AI positions ethics as an enabling condition rather than a constraint on innovation, particularly in high-stakes social domains such as education [14, 45]. In pedagogical contexts, this ethical imperative becomes more pronounced due to the formative nature of learning processes and the asymmetric power relations between learners, educators, and algorithmic systems [9, 46]. Concerns surrounding academic integrity dominate early and contemporary educational discourse on GAI. [17] and [47] demonstrate that GAI tools challenge conventional notions of authorship, originality, and assessment validity, especially in higher education. These challenges are not uniformly framed as technological failures but as pedagogical governance issues, echoing the argument by Bhuiyan et al. [16] that ethical risks often arise from institutional unpreparedness rather than from the technology itself. Studies examining assessment practices further note that unregulated GAI use can unintentionally privilege surface-level task completion over higher-order cognitive engagement [13, 48].

Additionally, bias and representational injustice constitute a second critical ethical domain. [26] and [17] highlight how LLMs embed linguistic, cultural, and epistemic biases due to their training data composition, which disproportionately reflects Global North knowledge systems. In educational settings, such biases risk marginalizing local knowledge traditions and disadvantaging non-native English speakers, particularly in the Global South [24, 31]. The work of Hara [19] and Sucipto and Negara [49] illustrates that educators in low-resource contexts often lack the technical capacity to interrogate algorithmic bias, thereby amplifying ethical vulnerabilities. Similarly, data governance and learner surveillance form a third ethical axis. Research on learning analytics and AI-driven personalization warns against opaque data practices that undermine informed consent and student agency [50, 51, 52]. These concerns are intensified in contexts with weak regulatory oversight, where institutional accountability mechanisms remain underdeveloped [53]. The guidance of UNESCO on AI in education emphasizes that ethical deployment requires systemic governance frameworks rather than reliance on individual educators' discretion [10, 11].

In this regard, while ethical principles such as transparency, accountability, and human oversight are widely articulated across the literature (24, 34, 54), their pedagogical operationalization remains uneven. [29] note that ethical alignment is rarely embedded into instructional design or teacher training curricula, resulting in fragmented implementation. Bibliometric evidence from this study further suggests that ethics-related themes are increasingly central to GAI pedagogy research (see Figure 12), yet their integration remains largely conceptual rather than practice-oriented. This disjunction underscores the necessity of anchoring responsible GAI within pedagogical ethics that are both context-sensitive and institutionally supported.

Table 4. Review of existing literature

Author, Year	Purpose	Method	Major Findings
[9]	Explore educators' views on human-centered AI in teaching	Phenomenology	Educators view AI as supportive but stress preserving teacher agency, ethics, and human values.
[17]	Examine AI's role in personalized learning and ethics	Qualitative	AI improves personalization and feedback but raises privacy, bias, and automation concerns.
[45]	Review approaches to teaching AI ethics	Mixed methods	AI ethics education improves ethical awareness but lacks real-world systemic integration.
[47]	Assess ethical issues of AI in medical education	Quantitative	AI enhances learning but raises privacy, bias, and transparency challenges.
[48]	Analyze student perceptions of ChatGPT	Quantitative survey	Students value efficiency gains but demand regulation and responsible curriculum guidance.
[52]	Examine clinical faculty perceptions of ChatGPT	Quantitative	Faculty show cautious optimism, citing trust, reliability, and ethical concerns.
[14]	Assess faculty knowledge of AI ethics	Cross-sectional survey	Faculty possess limited AI ethics knowledge, highlighting training and policy gaps.
[13]	Examine AI's role in educational leadership	Qualitative	AI enhances leadership efficiency but requires ethical safeguards and capacity building.
[51]	Examine GAI's role in advancing SDG4	Systematic review	GAI supports equity and adaptive learning but poses governance and bias challenges.
[50]	Analyze ChatGPT's academic strengths and risks	Quantitative	ChatGPT aids coding and research but risks overreliance and inaccuracies.
[53]	Develop policy guidance for GAI use	Quantitative survey	GAI policy needs vary by demographic and academic context, requiring adaptive governance.
[54]	Integrate ChatGPT into knowledge-centered pedagogy	Qualitative	Structured integration improves content accuracy and knowledge generation.
[34]	Examine responsible AI in primary education	Mixed methods	Teachers prioritize fairness, safety, and transparency over autonomy.
[46]	Integrate AI ethically into STEAM education	Grounded theory	Ethical AI strengthens sustainability, citizenship, and SDG-aligned learning.
[4]	Propose principle-based AI ethics education	Qualitative	Integrating medical and public health ethics prepares ethical AI practitioners.
[55]	Explore AI as curriculum transformation	Qualitative	AI offers curriculum innovation but faces ethical and rural infrastructure barriers.
[56]	Assess ChatGPT in anatomy education	Qualitative	ChatGPT boosts engagement but needs curriculum adaptation.
[57]	Identify student engagement profiles using AI analytics	Qualitative	AI-generated engagement profiles enhance understanding of learning behaviors beyond test scores.
[58]	Test TAM-based acceptance of ChatGPT	Mixed methods	Acceptance driven by usefulness, trust, competence, and self-regulated learning.
[59]	Integrate GAI into Society 5.0 education	Qualitative	GAI supports personalized, inclusive, and sustainable learning outcomes.
[19]	Examine AI in Lower Middle-Income Countries	Qualitative	AI improves access and equity but faces infrastructure and policy barriers.
[49]	Evaluate ChatGPT in assessment and feedback	Quantitative	ChatGPT moderately improves feedback and digital literacy.
[60]	Evaluate ChatGPT as teaching assistant	Mixed methods	Effective for basics but limited for advanced personalization.
[61]	Promote culturally adaptive AI education	Qualitative	Human-centered AI fosters ethics and inclusivity across cultures.
[62]	Examine ChatGPT's pedagogical benefits	Qualitative	ChatGPT enhances learning but risks misinformation and bias.

Pedagogical adoption of GAI in resource-constrained contexts. GAI has been increasingly positioned as a transformative pedagogical resource capable of addressing systemic constraints within education systems of the Global South [27, 29]. [55] and [56] identify personalization, scalability, and adaptive feedback as core affordances of AI-enabled learning, attributes particularly relevant in contexts characterized by high student–teacher ratios and limited instructional resources. Subsequent studies extend this argument by demonstrating how generative tools support lesson planning, formative assessment, and multilingual instruction [7, 57]. Further, empirical investigations conducted in low- and middle-income countries illustrate that GAI applications are most frequently deployed in language education, teacher professional support, and content generation [23, 24]. For example, [19] reports that AI-assisted feedback systems enhance learner engagement and reduce instructors' administrative workload in higher education institutions across Sub-Saharan Africa. Similarly, [58] and [59] document positive perceptions of AI-supported writing tools among pre-service teachers in Southeast Asia, particularly where access to pedagogical materials is limited.

Despite these pedagogical benefits, adoption remains uneven and contingent upon structural and institutional conditions. [8] and [49] emphasize that technological innovation in resource-constrained environments is often constrained by infrastructural instability, limited digital literacy, and weak policy alignment. Studies examining educator perspectives consistently identify lack of training, unclear ethical guidelines, and institutional ambivalence as major impediments to sustained GAI integration [60, 61]. From a sustainability perspective, GAI is framed as both a solution and a potential risk. On one hand, AI-enabled automation and personalization are associated with efficiency gains and expanded access to education, aligning with SDG4 [11, 51]. On the other hand, dependency on externally developed platforms raises concerns regarding technological sovereignty and long-term resilience in the Global South [14, 62]. [23] further caution that without contextual adaptation, GAI adoption may reproduce existing inequalities rather than mitigate them.

However, across the literature, several determinants recur as central to pedagogical adoption: perceived instructional usefulness, usability, institutional support structures, educator competence, ethical clarity, and infrastructural readiness [17, 45, 48, 51, 58]. Although these factors are often examined independently, their convergence suggests the need for an integrative adoption framework. Bibliometric patterns indicating the prominence of usability, personalization, and governance-related keywords provide limited but consistent support for this observation (see Figure 9). Therefore, this systematic review establishes a strong foundation for employing an acceptance-based model capable of capturing both pedagogical value and contextual constraints.

Conceptual framework for global south. To synthesize the ethical and pedagogical insights emerging from the literature, this study adopts the technology acceptance model (TAM) as the theoretical basis for conceptualizing responsible GAI adoption in education. Originally proposed by Fred Davis in 1989, TAM posits that Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) are primary determinants of users' attitudes and behavioral intentions toward technology [63, 64]. The model has been extensively validated in educational technology research across diverse cultural contexts [58, 65]. The applicability of TAM to GAI in education is supported by multiple empirical studies, such as [66] and [67], demonstrating that educators' willingness to adopt AI tools is strongly influenced by perceived pedagogical benefits, such as instructional efficiency, learner engagement, and assessment support [65, 68]. Similarly, ease of interaction, language accessibility, and system transparency are shown to shape both initial experimentation and sustained use [5, 69].

However, the literature also indicates that classical TAM does not fully capture the ethical and contextual complexities of GAI adoption in resource-constrained settings of the Global South [29, 58]. Ethical trust, institutional legitimacy, and contextual feasibility emerge as critical external factors [25, 26]. [24] argue that ethical alignment significantly conditions perceived usefulness, particularly in educational domains where moral legitimacy is central. Trust in AI systems, shaped by transparency and accountability, further mediates educators' acceptance decisions [50, 53]. Further, institutional support represents another pivotal external variable [14]. Studies consistently demonstrate that professional development, policy guidance, and leadership endorsement enhance both PU and PEOU, especially in under-resourced institutions [9, 17, 51]. Digital infrastructure and educator AI competence similarly function as enabling conditions rather than mere background variables, particularly in the Global South, where access disparities remain pronounced [45, 58].

Accordingly, the proposed conceptual framework extends the TAM by incorporating ethical awareness, trust, trust in AI systems, institutional support, infrastructural readiness, and AI competence as key external variables influencing individuals' attitudes toward the use of responsible GAI (see Figure 13). Attitude is further expected to positively affect behavioral intention, which in turn leads to the adoption of responsible GAI in educational contexts. The framework conceptualizes adoption as a socio-technical process shaped by pedagogical values and structural constraints, particularly within the Global South. Grounded in systematic scholarly evidence, this extended model offers a context-sensitive approach that can guide empirical validation and inform policy and practice in responsible GAI–enabled pedagogical systems.

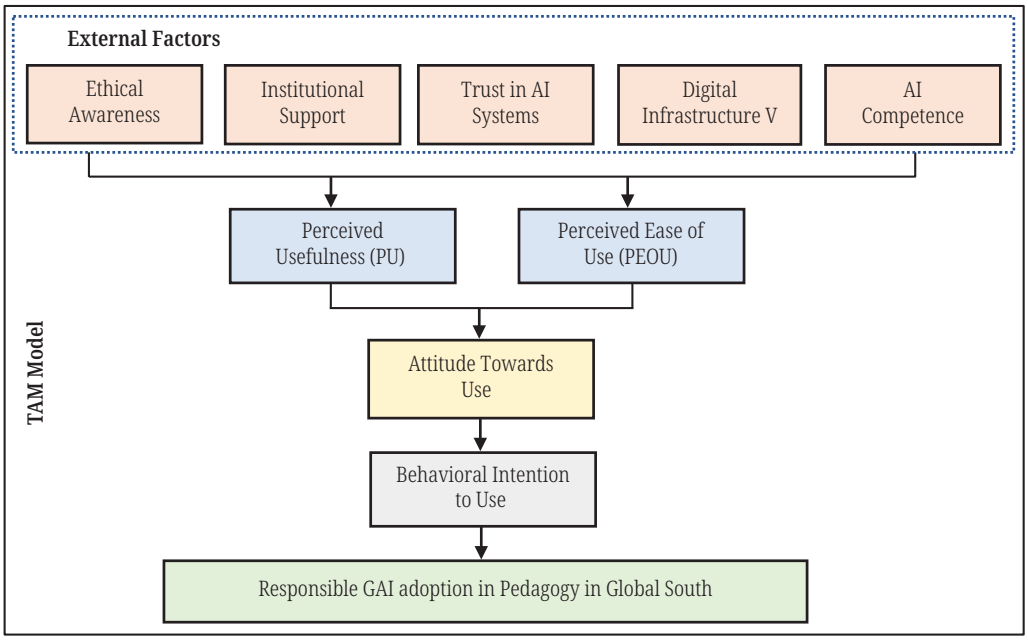

Fig. 13. Conceptual framework for GAI in pedagogy in global south

4 CONCLUSION

This study aimed to examine the growth and intellectual structure of scholarly literature on responsible GAI in pedagogy and to develop a context-sensitive conceptual framework for its adoption in the Global South. Bibliometric findings

reveal a sharp annual growth rate (18.92%) in publications between 2022 and 2025, indicating a rapid increase in academic attention. Medical education journals such as *BMC Medical Education* (22 articles, 227 citations) and *JMIR Medical Education* (13 articles, 355 citations) emerged as the most productive sources, while *Scientific Reports* demonstrated the highest citation impact (8 articles, 628 citations). The United States (40 articles), China (35 articles), and Australia (16 articles) dominated research output, though several Global South countries, such as the United Arab Emirates (497 citations), contributed highly influential studies. Thematic analysis shows a strong concentration on artificial intelligence, generative AI, medical education, and language teaching, with ethics, governance, and sustainability remaining underdeveloped but emerging themes. The systematic review highlights ethical awareness, trust, institutional support, infrastructural readiness, and AI competence as critical determinants of adoption. Accordingly, synthesizing these insights, the study proposes an extended TAM-based framework that conceptualizes responsible GAI adoption as a socio-technical process embedded within pedagogical values and contextual constraints of the Global South.

The findings offer important implications for education systems in the Global South by emphasizing that responsible GAI adoption requires ethical governance, institutional readiness, and capacity building rather than technological access alone. For Society 5.0, the study underscores human-centered, trust-based integration of GAI to enhance inclusivity and sustainability. Looking toward emerging Society 6.0, the framework highlights the need to align intelligent systems with social well-being as well as SDG4, ethical resilience, and sustainable knowledge ecosystems. Policymakers and institutions can use the proposed model to design context-sensitive AI strategies and professional development initiatives. Future research should empirically validate the framework across diverse educational levels, conduct comparative Global North–South analyses, and explore longitudinal impacts of responsible GAI on learning equity and pedagogical transformation.

4.1 Declaration of interest

The author declares no competing financial or non-financial interests related to this study.

4.2 Funding

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