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Tracing Two Decades of Artificial Intelligence in Education: A Bibliometric Analysis of Trends, Themes, and Future Directions (2000–2025)

Meikardo Samuel Prayuda* 

Universitas Katolik Santo Thomas,
INDONESIA

Fiber Yun Almanda Ginting 

Universitas Katolik Santo Thomas,
INDONESIA

Losten Tamba 

Universitas Katolik Santo Thomas,
INDONESIA

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Abstract: Despite the increasing integration of artificial intelligence (AI) into education, a comprehensive understanding of how scholarly discourse has evolved over time remains limited. Most existing studies focus on technical implementation or short-term pedagogical outcomes, often lacking longitudinal scope or thematic synthesis. This study addresses that gap by offering a 25-year bibliometric analysis of AI-related educational research, mapping its conceptual development, publication trends, and emerging priorities from 2000 to 2025. Using data sourced from Lens.org and processed through Biblioshiny (R-Studio) and VOSviewer, 350 peer-reviewed articles were analyzed based on their thematic focus, keyword evolution, authorship patterns, and citation networks. The novelty of this study lies in its integration of bibliometric mapping with temporal thematic evolution, enabling a detailed understanding of how foundational concepts, such as lifelong learning, AI literacy, and ethics, have transitioned from peripheral concerns to central research themes. Findings show a sharp increase in publication volume after 2018, reflecting the impact of cloud-based AI platforms and the pandemic-induced pivot to remote education. While “artificial intelligence” and “education” remain dominant keywords, emerging themes such as “student well-being,” “digital competency,” and “personalized learning” suggest a shift toward more human-centered and ethically conscious AI applications. The study concludes by identifying persistent gaps related to pedagogical effectiveness, global equity, and critical digital literacy, offering a roadmap for future interdisciplinary research and inclusive educational policy.

Keywords: *AI literacy, artificial intelligence in education, bibliometric analysis, educational equity, lifelong learning.*

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Introduction

Over the past two and a half decades, the intersection of artificial intelligence (AI) and education has transformed from a peripheral curiosity into a central axis of academic innovation and discourse, evolving alongside digital technologies and the expansion of data-driven practices in pedagogy (Liu et al., 2021; Schleicher, 2024). As societies around the world grapple with digitization, educational systems have been propelled toward reimagining teaching and learning paradigms, particularly through the adoption of AI technologies that offer adaptive learning, intelligent tutoring systems, and automated assessments (García-Martínez et al., 2023; Robson et al., 2020; D. Zhang & Nunamaker, 2003). This shift has been underpinned by global investment in educational technology (EdTech), growing research interest in learner analytics, and the widespread accessibility of cloud-based educational platforms (Açıkgöz et al., 2022; Uçar et al., 2025; X. Zhang et al., 2019). Consequently, the role of AI in reshaping cognitive engagement, instructional design, and assessment efficacy is no longer speculative but has become a measurable and intensively studied reality.

Despite this burgeoning interest, substantial questions remain regarding the thematic direction, consistency, and scope of AI-related educational research conducted since the early 2000s, especially as technologies have accelerated rapidly in the post-2015 period (Elyakim, 2025; Kasinidou et al., 2025; Kim, 2024). Previous studies, while rich in exploratory models and emerging frameworks, often exhibit conceptual fragmentation and methodological inconsistency. Many focus narrowly on isolated technological or pedagogical dimensions without integrating longitudinal or cross-disciplinary

* Corresponding author:

Meikardo Samuel Prayuda, Jl. Setia Budi No.479, Tj. Sari, Kec. Medan Selayang, Kota Medan, Sumatera Utara 20133, Indonesia.

✉ meichardohanon@gmail.com



perspectives capable of capturing the field's developmental trajectory. This limitation has resulted in a lack of continuity across decades, preventing the establishment of coherent narratives on how AI-integrated pedagogical goals have evolved (Biagini, 2025; Raffaghelli et al., 2020). Moreover, prior research frequently overlooked critical dimensions such as ethical accountability, equitable access, and students' emotional and cognitive well-being, particularly among digital-native cohorts like Millennials and Gen Z, leaving gaps in understanding how AI influences learner diversity, digital resilience, and inclusion (Allil, 2024; Furtner et al., 2022). Consequently, despite the proliferation of AI-related educational research, the field remains fragmented and overly descriptive, with limited synthesis connecting technological innovation to broader pedagogical and humanistic objectives. The dataset analyzed in this study, which encompasses 350 scholarly works from 2000 to 2025, underscores these weaknesses: while "artificial intelligence" and "education" dominate the discourse, underexplored yet crucial themes such as "AI literacy," "personalized learning," and "student well-being" remain peripheral, reflecting persistent thematic gaps and underdeveloped research domains.

Building upon these identified gaps, this study advances the discourse by integrating bibliometric mapping with thematic evolution to address the absence of longitudinal synthesis in prior works. Earlier research has often provided partial or short-term perspectives, concentrating either on technological applications or pedagogical innovations without connecting them across time or theoretical development. This study explicitly fills that void by examining how AI-related educational research has evolved conceptually and temporally over the past twenty-five years (Tlili et al., 2021; F. Zhang et al., 2025). In doing so, it moves beyond descriptive cataloging to reveal structural patterns, how dominant ideas have shifted, converged, or faded as the field matured. The analysis also bridges previously neglected intersections between cloud computing, ethical design, generational learning behaviors, and lifelong learning as critical vectors for understanding AI's educational trajectory (Liu et al., 2021; Schleicher, 2024). By incorporating multidimensional constructs such as well-being, student engagement, and educational equity areas rarely integrated into bibliometric syntheses, this research not only underscores the limitations of earlier studies but also positions itself at the intersection of technological innovation and human-centered education, contributing a cohesive and forward-looking perspective to the evolving discourse on AI in education.

What distinguishes this research further is its explicit response to the conceptual and methodological limitations identified in prior bibliometric analyses of AI in education. Earlier studies, while valuable in mapping publication growth or keyword frequencies, often failed to capture the intellectual evolution of the field, how underlying theories, epistemologies, and pedagogical orientations have transformed over time. For instance, F. Zhang et al. (2025) in *Frontiers in Education* highlighted that most existing reviews remain confined to surface-level trend analyses, lacking interpretive depth to explain why certain research directions dominate and how conceptual interrelations emerge or dissolve. Similarly, Akgun and Greenhow (2021) in the *EURASIA Journal of Mathematics, Science and Technology Education* emphasized that AI-in-education studies still operate within fragmented methodological silos, focusing predominantly on technical performance or short-term learning outcomes rather than longitudinal conceptual coherence. Addressing these shortcomings, the present study applies a multi-phase thematic evolution approach that not only tracks publication patterns but also interrogates the shifting intellectual structures underpinning AI and education across twenty-five years (Biagini, 2025; Raffaghelli et al., 2020). Its uniqueness lies in situating "lifelong learning" and "AI literacy" as dual conceptual anchors, dimensions that were previously overlooked yet are critical to understanding how AI now mediates learner autonomy, ethical awareness, and digital adaptability. By juxtaposing traditional classroom paradigms with cloud-mediated, AI-augmented ecosystems, this research provides an integrative and forward-looking lens for redefining education in an era governed by algorithmic reasoning and distributed knowledge networks (Chung et al., 2025; Elyakim, 2025; Kasinidou et al., 2025).

This research, therefore, is structured around five principal questions, each formulated to address specific conceptual and empirical voids identified in previous studies and to construct a coherent framework for understanding the evolution of AI in education. The first question examines how the volume and thematic focus of AI-related educational research have evolved from 2000 to 2025. This inquiry is grounded in the need to capture the longitudinal growth and intellectual clustering of the field, an aspect largely overlooked in earlier reviews that treated AI adoption as episodic rather than developmental. The second question explores how the concepts of lifelong learning and AI literacy have emerged and matured within scholarly discourse. These two constructs serve as critical rational anchors, as prior analyses have seldom connected them to the larger epistemological shift from technological innovation toward human capability building and sustainable learning ecosystems. The third question investigates the influence of cloud-based AI technologies on educational methods and research priorities. This focus arises from the scarcity of studies examining how cloud infrastructure reconfigures both pedagogical practices and academic inquiry across institutional and national contexts. The fourth question addresses the role of AI in fostering or impeding personalized learning, student engagement, and well-being across educational levels, responding to persistent criticism that existing studies prioritize efficiency metrics while neglecting affective and ethical dimensions of AI-mediated learning. Finally, the fifth question seeks to identify and interpret underexplored gaps concerning ethical implications, equity, and pedagogical impact, thereby guiding future scholarly engagement toward more inclusive, context-aware, and ethically grounded directions for AI in education research.

The expectation underpinning this inquiry is that it will catalyze new debates, encourage multidisciplinary dialogue, and spark further investigations into the interplay between AI and education. As the educational landscape continues to evolve under the influence of intelligent systems, it is critical to ensure that research keeps pace with practice, offering not only descriptive analyses but also prescriptive insights. In bringing together 25 years of scholarly data, this study endeavors to offer a panoramic yet detailed lens through which the future of education shaped by both cloud infrastructure and algorithmic intelligence can be thoughtfully reimagined.

Methodology

To investigate the evolution of artificial intelligence in educational research over the past 25 years, this study adopted a bibliometric analysis approach, which enables the mapping of scholarly trends, thematic shifts, and intellectual structures through quantitative indicators embedded in scientific literature. Bibliometric methods are especially suited for synthesizing large volumes of academic publications, offering a structured means of evaluating research growth, topic prevalence, and authorial networks over extended periods (Erümit et al., 2024; Zhong et al., 2024). Given the longitudinal scope and exploratory nature of the research questions, this method was selected to ensure a high level of objectivity, replicability, and depth in interpreting the developmental arc of AI in education.

The data source selected for this analysis was Lens.org, an open-access scholarly discovery platform that integrates metadata from multiple repositories, including CrossRef, Microsoft Academic, PubMed, and ORCID. Compared with proprietary databases such as Scopus, Web of Science, and ERIC, Lens.org offers three key advantages that align with the objectives of this study. First, it provides comprehensive coverage of interdisciplinary publications across both STEM and education fields, which is essential for capturing the multifaceted nature of AI in education research. Scopus and Web of Science, while robust, often apply restrictive indexing policies that underrepresent open-access journals and emerging regional scholarship. Second, Lens.org facilitates transparent and replicable data retrieval through its open-access API and export functions, enabling the validation of bibliometric workflows without subscription barriers, a crucial factor for methodological transparency in open science. Third, the platform includes up-to-date indexing of newly released articles and preprints, ensuring temporal currency in identifying cutting-edge research between 2020 and 2025, a period of accelerated AI adoption in education. In contrast, ERIC primarily focuses on pedagogical and policy literature within the U.S. context, limiting the global and cross-disciplinary reach required for this study's analytical scope. Therefore, Lens.org was chosen not only for its inclusivity and accessibility but also for its capacity to support a longitudinal, global, and thematically rich bibliometric mapping of AI-related educational research from 2000 to 2025.

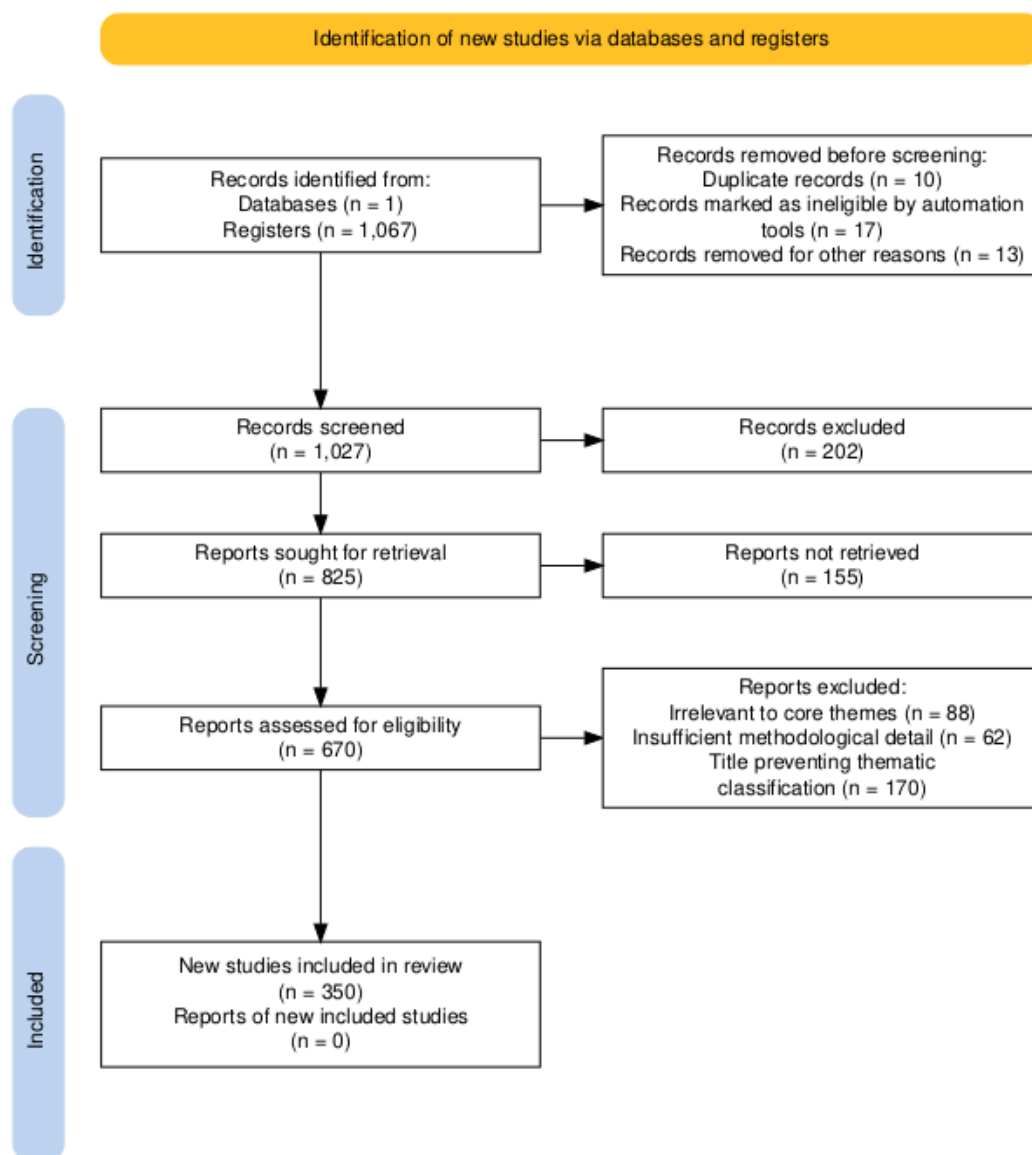


Figure 1. PRISMA Guideline

The data screening and inclusion process adhered to the PRISMA 2020 framework, as illustrated in Figure 1, which summarizes the sequential stages of identification, screening, eligibility, and inclusion that refined the dataset from 1,067 to 350 documents. Data refinement followed the PRISMA 2020 guidelines for inclusion and exclusion, employing both automated and manual filtering techniques to achieve a robust and focused dataset. In the first stage, automated filtering excluded document types not aligned with the study's criteria, retaining only those categorized as "Journal Article," "Proceeding," "Journal Review," and "Proceeding Review," which reduced the dataset to 1,027 entries. The second stage involved a manual review to retain only peer-reviewed journal articles and reviews, resulting in 825 entries. Subsequently, the third stage excluded records with incomplete metadata, such as missing author information or publication details, bringing the dataset down to 670 entries. The final and most critical stage involved manual screening based on thematic relevance to the research objectives, ultimately identifying 350 documents that directly addressed AI applications, discourse, and innovation in educational settings.

For data analysis, the study employed RStudio's Biblioshiny interface, a widely used platform in bibliometric research for constructing co-word maps, generating thematic trends, and calculating productivity indicators such as publication volume and author impact. To support visualization and network-based insights, VOSviewer was also utilized to develop co-authorship, keyword co-occurrence, and citation networks (van Eck & Waltman, 2010). Within the analysis process, the authors assumed clearly defined and complementary roles to strengthen methodological transparency and reliability. The first author was responsible for developing the bibliometric strategy, managing data extraction from Lens.org, and ensuring consistency in the application of inclusion and exclusion criteria. The second author conducted the technical processing of data using RStudio's Biblioshiny and VOSviewer, generating co-word, co-citation, and thematic evolution maps. The third author performed the interpretative synthesis, contextualizing bibliometric patterns through educational theories and AI ethics frameworks. All authors jointly reviewed and validated the visualizations and thematic categorizations to guarantee analytical accuracy and conceptual coherence. This collaborative division of roles, combined

with the integrated use of analytical tools, ensured triangulation of findings and enhanced the robustness of insights drawn from the dataset.

In interpreting the data, the study adopted a systematic descriptive analysis strategy that combined both quantitative bibliometric mapping and qualitative interpretation to ensure depth and coherence in the findings. This process was achieved through several structured stages. First, the bibliometric outputs generated by Biblioshiny and VOSviewer, such as co-word maps, thematic clusters, and citation networks, were systematically exported and examined to identify dominant patterns, thematic densities, and temporal trends. Second, these outputs were narratively synthesized by comparing visual network structures with conceptual frameworks drawn from educational theory, digital learning paradigms, and AI ethics. Third, each major theme was interpreted collaboratively by the authors, who cross-checked how recurring keywords and cluster transitions aligned with theoretical categories such as personalization, ethics, or learner engagement. This iterative interpretation cycle ensured that the meaning behind numerical indicators was grounded in conceptual and pedagogical significance rather than descriptive enumeration. Through this combined quantitative and qualitative approach, the study achieved interpretive validity and produced an analysis that is both statistically robust and theoretically resonant with broader scholarly and societal developments.

Findings

The bibliometric dataset analyzed in this study spans a comprehensive timespan from 2000 to 2025, offering a longitudinal lens through which to assess the evolution of artificial intelligence in educational research. A total of 350 documents were included in the final dataset, all of which were categorized as journal articles, ensuring consistency in peer-reviewed academic quality across the collection. These articles were sourced from 103 unique publication outlets, indicating a relatively broad and multidisciplinary interest in the topic, though certain journals exhibited a higher degree of thematic relevance and concentration.

The dataset exhibits a notable annual growth rate of 18.94%, indicating an increasing scholarly interest in the application of AI within educational contexts. This upward trajectory aligns with the broader expansion of educational technology and digital transformation, particularly during and following the COVID-19 pandemic, which acted as a catalyst for increased AI adoption and research output. The average age of documents is approximately 2.37 years, indicating a predominantly recent publication trend, which reinforces the contemporary relevance of the literature and its alignment with cutting-edge technological developments.

On average, each document in the dataset received approximately 27.41 citations, revealing a moderate to high impact level for the topic under review. The total number of references cited across the dataset amounts to 16,385, illustrating the depth and intertextuality of the included works and reflecting a scholarly community that is highly engaged with both foundational and emerging research. Furthermore, the dataset contains 191 Author Keywords and 191 Keywords Plus, which suggests a diverse but consistent vocabulary around key concepts, making it amenable to robust co-word and thematic analyses.

Table 1. Data Main Information

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2000:2025
Sources (Journals, etc)	103
Documents	350
Annual Growth Rate %	18.94
Document Average Age	2.37
Average citations per doc	27.41
References	16385
DOCUMENT CONTENTS	
Keywords Plus (INTERNATIONAL)	191
Author's Keywords (DE)	191
AUTHORS	
Authors	343
Authors of single-authored docs	343
AUTHORS COLLABORATION	
Single-authored docs	345
Co-Authors per Doc	0.986
International co-authorships %	0
DOCUMENT TYPES	
Journal article	350

The analysis identifies a total of 343 unique authors, highlighting a broad base of scholarly contributions; however, it is worth noting that the data also indicates that all documents are single-authored, with 345 documents identified as single-authored entries. This anomaly suggests either an inconsistency in metadata or a limitation in how collaborative authorship was recorded or extracted during data import. Additionally, the co-authorship index is 0.986, and the international co-authorship rate is recorded at 0%, both of which reinforce the single-authorship pattern and suggest limited international collaborative research in this field, at least within the dataset parameters.

The annual scientific production of research on artificial intelligence in education from 2002 to 2025 reveals a dramatic and accelerating upward trend, particularly in the final five years of the study period. While the earliest recorded publication in 2002 marked the inception of this research niche, the field remained relatively underdeveloped for over a decade, with only a handful of studies appearing annually. From 2002 to 2015, yearly article output was consistently below five, reflecting limited engagement from the academic community during AI’s nascent integration into educational frameworks.

A clear inflection point becomes visible around 2017, where annual publications began to rise from fewer than 5 to a steady growth trajectory. This shift aligns with the global surge in educational technology adoption, digital transformation strategies in higher education, and the increasing accessibility of AI-driven tools for learning and assessment. Notably, the years 2021 to 2023 exhibited exponential growth, peaking at 145 articles in 2024, which represents the highest volume recorded in the entire 25-year timespan. This surge may be attributed to multiple converging factors, including the acceleration of remote learning during the COVID-19 pandemic, heightened interest in AI’s role in personalized learning, and increased funding for EdTech innovations globally.

Table 2. Articles Distribution

Year	Articles
2002	1
2003	1
2004	3
2005	1
2006	1
2007	1
2008	1
2009	0
2010	0
2011	1
2012	1
2013	0
2014	0
2015	0
2016	3
2017	2
2018	9
2019	4
2020	9
2021	23
2022	31
2023	58
2024	146
2025	54

Despite the peak in 2024, the subsequent decrease to 54 articles in 2025 could reflect either a stabilization of output, a lag in indexing for the current year, or shifts in academic focus within the broader field of educational technology. Importantly, this decline does not suggest a diminished interest but rather may indicate that research is maturing or being redistributed across interdisciplinary domains, such as AI ethics, digital well-being, or human-AI collaboration in learning environments. The analysis of average total citations per article from 2002 to 2025 provides critical insights into the scholarly influence and visibility of research at the intersection of artificial intelligence and education. As shown in the visualization above, citation patterns demonstrate significant year-to-year fluctuations, which can be attributed to both the uneven distribution of highly cited foundational papers and the natural lag time associated with citation accrual.

The early years of the dataset, particularly 2003, show an exceptionally high average of 375 citations per article, likely driven by a single seminal publication that has garnered extensive scholarly attention over time. This citation spike is followed by consistently high but variable citation values from 2004 to 2006, with averages ranging from approximately

145 to 185 citations per article. These figures highlight the significance of early, pioneering works in this field, which may have influenced foundational debates and frameworks in AI-driven pedagogy and digital learning environments.

Table 3. Annual Citation Distribution

Year	Mean TC per Art	N	Mean TC per Year	Citable Years
2002	18	1	0.75	24
2003	375	1	16.3	23
2004	173.67	3	7.89	22
2005	146	1	6.95	21
2006	184	1	9.2	20
2007	3	1	0.16	19
2008	21	1	1.17	18
2011	46	1	3.07	15
2012	16	1	1.14	14
2016	101	3	10.1	10
2017	23	2	2.56	9
2018	45.33	9	5.67	8
2019	29.5	4	4.21	7
2020	54.44	9	9.07	6
2021	78.78	23	15.76	5
2022	43.1	31	10.78	4
2023	49.12	58	16.37	3
2024	6.09	146	3.04	2
2025	0.24	54	0.24	1

From 2007 through the early 2010s, average citation rates per article declined, suggesting that publications during this period may not have had the same degree of influence, possibly due to narrower topical focus or slower dissemination. A modest recovery is observed between 2015 and 2017, during which average citations rose again, peaking at over 100 citations per article in 2016, indicating renewed academic engagement likely linked to the broader adoption of AI technologies in mainstream educational systems.

In recent years, particularly since 2020, the average citation count per article has shown a general downward trend, with values tapering off toward 2024 and 2025. This decline is expected and largely reflects the citation time-lag effect, where newer articles have not yet had sufficient time to accumulate citations. Nevertheless, given the sharp increase in publication volume during this same period, the observed citation density remains a meaningful metric of scholarly relevance.

Leading the dataset by a significant margin is the journal *Education and Information Technologies*, which published 80 of the 350 analyzed articles, accounting for nearly 23% of the total scholarly output. As a high-impact and widely indexed journal in the EdTech field, its dominant presence underscores its role as a central hub for disseminating AI-related educational research. The journal's thematic openness to emerging technologies, adaptive learning environments, and digital innovation likely contributes to its prominence within this domain.

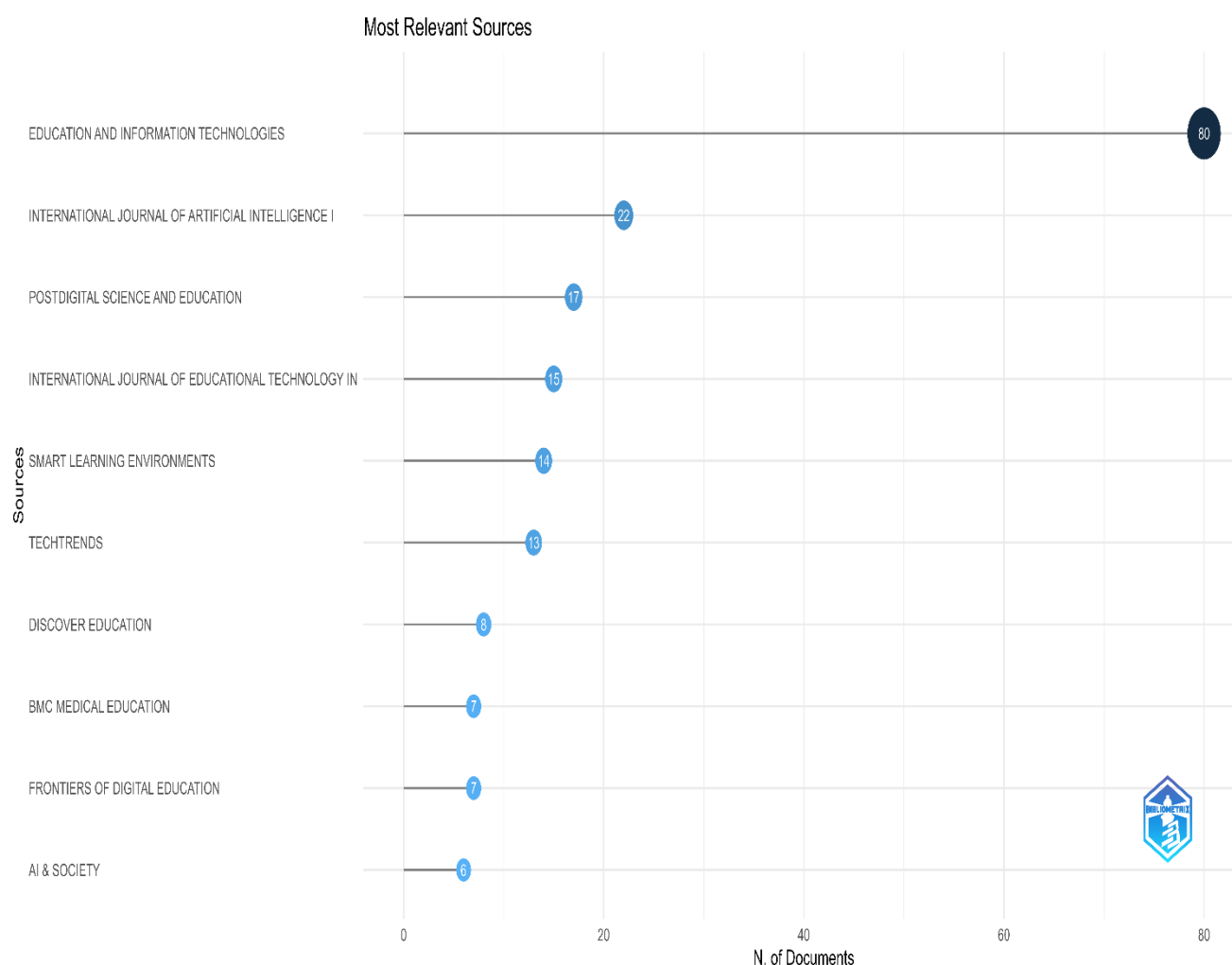


Figure 2. Most Relevant Sources

As shown in Figure 2, the annual scientific production demonstrates a steady upward trajectory, with a pronounced surge in publications after 2018, coinciding with the global acceleration of AI adoption in education during the post-pandemic period. The International Journal of Artificial Intelligence in Education ranks second with 22 articles, followed by Postdigital Science and Education with 17 articles, and the International Journal of Educational Technology in Higher Education with 15 articles. These journals collectively represent the intersection of computer science, educational theory, and policy, reflecting the interdisciplinary nature of research at the AI-education nexus. Several additional sources, including Smart Learning Environments (14 articles), TechTrends (13 articles), and Discover Education (8 articles), also feature prominently. These outlets tend to publish empirical and theoretical work focusing on practical implementation, instructional design, and digital pedagogy, which aligns closely with the field's applied research trajectory.

The longitudinal productivity of key journals publishing research on artificial intelligence in education reflects both the thematic evolution of the field and the shifting priorities of academic discourse. Analyzing annual contributions from the five most prolific sources offers a clearer view of how journal-specific engagement has developed across the 2002–2025 period. The most consistently productive source, Education and Information Technologies, exhibited minimal output in the early years, with negligible contributions before 2015. However, beginning around 2019, the journal's publication volume increased significantly, reaching its peak in 2024, when it contributed a notable share to the year's overall publication surge. This trend mirrors the broader rise in AI-related educational research and suggests that the journal has positioned itself as a leading venue for interdisciplinary, practice-oriented scholarship in this domain.

The International Journal of Artificial Intelligence in Education, although it receives fewer total contributions compared to the leading journal, exhibits a more stable and evenly distributed output pattern. It made early contributions as far back as 2006 and maintained modest but regular publication activity throughout the dataset period, indicating its role as a steady, high-quality source of foundational research. Postdigital Science and Education, a relatively newer entrant in academic publishing, began contributing meaningfully only after 2019, with its productivity peaking in 2023. This delayed but rapid growth aligns with its editorial mission of engaging critically with emergent technologies, and its rise coincides with an increased scholarly focus on AI ethics, digital citizenship, and socio-technological entanglements in education.

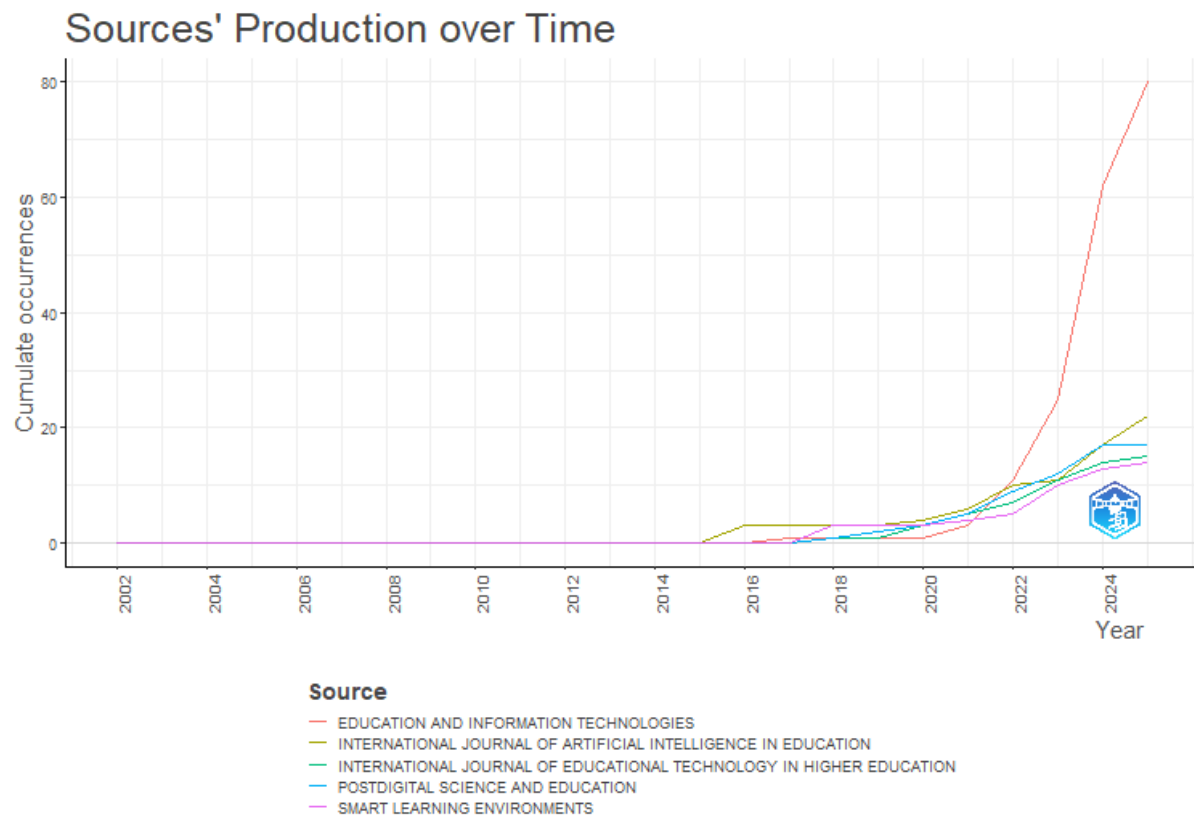


Figure 3. Sources' Production Over Time

The distribution of articles across journals, presented in Figure 3, indicates a concentration of research output within a few core outlets, underscoring the emergence of specialized venues for AI-in-education scholarship. The International Journal of Educational Technology in Higher Education and Smart Learning Environments show similar patterns of late emergence and focused activity in the last five years of the dataset. Both journals began contributing to the AI-in-education discourse primarily after 2018, and their concentrated publication bursts between 2020 and 2024 suggest a topical realignment or expansion to include AI-centered pedagogical themes within their scopes. These productivity patterns indicate a clear temporal clustering in source engagement, with the vast majority of contributions from top journals occurring after 2018, particularly between 2021 and 2024. This clustering reflects the broader disciplinary consolidation of AI in education as a distinct and maturing field of inquiry, while also emphasizing the role of certain journals in shaping and disseminating its intellectual trajectory.

An examination of the most productive authors in the field of artificial intelligence in education, as captured by the dataset, provides insights into individual scholarly contributions and the distribution of authorship across the literature. The productivity measure used here reflects both full and fractional authorship counts, offering a view of individual output while accounting for collaborative publishing. The most prolific contributors in the dataset include B. Williamson and D. Schiff, each credited with 2 full articles, both in total and fractionalized terms. These authors, having contributed multiple publications independently or as primary contributors, emerge as notable figures within the field's publishing landscape. While the article count may appear modest, this is consistent with the relatively small average number of publications per author across specialized research domains, such as AI in education, especially given the single-authorship pattern observed in the dataset.

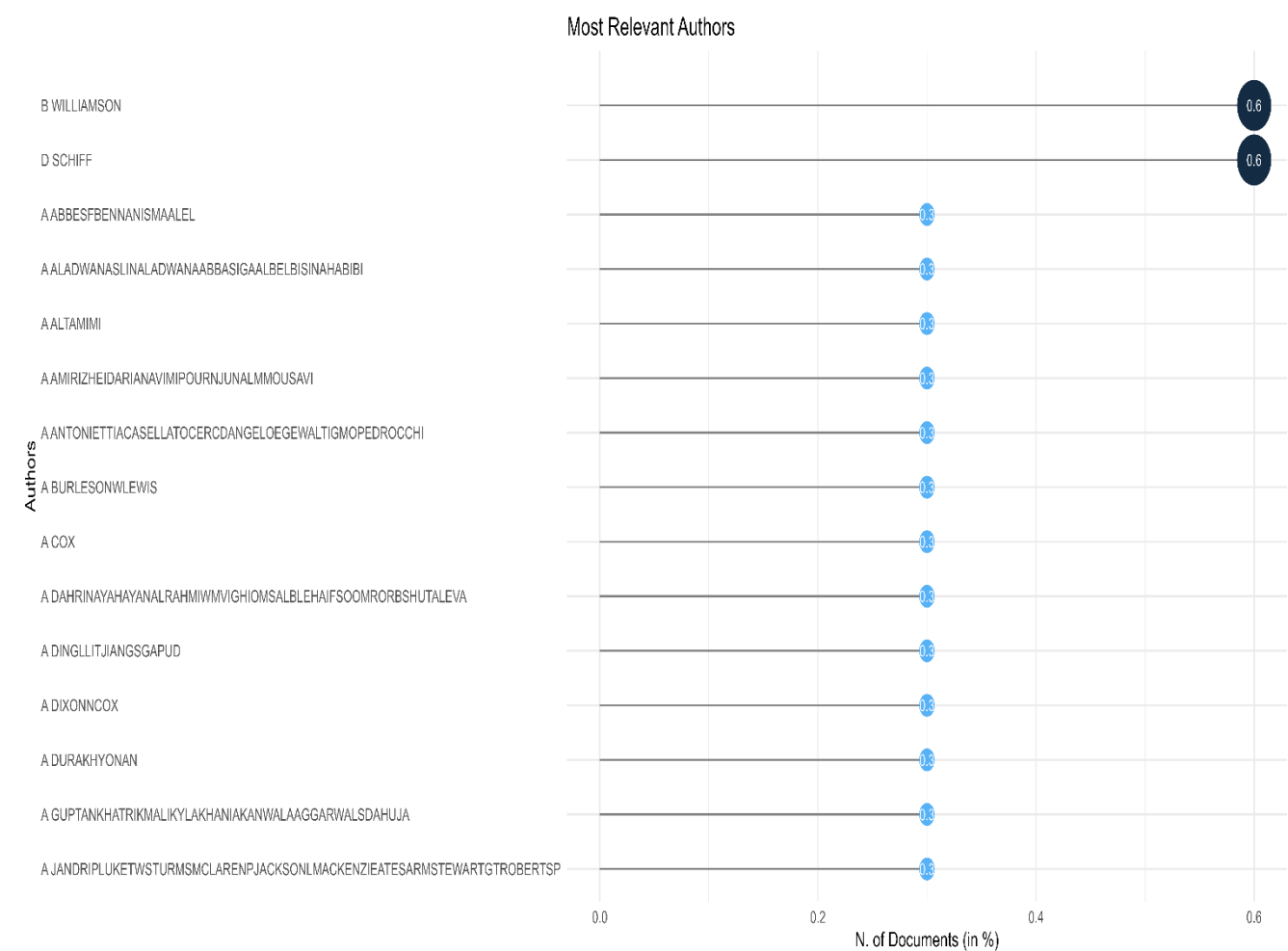


Figure 4. Most Relevant Authors

Author productivity patterns are visualized in Figure 4, which highlights key contributors and reveals a predominance of single-authored publications, reflecting the still-decentralized nature of this research domain. Beyond these two, all other authors listed contributed a single article each, with fractional authorship scores also at 1.0, indicating either sole authorship or an equal distribution of credit in co-authored works. Names such as A. Altamimi, A. Amiri, and A. Burleson appear within this group, though many entries in the dataset involve concatenated author names without standard separation, indicating possible metadata inconsistencies during export or import (Altamimi, 2024; Amiri et al., 2024; Burleson & Lewis, 2016). This issue underscores the importance of data cleaning in bibliometric studies, particularly when dealing with automated or aggregated databases.

The relatively flat authorship distribution implies that while the field is growing, it is not yet dominated by a small number of "core" authors; rather, it reflects a decentralized scholarly landscape where many researchers contribute sporadically. This may be indicative of an emerging interdisciplinary area, where researchers from different domains such as educational technology, computer science, psychology, and policy studies intersect briefly with AI in education without a sustained longitudinal focus. Notably, the dominance of single-authored publications in this dataset further limits the identification of collaborative author networks, which are typically used to map intellectual structure and scholarly communities. The absence of prominent author clusters suggests that AI in education, while expanding, remains an intellectually dispersed and methodologically diverse field, traits often associated with maturing but still structurally fluid research domains.

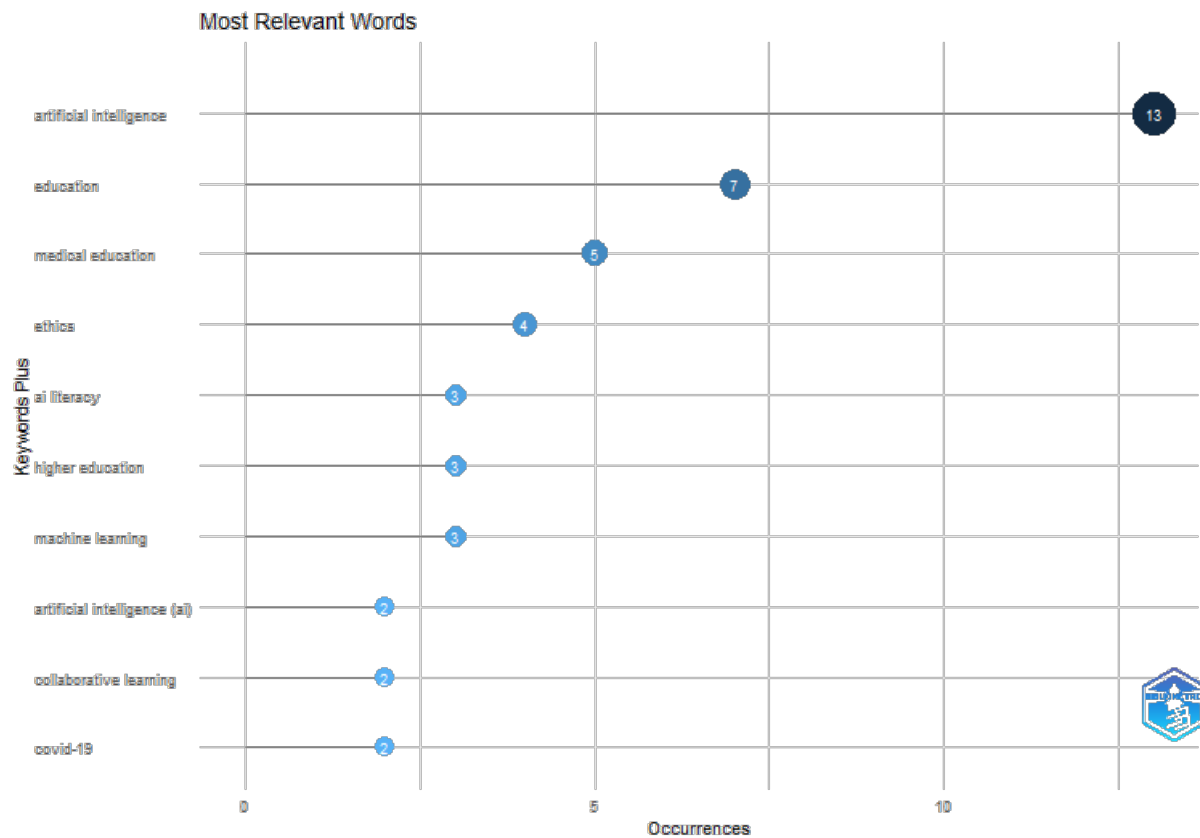


Figure 5. Most Relevant Words

Keyword frequency patterns, illustrated in Figure 5, reveal “artificial intelligence” and “education” as dominant descriptors, while emerging terms such as “AI literacy” and “ethics” suggest a recent conceptual broadening toward human-centric concerns. The keyword frequency analysis provides valuable insight into the thematic priorities and conceptual vocabulary prevalent in AI-in-education literature over the past two decades. By analyzing recurring terms used by authors, we can trace dominant research orientations, recurring concerns, and the field’s evolving discourse. In this dataset, which spans from 2002 to 2025, a total of 191 author-supplied keywords were identified, with several terms emerging as thematic anchors in the literature.

While “artificial intelligence” and “education” naturally appear as dominant descriptors in the dataset, their prominence reflects the structural parameters of the search strategy rather than thematic centrality. As such, these terms function more as contextual anchors than as indicators of novel or specialized research directions. In contrast, the first foreground keyword identified through co-word analysis is “medical education,” which appears in multiple publications and represents a distinct and rapidly expanding subfield within the broader AI-in-education discourse. As shown in Figure 5, this keyword signals an emerging interdisciplinary convergence between artificial intelligence, health sciences, and professional education, particularly in simulation-based training, diagnostic modeling, and ethical data use. Other recurring yet substantively meaningful terms, such as “ethics,” “AI literacy,” and “personalized learning,” further demonstrate a conceptual shift away from generic technological descriptors toward human-centered, context-specific applications of AI in education.



Figure 6. Word Cloud Analysis

The term “medical education” emerges as the most frequent and thematically dominant keyword, appearing in five publications. Its prominence highlights the growing interdisciplinary convergence between artificial intelligence and health-related pedagogy, marking a distinct research frontier where AI supports clinical simulations, diagnostic modeling, and adaptive training systems. This finding suggests that educational AI research has been increasingly extending beyond general classroom contexts to professional and vocational domains, particularly those requiring precision, ethical sensitivity, and experiential learning. Closely following are the keywords “ethics” (4 occurrences) and “AI literacy” (3 occurrences), which collectively underscore a significant discursive shift in the literature, from viewing AI merely as a technological innovation to understanding it as a transformative pedagogical and ethical phenomenon. The recurring presence of these terms suggests that questions surrounding algorithmic fairness, data privacy, and human-centered design have taken a decisive step forward in the forefront of educational AI scholarship.

Other recurring terms, such as “higher education”, “machine learning”, and “collaborative learning” (each with 3 or more mentions), reveal the conceptual intersections between technical capabilities and pedagogical models. Interestingly, “COVID-19” appears among the top ten keywords, indicating that the pandemic served as both a contextual accelerator and a content area within AI-education research, possibly influencing the dramatic rise in publications from 2020 to 2023.

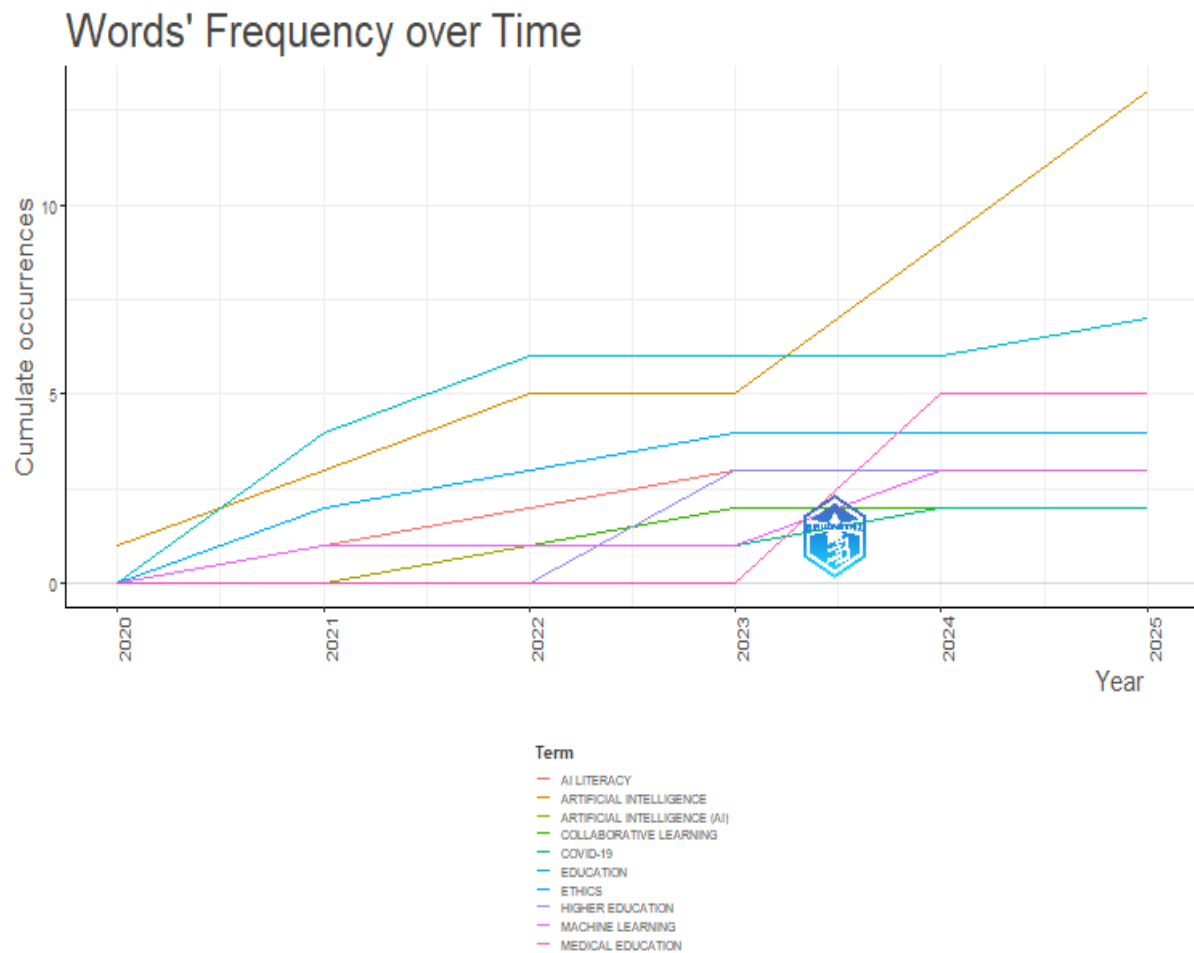


Figure 7. Words' Frequency over Time

As shown in Figure 7, the longitudinal analysis of keyword frequency illustrates how thematic priorities within AI-in-education research have shifted between 2020 and 2025. The figure highlights the steady rise of “artificial intelligence” as the field’s central analytic lens, alongside the later but rapid emergence of “medical education,” which gained visibility only after 2024. This temporal mapping highlights the dynamic evolution of scholarly interest, revealing how newer domains, such as clinical simulation, ethics, and AI literacy, have gradually shaped the research agenda over time. The longitudinal analysis of keyword frequency reveals the shifting thematic landscape of AI-related educational research between 2020 and 2025. Tracking the prevalence of key terms offers insights into not only what topics were prioritized but also how scholarly discourse has adapted to changing technological, educational, and societal contexts. The keyword “artificial intelligence” has shown the most substantial growth, rising from a single mention in 2020 to 13 occurrences by 2025. This upward trajectory suggests a dramatic increase in the centrality of AI within educational discourse, likely influenced by both technological advancements and the widespread integration of AI tools in digital learning environments. Its consistent year-on-year growth confirms that AI has moved from a peripheral innovation to a dominant lens for examining educational change.

Given that all documents in the dataset inherently belong to the education domain, the consistent presence of the term “education” across the timeline serves primarily as a structural indicator rather than a thematic finding. The more meaningful insight lies in the diversification of educational subfields that have emerged within the broader discourse on AI in education. Among these, “medical education” stands out as a leading and rapidly expanding research theme, first appearing in 2024 with five occurrences. This surge highlights the growing integration of AI technologies into clinical training, diagnostic simulation, and healthcare pedagogy areas where precision, adaptability, and experiential learning are central. This trend reflects a broader disciplinary expansion of AI applications, where pedagogical innovation intersects with domain-specific expertise. Alongside this, the increasing recurrence of keywords such as “ethics,” “AI literacy,” and “collaborative learning” suggests a transition from foundational educational inquiries to more specialized, context-driven, and ethically informed research directions within the field.

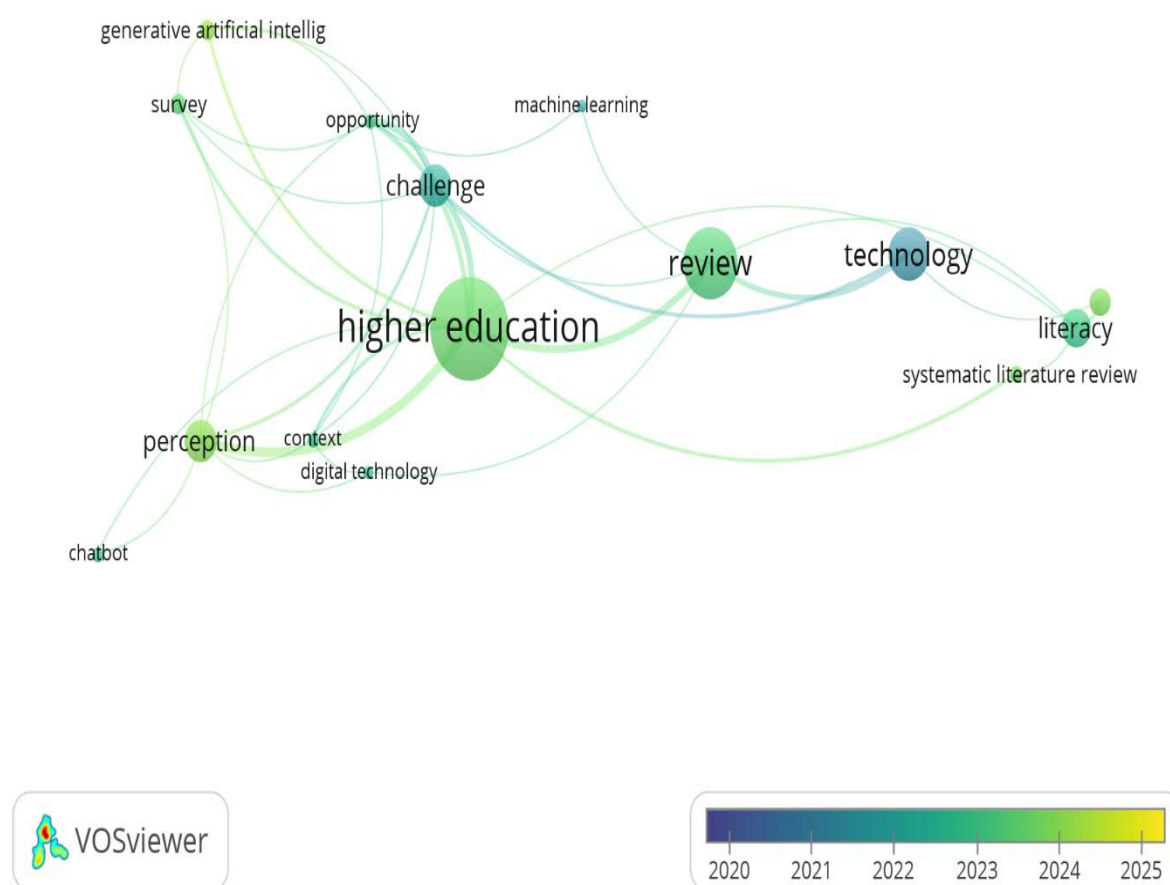


Figure 8. Trend Topics

As illustrated in Figure 8, the trend topic analysis captures the evolving focus areas in AI-in-education research, with certain keywords gaining consistent prominence over time. Notably, ethics, AI literacy, and medical education display upward trajectories, signaling a shift toward responsible, interdisciplinary, and skill-oriented applications of AI in learning environments. These patterns reveal how scholarly priorities have gradually expanded from technical optimization to critical engagement with social, ethical, and pedagogical dimensions of AI use.

In light of these findings, several future research directions emerge. First, the growing emphasis on ethics underscores the need for empirical investigations into the governance of AI systems in classrooms, examining issues such as algorithmic transparency, data privacy, and bias mitigation. Second, the rise of AI literacy highlights a fertile research domain centered on curriculum design, teacher professional development, and student competencies required for AI-mediated learning environments. Third, the expansion of medical education indicates potential for cross-sectoral inquiry into simulation-based learning and human-machine collaboration in professional training contexts. Beyond these, steady interest in collaborative learning and higher education suggests continued opportunities to explore how AI tools facilitate community-based and institutional learning ecosystems. Collectively, these trajectories point toward a maturing research landscape that increasingly values human-centered, ethically grounded, and contextually adaptable approaches to integrating AI in education.

Another important theme is “ethics”, which increased in frequency from 2 mentions in 2021 to 4 by 2023 and 2024, suggesting a rising concern over the responsible use of AI in learning settings. This aligns with the broader societal discussion about AI safety, algorithmic bias, and the necessity of transparency in machine-assisted decision-making, particularly in sensitive contexts such as student evaluation or adaptive learning. “AI literacy” also demonstrated a notable rise, with consistent mentions beginning in 2021 and peaking at 3 occurrences by 2023 and 2024. This indicates growing academic focus on the competencies learners and educators need to navigate AI-mediated environments, an important precursor to curriculum development and teacher training reforms.

The terms “higher education” and “machine learning” both showed minor but stable growth from 2022 onward, underscoring their supporting roles in the broader AI-education conversation. Likewise, “collaborative learning” and “COVID-19” experienced modest upticks, particularly around 2021–2022, likely in response to shifts in educational delivery and pedagogy brought about by the pandemic. The bibliographic coupling map illustrates how documents in the dataset cluster together based on shared citation patterns, revealing intellectual proximity and conceptual cohesion among groups of studies.

the intellectual proximity and thematic cohesion among groups of related works. In this network, documents that cite similar sources cluster closely together, indicating a common theoretical foundation or methodological orientation.

The coupling analysis identifies several major clusters that correspond to distinct thematic foci within AI in education research. One large cluster centers on machine learning applications in educational settings, reflecting early empirical studies on automation, prediction models, and adaptive assessment. Another cluster relates to AI-driven pedagogical innovation and teacher education, where the literature emphasizes digital competency and AI literacy as emerging frameworks. A smaller yet distinct cluster represents ethics and data governance, highlighting recent scholarship focused on transparency, fairness, and the responsible integration of AI in learning environments.

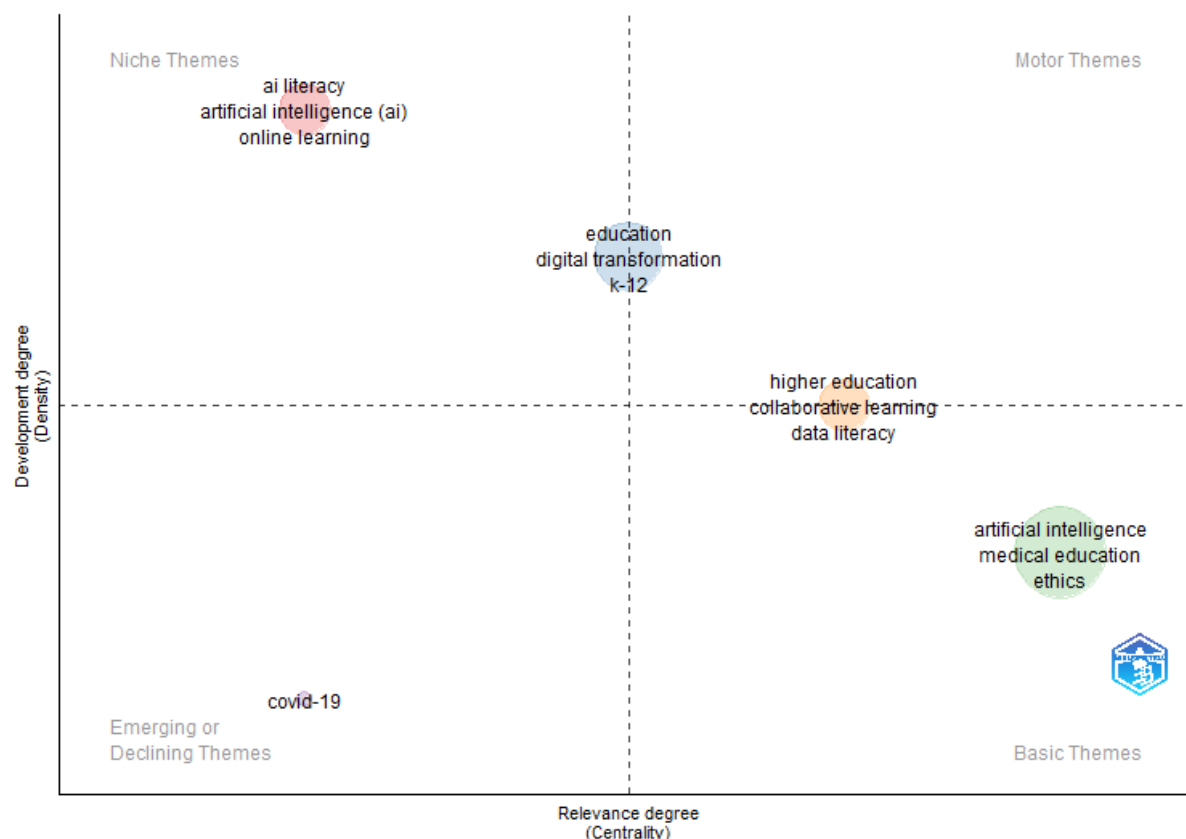


Figure 11. Thematic Mapping

Figure 11 presents the thematic mapping analysis of AI-in-education research covering the full period from 2000 to 2025. This visualization, generated through Biblioshiny's strategic diagram, organizes keywords into four quadrants according to two dimensions: centrality, which measures a theme's relevance across the entire research network, and density, which indicates its internal development and conceptual maturity.

In the basic themes quadrant (bottom-right), we observe the presence of terms such as "artificial intelligence," "medical education," and "ethics," all of which possess high centrality but relatively moderate levels of internal density. Their placement suggests that these themes are not only widely cited and foundational to the literature but also remain under continued theoretical and methodological development. In particular, the positioning of "ethics" alongside "artificial intelligence" highlights a growing scholarly interest in questions of fairness, transparency, and responsibility in the deployment of AI in learning environments, particularly within high-stakes contexts such as clinical and professional training.

In contrast, the motor themes quadrant (top right), which typically contains highly developed and influential themes that drive the field forward, appears underpopulated. This absence indicates that while the field of AI in education is thematically rich, few research areas have yet achieved the critical combination of maturity and interdisciplinary centrality required to be considered driving forces. However, several keywords, including "collaborative learning," "data literacy," and "higher education," are positioned close to this quadrant, suggesting that they may soon evolve into dominant thematic engines as the field continues to mature.

The niche themes quadrant (top-left) contains well-developed but less central topics, such as "AI literacy," "artificial intelligence (AI)," and "online learning." These themes, while internally coherent and conceptually robust, remain somewhat isolated from the broader network of AI-in-education research. Their positioning indicates that these themes are currently more relevant to specialized audiences or institution-specific applications than to the field as a whole. The emergence of "AI literacy" in this quadrant is especially important, as it signals growing concern with the competencies

learners and educators require to critically engage with AI technologies, a discourse increasingly linked to curriculum innovation, teacher training, and digital inclusion.

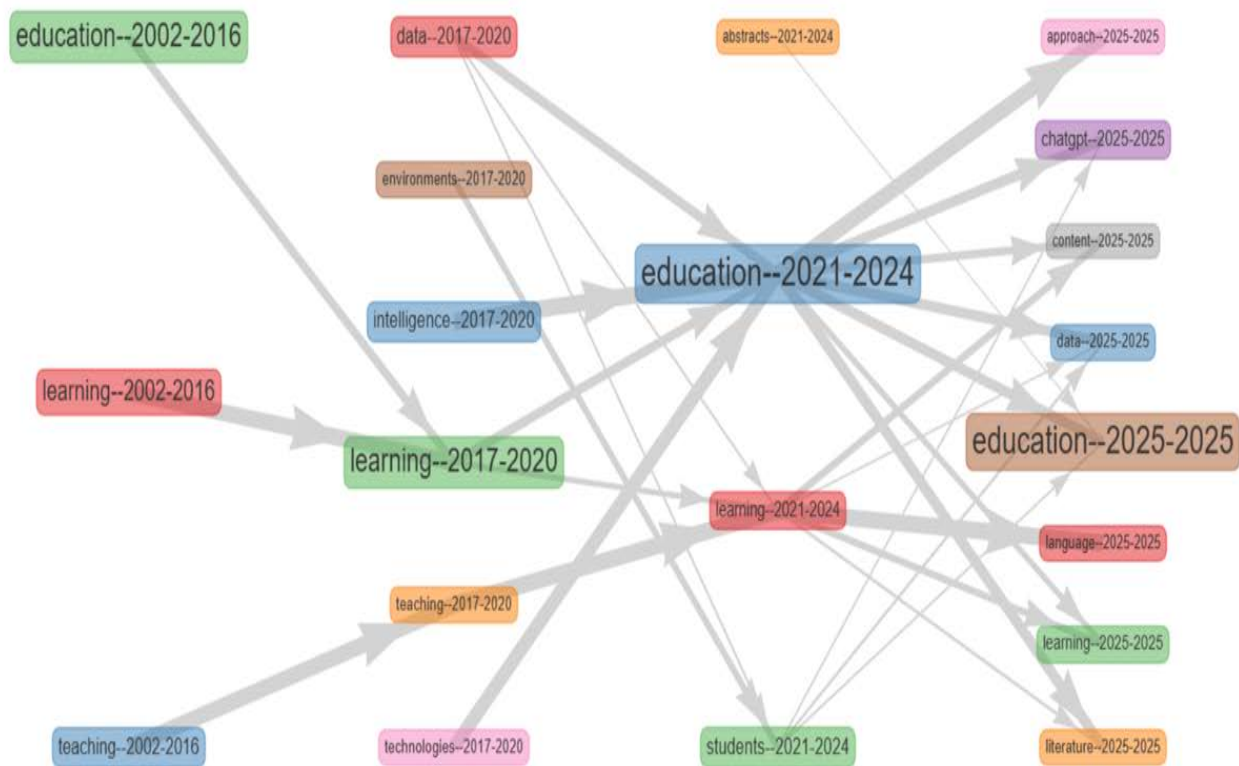


Figure 12. Thematic Evolution Mapping

Figure 12 illustrates the thematic evolution of artificial intelligence in education research across three distinct periods, namely 2016, 2020, and 2024. Each period represents a significant stage in the intellectual and pedagogical development of the field. In the early 2010s, the research landscape was dominated by technologically oriented studies that concentrated on artificial intelligence, machine learning, and education. These terms represented broad conceptual categories that reflected early enthusiasm for automation, adaptive learning systems, and algorithmic teaching models. However, the findings from this phase indicate that pedagogical integration remained minimal. Studies often explored the capabilities of AI from a technical perspective, with limited attention to instructional design or classroom practice. In general education, the discussion of AI was largely theoretical, focusing on how technology could potentially support instruction rather than how it actually transformed learning processes. In the field of language education, the use of AI was confined to narrow applications such as grammar correction, automated essay scoring, and basic feedback generation, with little focus on interaction, communication, or cognitive engagement.

The second period, around 2020, marks a major shift in the thematic structure of the field, strongly influenced by the global transition to digital learning environments during the COVID-19 pandemic. Research emphasis expanded toward online learning, digital transformation, and student engagement, demonstrating that AI had moved from experimental implementation to practical deployment. Studies began addressing access, equity, and inclusivity, while discussions on ethical implications and data privacy became increasingly visible. Within general education, AI has begun to be recognized as a catalyst for innovative pedagogy that can sustain learning continuity, personalize assessments, and provide adaptive support to diverse learners. In language education, this period introduced interactive AI tools such as intelligent chatbots, translation systems, and automatic speech recognition for pronunciation training. These developments indicated a growing interest in how AI could facilitate real-time feedback and self-directed learning, making the role of the teacher more dynamic and student-centered.

The third period, represented by 2024, marks a stage of consolidation and maturity, where AI is perceived not only as a technological tool but also as an integral component of curriculum and pedagogy. The rise of concepts such as AI literacy, data literacy, collaborative learning, and medical education indicates an educational system that has begun to incorporate AI into its foundational design. For general education, this phase signifies a deeper shift toward ethical, reflective, and value-based learning, where the integration of AI is aligned with critical thinking, problem-solving, and social responsibility. In language education, the findings indicate a shift toward more context-aware and learner-centered approaches. AI applications are increasingly used to support cross-cultural communication, digital storytelling, adaptive

reading and writing platforms, and affect-sensitive learning environments that can respond to emotion, motivation, and creativity.

Taken together, the thematic evolution between 2016 and 2024 portrays a field that has progressed from technological experimentation to pedagogical transformation. The overall implication for education is that AI now functions as a partner in knowledge construction and learner development rather than merely as an instructional aid. Specifically, for language education, this transformation presents new opportunities for integrating intelligent systems that foster communicative competence, empathy, and cognitive flexibility while preserving human agency and cultural awareness. The research trajectory, therefore, suggests that the future of AI in education will depend not only on innovation but also on how educators, institutions, and learners cultivate ethical and meaningful engagement with intelligent technologies.

Conclusion

This study provides a comprehensive overview of how artificial intelligence has evolved within educational research from 2000 to 2025, offering new knowledge about the field's conceptual growth, thematic direction, and intellectual maturity. Through the integration of bibliometric mapping and thematic evolution analysis, the research reveals that AI in education has transitioned from fragmented, technology-centered experimentation to a more coherent and human-oriented paradigm. This transformation signifies a shift from investigating what AI can do toward understanding how AI reshapes learning, teaching, and educational values. The new contribution of this study lies in its identification of three distinct evolutionary stages that redefine the relationship between technology and pedagogy. First, the early phase demonstrates the predominance of technical innovation without sufficient pedagogical grounding. Second, the pandemic era introduces context-driven adaptation, where digital transformation and online learning have become dominant educational priorities. Third, the most recent phase highlights a mature orientation emphasizing AI literacy, ethics, and learner well-being, which together form the foundations of a sustainable and inclusive AI-in-education framework.

Beyond mapping research trends, this study advances theoretical understanding by connecting bibliometric evidence with educational practice. It reveals that the center of scholarly attention is gradually moving from algorithmic design toward the cultivation of cognitive, ethical, and emotional literacies. In general education, this finding enriches our understanding of how AI supports personalized, equity-focused learning ecosystems. In language education, it introduces a novel perspective that positions AI as an agent of linguistic empowerment, promoting autonomous, intercultural, and creativity-driven communication. Overall, the study contributes new empirical and conceptual insights into how artificial intelligence is not only transforming educational research but also redefining what it means to learn and teach in the digital era. The findings establish a theoretical bridge between technology and pedagogy, providing a basis for future interdisciplinary work that seeks to align AI innovation with human development, ethical responsibility, and meaningful educational engagement.

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Generative AI Statement

The authors declare that they used generative artificial intelligence (AI) tools, such as QuillBot and Grammarly, exclusively to enhance the clarity, grammar, and readability of the manuscript. These tools did not influence the conceptual development, data analysis, interpretation, or intellectual content of the research. All core ideas, findings, and conclusions presented in this paper are the authors' original scholarly work.

Authorship Contribution Statement

Prayuda: Conceptualized the study, conducted the bibliometric analysis, interpreted the findings, and drafted the manuscript. Ginting: Contributed to project administration and secured research funding through the 2024 Educational Innovation Research Scheme. Tamba: Contributed to the refinement of the final manuscript. His role focused on maintaining the academic integrity, clarity, and stylistic consistency of the paper prior to submission. All authors reviewed and approved the final version of the manuscript.

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