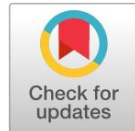


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## Beyond the Code: Teachers' Lived Experiences and Narrative Identities in the Age of Artificial Intelligence

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### ABSTRACT

**Background.** Artificial Intelligence (AI) has rapidly transformed twenty-first-century education, evolving from a supplementary tool into a central component of data-driven pedagogical ecosystems. Previous bibliometric studies have focused mainly on thematic trends or specific contexts, with limited integration of publication dynamics, collaboration networks, citation structures, and thematic evolution within a single framework. Existing studies also often cover publications only up to 2023 or 2024, leaving recent generative AI developments underexplored.

**Purpose.** This study provides a comprehensive bibliometric analysis of AI research in education indexed in Scopus from 2008 to 2026, examining publication trends, collaborative networks, citation impact, and thematic evolution, with particular focus on the generative AI era.

**Method.** A total of 1,094 journal articles were analyzed using Biblioshiny (Bibliometrix-R). Performance analysis and science mapping techniques assessed annual growth, scholarly impact, international collaboration, thematic evolution, and keyword network structures.

**Results.** Findings reveal a 23.55% annual growth rate, with sharp acceleration after 2017 and peak productivity in 2025, averaging 35.28 citations per document and a 27.97% international co-authorship rate dominated by China and the United States. Thematic evolution shows a shift from conceptual discussions toward adaptive learning, machine learning, learning analytics, classroom implementation, and AI-based assessment.

**Conclusion.** AI in education has evolved into a globally interconnected pedagogical paradigm, offering insights for future policy and responsible AI integration.

### KEYWORDS

21<sup>st</sup> Century, Artificial Intelligence, Educational, Bibliometric Analysis

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## INTRODUCTION

The rapid expansion of Artificial Intelligence (AI) research in education over the past decade has created an increasingly fragmented and interdisciplinary body of knowledge. The emergence of generative AI technologies,

adaptive learning systems, and data-driven educational platforms has accelerated publication growth while simultaneously complicating efforts to systematically understand the intellectual structure, thematic evolution, and collaborative dynamics of the field. Although AI in education has become one of the fastest-growing areas in contemporary educational research, existing studies remain fragmented across technological, pedagogical, and policy-oriented discussions. Consequently, a comprehensive bibliometric mapping is required to clarify how the field has evolved structurally, collaboratively, and conceptually during the era of rapid digital transformation. As AI continues to evolve, research in education has also shown significant growth. AI is not only used to support online learning but is also applied in learning assessment, curriculum development, and mapping students' learning needs (Zawacki-Richter et al., 2019a). In this context, AI is understood as a means to enhance learning efficiency while opening new opportunities for personalized learning, particularly through adaptive learning systems and intelligent tutoring systems (Chen et al., 2020; Hwang et al., 2020; Pedró et al., 2019).

This technology enables students to learn according to their individual capabilities, meaning that learning is no longer entirely dependent on uniform classroom approaches (Ouyang & Jiao, 2021). Other studies also show that AI supports personalized learning by automatically adjusting methods, content, and feedback based on students' needs and learning styles, thereby significantly improving engagement and learning outcomes (S. Hu, 2024; Merino-Campos, 2025). Thus, AI has the potential to transform the relationship between teachers, students, and learning materials into a more adaptive, responsive, and data-driven learning ecosystem.

However, the increasing use of AI also introduces new challenges, particularly regarding ethical issues, technological access gaps, and educators' readiness to utilize such technologies (Williamson & Eynon, 2020a). Several studies indicate that despite the benefits of AI, its implementation still faces obstacles such as limited infrastructure and low digital literacy among teachers (Popenici & Kerr, 2017). Therefore, understanding the direction of AI research development in education is crucial to examining how this technology is positioned within the global education system.

To systematically understand these developments, an approach capable of mapping research trends comprehensively is required. One widely used approach is bibliometric analysis. Bibliometric analysis is used to examine scientific publication patterns based on the number of articles, author networks, countries of origin, and emerging research themes over a certain period (Donthu et al., 2021). This approach not only reveals literature growth but also helps identify dominant research focuses and existing research gaps.

Several bibliometric studies on AI in education have been conducted. For instance, Zawacki-Richter et al. (2019) show that AI research in education is dominated by topics such as adaptive learning and learning analytics. Meanwhile, Chen et al. (2020) found that publications on AI in education increased sharply after 2015, especially in internationally reputable journals. Similar findings were reported by Ouyang & Jiao (2021), who mapped research themes in higher education AI. This indicates that AI has become a global issue in 21st-century educational discourse. Although previous bibliometric studies have contributed significantly to understanding AI research in education, several important limitations remain. Zawacki-Richter et al. (2019) primarily focused on higher education contexts and early AI applications, while Chen et al. (2020) emphasized publication growth without extensively examining collaboration structures and thematic transformation. Similarly, Ouyang and Jiao (2021) proposed conceptual paradigms of AI in education but did not comprehensively integrate publication dynamics, global collaboration patterns, citation structures, and thematic evolution within a single analytical framework.

Furthermore, most previous studies only covered publications up to 2023 or earlier, thereby limiting their ability to capture the rapid expansion of generative AI discourse after the emergence of technologies such as ChatGPT. Therefore, this study contributes by providing a more updated and comprehensive bibliometric mapping covering the period 2008–2026, enabling a deeper understanding of how AI in education has evolved from a technological support tool into a globally interconnected pedagogical ecosystem.

On the other hand, bibliometric studies show that attention to ethical and policy aspects of AI in education has increased significantly in recent years, in line with Williamson & Eynon (2020), who emphasized the importance of social and regulatory dimensions in AI education research. These issues arise due to growing concerns about student data protection, algorithm transparency, and the risk of bias in automated systems. This is further reinforced by Efendi et al. (2025), who argue that AI use in schools must be accompanied by ethical frameworks and regulations to prevent data misuse and algorithm-based inequality. Additionally, Supriyatin et al. (2026) highlight that AI-based evaluation systems may alter pedagogical relationships if not regulated by clear institutional policies oriented toward educational equity. Thus, consistent with Williamson and Eynon (2020), AI research in education should not be viewed solely as a technical innovation but also as a social practice requiring serious attention to ethics and public policy.

Despite the increasing number of studies on AI in education, comprehensive mapping of research trends remains limited, particularly those integrating thematic development, researcher collaboration, and publication dynamics within a single analytical framework. Therefore, bibliometric analysis is essential to provide a comprehensive overview of AI research development in 21st-century education. This study is limited to Scopus-indexed journal articles published between 2008 and 2026 and focuses exclusively on bibliometric indicators rather than full-text qualitative analysis. Based on this background, this study addresses the following research questions:

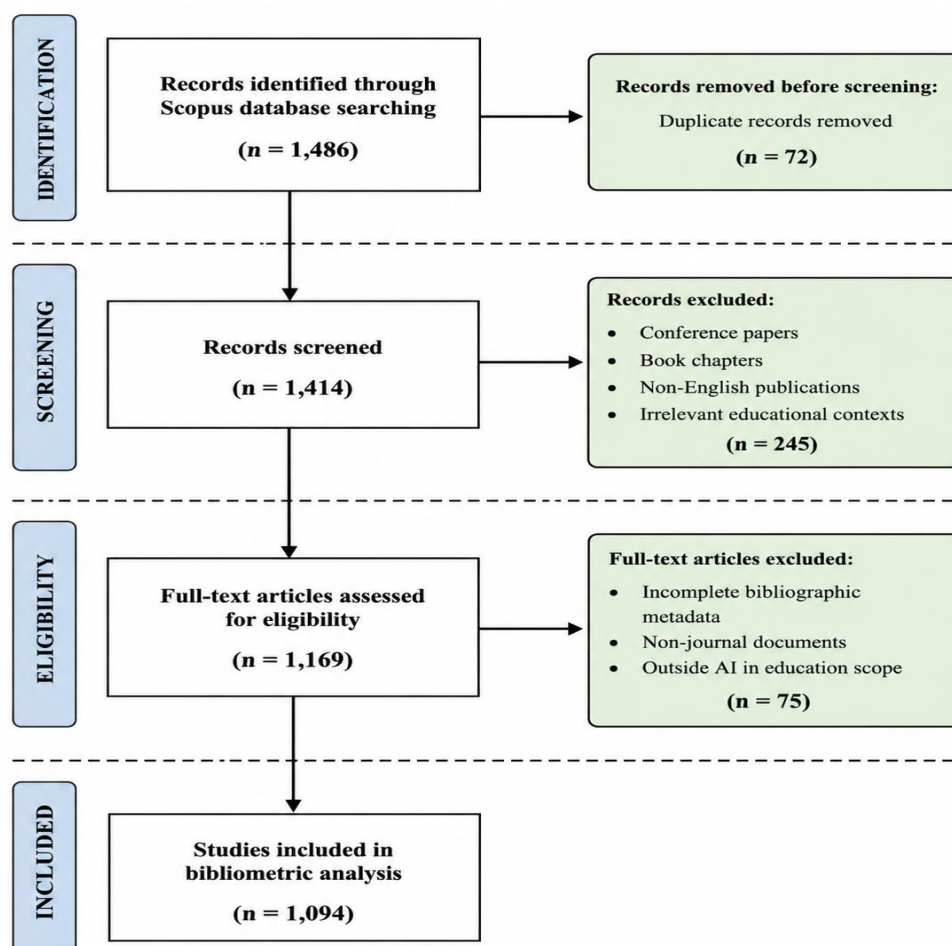
1. How has publication productivity in AI in education evolved from 2008 to 2026?
2. Which authors, institutions, and countries are the most influential in the field?
3. What thematic structures and keyword relationships dominate AI in education research?
4. How has the intellectual and collaborative structure of the field evolved over time?

This study aims to map research trends on Artificial Intelligence in education through bibliometric analysis. This mapping is expected to provide insights into topic development, key research actors, and emerging thematic trends in scientific literature. The results are expected to serve as a reference for researchers and educators in understanding the position of AI in contemporary educational studies and potential future research directions.

## RESEARCH METHODOLOGY

This study employed a bibliometric analysis approach. Bibliometric analysis is a quantitative method used to systematically classify, evaluate, and map bibliographic data within a specific research domain (Donthu et al., 2021). The data were retrieved from the Scopus database by searching titles, abstracts, and keywords to ensure comprehensive coverage of relevant publications. Scopus was selected as the primary database because it provides broader international coverage, particularly for interdisciplinary research related to education, technology, and social sciences. Compared with Web of Science, Scopus indexes a larger number of educational technology journals and offers more comprehensive bibliographic metadata suitable for bibliometric mapping. Meanwhile, Dimensions was excluded due to inconsistencies in metadata standardization and citation indexing across document types. This study focused exclusively on journal articles to

ensure scientific rigor, peer-review consistency, and conceptual stability of the analyzed documents. Although conference proceedings are highly influential in AI and computer science research, many proceedings emphasize short-term technical experimentation rather than mature pedagogical discussion. Therefore, limiting the dataset to journal articles enabled a more stable and in-depth analysis of the intellectual development of AI in education research. The search query applied was: TITLE-ABS-KEY(("artificial intelligence" OR "AI" OR "machine learning" OR "deep learning" OR "intelligent tutoring system\*" OR "adaptive learning system\*") AND ("education" OR "learning" OR "teaching" OR "higher education" OR "educational technology"))AND PUBYEAR > 1999 AND PUBYEAR < 2027AND LIMIT-TO(DOCTYPE,"ar") AND LIMIT-TO(LANGUAGE,"English"). The publication period was limited to 2000–2026 to capture research developments within the twenty-first-century educational context. Although the search period was initially set from 2000 to 2026, no Scopus-indexed journal articles meeting the inclusion criteria were identified between 2000 and 2007. Therefore, the effective dataset spans the period from 2008 to 2026. Only journal articles were included to ensure the scientific rigor and consistency of the dataset. The retrieved bibliographic records were subsequently exported for further analysis. The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, and the procedure is illustrated in the flow diagram presented in Figure 1.



**Figure 1.** Prisma flow diagram of the article selection process

The bibliometric analysis was conducted using two complementary techniques: performance analysis and science mapping. Performance analysis was used to examine publication productivity, citation impact, and collaboration patterns, while science mapping was applied to explore intellectual structure, thematic evolution, and relationships among research components within the

field. Biblioshiny, a web interface of the Bibliometrix package in R, was used to generate bibliometric indicators, network visualizations, and thematic maps. This approach enabled the identification of research trends, collaboration networks, and knowledge structures, providing a comprehensive understanding of the development and consolidation of Artificial Intelligence research in education.

## RESULT AND DISCUSSION

### Overview of Publication Data on Artificial Intelligence in 21st-Century Education from the Scopus Database

The results of the bibliometric analysis indicate that publications in the examined field span the period from 2008 to 2026, with a total of 1,094 documents distributed across 680 scientific publication sources. The annual growth rate of 23.55% demonstrates a consistent increase in academic attention over time. This figure not only reflects productivity but also indicates that the topic is gaining increasing legitimacy within scientific discourse. These findings are consistent with the bibliometric study conducted by Saleng et al. (2026), which identified an exponential growth pattern in technology-based education research after 2015. Therefore, the upward trend in publications within this dataset can be understood as part of a broader global dynamic.

The average document age of 3.05 years suggests that the literature is relatively recent and aligned with current developments. In the context of educational research influenced by rapid digital technological advancements, updating references is essential, as both conceptual frameworks and practices evolve quickly. Khaddar et al. (2025) emphasize that the acceleration of technology-based educational research over the past decade has been driven by the integration of artificial intelligence and digital transformation in learning. Consequently, the dominance of relatively recent documents indicates that this field is in an active phase of development and is highly adaptive to ongoing changes.

In terms of scientific impact, the average citation rate of 35.28 per document reflects a relatively strong level of influence. High citation counts indicate that the publications within this dataset are not only numerous but also contribute significantly to shaping future research directions. In bibliometric studies, citations are often interpreted as indicators of a field's visibility and scientific relevance (Saleng et al., 2026). Thus, it can be argued that the analyzed field occupies a strategic position in global academic discourse, particularly in advancing both theoretical and practical aspects of contemporary education.

Authorship characteristics reveal a strong dominance of collaboration, with an average of 4.07 authors per document out of a total of 4,011 contributing authors, while only 133 authors produced single-authored works. This pattern suggests that knowledge production in this field heavily relies on teamwork and academic networking. The proportion of international collaboration, at 27.97%, further highlights significant cross-country connectivity. Khaddar et al. (2025) also demonstrate that collaborative networks across institutions and countries contribute to improving research quality and impact. In addition, the diversity of 5,759 Keywords Plus and 3,197 Author's Keywords illustrates the breadth and complexity of evolving research themes. Overall, these findings confirm that the field under study is not only growing quantitatively but also strengthening collaboratively and substantively within the global educational research landscape. Further details can be seen in Table 1 below.



**Table 1.** demonstrates that research on Artificial Intelligence (AI) in education

| Main Information About Data     |           |
|---------------------------------|-----------|
| Timespan                        | 2008:2026 |
| Sources (Journals, Books, etc)  | 680       |
| Documents                       | 1094      |
| Annual Growth Rate %            | 23.55     |
| Document Average Age            | 3.05      |
| Average citations per doc       | 35.28     |
| DOCUMENT CONTENTS               |           |
| Keywords Plus (ID)              | 5759      |
| Author's Keywords (DE)          | 3197      |
| AUTHORS                         |           |
| Authors                         | 4011      |
| Authors of single-authored docs | 133       |
| AUTHORS COLLABORATION           |           |
| Single-authored docs            | 136       |
| Co-Authors per Doc              | 4.07      |
| International co-authorships %  | 27.97     |
| DOCUMENT TYPES                  |           |
| article                         | 1094      |

Table 1 demonstrates that research on Artificial Intelligence (AI) in education has experienced substantial growth and increasing scientific consolidation over the last decade. The dataset consists of 1,094 journal articles published between 2008 and 2026 across 680 scientific sources, indicating that AI in education has evolved into a highly dynamic interdisciplinary research field. The annual growth rate of 23.55% reflects a rapid expansion of scholarly attention, particularly after the acceleration of digital transformation in global education systems.

The average citation per document (35.28) further indicates that publications in this field possess strong academic influence and are widely utilized as scientific references in subsequent studies. This finding confirms that AI in education is no longer an emerging peripheral topic but has entered a mature stage of international academic discussion. In addition, the average document age of 3.05 years suggests that the literature is dominated by recent studies, demonstrating that the field continues to evolve alongside advances in educational technology and generative AI.

From the collaboration perspective, the average of 4.07 co-authors per document and the international collaboration rate of 27.97% indicate that AI research in education is increasingly developed through global academic networks. This pattern signifies that educational AI research requires multidisciplinary expertise involving education, computer science, learning analytics, and data science. Therefore, the findings highlight the growing institutional and international integration within AI-based educational research.

The novelty of this study lies in its comprehensive bibliometric mapping that simultaneously integrates publication productivity, collaboration structures, citation impact, and thematic evolution in AI-based education research from 2008–2026. Unlike previous studies that mainly focused on conceptual reviews or limited thematic analyses, this research provides a broader scientific landscape showing how AI in education has transformed from a technology-support topic into a globally interconnected pedagogical ecosystem.

### Number of Manuscripts Published on Artificial Intelligence per Year

The development in the number of publications shows a very clear growth pattern over time. In the early period, particularly between 2008 and around 2014, the number of published articles remained very limited, ranging only from zero to two documents per year. This indicates that the topic under study had not yet become a primary focus within the global research agenda. However, entering the period after 2017, the

number of publications began to increase gradually and demonstrated a more stable trend. This pattern reflects a transition phase from an exploratory stage to an expansion stage, as commonly observed in the development of a scientific field that is beginning to establish its theoretical and practical relevance. Further details can be seen in Table 2 below:

**Table 2.** Number of Publications per Year

| Year | Articles |
|------|----------|
| 2008 | 1        |
| 2009 | 0        |
| 2010 | 2        |
| 2011 | 0        |
| 2012 | 1        |
| 2013 | 4        |
| 2014 | 3        |
| 2015 | 4        |
| 2016 | 7        |
| 2017 | 8        |
| 2018 | 24       |
| 2019 | 36       |
| 2020 | 53       |
| 2021 | 103      |
| 2022 | 135      |
| 2023 | 144      |
| 2024 | 229      |
| 2025 | 295      |
| 2026 | 45       |

Table 2 clearly illustrates the longitudinal development of scientific publications related to Artificial Intelligence (AI) in education from 2008 to 2026. During the early phase between 2008 and 2017, publication productivity remained relatively low and unstable, with fewer than ten articles published annually. This condition indicates that AI in education was still positioned as an emerging and exploratory research area, where scholarly discussions were largely conceptual and had not yet developed into a comprehensive global research agenda. At this stage, research primarily focused on introducing the potential of AI technologies in supporting teaching and learning processes rather than examining their large-scale pedagogical implementation.

A significant transformation began after 2018, marked by a sharp increase in publication output. The number of publications rose from 24 articles in 2018 to 103 articles in 2021 and reached its highest peak in 2025 with 295 publications. This rapid acceleration demonstrates that AI has evolved into one of the dominant themes in contemporary educational research. The trend reflects the growing integration of digital learning environments, online education systems, adaptive learning technologies, and generative AI tools into educational practices worldwide. Therefore, the increasing number of publications does not merely represent rising academic interest, but also indicates a broader transformation in the global educational ecosystem driven by technological innovation.

The sharp growth after 2022 further suggests that educational institutions and researchers are increasingly responding to technological disruption and the urgent need for digital transformation in education. Research attention has expanded toward issues such as personalized learning, learning analytics, AI literacy, adaptive systems, automated assessment, and AI-assisted pedagogy. This finding indicates a clear shift from technology-oriented discussions toward more pedagogically and

socially oriented approaches that emphasize the effectiveness, ethics, and sustainability of AI implementation in education.

This acceleration also reflects the simultaneous consolidation and expansion of scientific discourse at the international level. Similar findings have been reported by Shen et al. (2026), who explain that the increasing integration of AI features in educational settings has significantly strengthened research interest in reputable international journals. In addition, J. C. Liu et al. (2026) highlight that the emergence of institutional policies regarding AI tools such as ChatGPT has intensified global academic discussions concerning digital literacy, educational inequality, and access to technology. Furthermore, Li et al. (2026) argue that AI literacy, self-efficacy, and creative mindset have become critical dimensions in the era of generative AI. These studies reinforce the interpretation that the increase in publication productivity is driven not only by technological advancement but also by the growing need to understand the pedagogical, ethical, and psychosocial implications of AI in education.

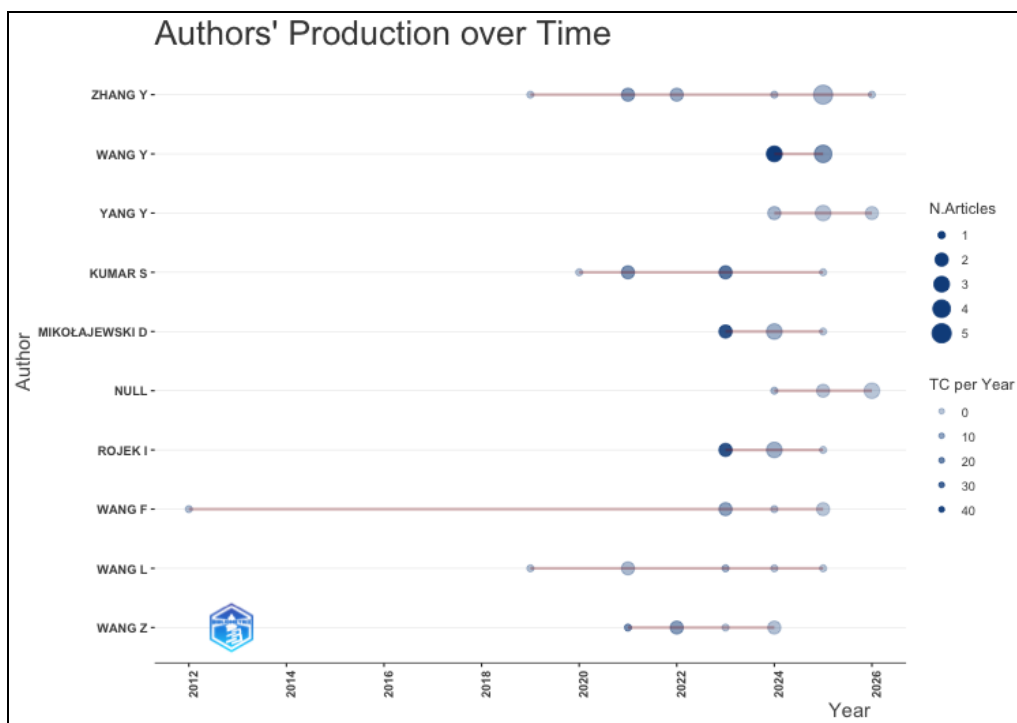
Meanwhile, the lower number of publications recorded in 2026, totaling 45 documents, is most likely influenced by the indexing process, as the year was still ongoing during data collection. Consequently, the decline should not be interpreted as a reduction in scholarly interest but rather as a temporary limitation of database coverage.

Overall, the publication trend presented in Table 2 confirms that AI in education has entered a mainstream phase of global educational research characterized by rapid expansion, interdisciplinary collaboration, and strong practical relevance. The novelty of this study lies in its ability to identify the transformation of AI in education from a fragmented and exploratory research topic into a globally interconnected research field within less than two decades. Unlike previous studies that primarily focused on conceptual discussions or limited thematic reviews, this study provides a comprehensive bibliometric perspective demonstrating how AI has evolved into a strategic and data-driven pedagogical framework shaping the future direction of contemporary education.

### Author Productivity

The analysis of author productivity reveals a clear shift in contribution patterns over time. In the early phase, prior to 2017, author appearances were sporadic and largely individual. Publications emerged without strong continuity across years, resulting in a fragmented development of the field. This situation is typical of the embryonic stage of a research topic, when academic discourse is still searching for stable conceptual and methodological foundations. Further details can be seen in Figure 2 below:





**Figure 2.** Author's Production over time

Figure 2 illustrates the pattern of authors' productivity over time in Artificial Intelligence (AI) research within the field of education. The visualization demonstrates that the development of scholarly contributions evolved gradually from a fragmented and sporadic pattern into a more structured and collaborative research ecosystem. In the early phase, particularly before 2018, author productivity remained relatively limited and inconsistent. Only a small number of researchers appeared in the publication network, and their contributions were generally isolated within certain years. This condition indicates that AI in education was still in an exploratory stage, where academic discussions were primarily conceptual and had not yet formed a stable scientific community.

Changes began to emerge during the 2019–2021 period, when several authors demonstrated recurring contributions within relatively short time intervals. Authors such as Zhang Y, Kumar S, and Wang L began to appear consistently across multiple years, indicating the initial formation of a more sustainable research trajectory. This phenomenon reflects the emergence of a more stable academic community and signals that research on AI in education was no longer experimental in nature but had started to develop into a systematic scholarly agenda. In the context of AI-based education, the strengthening of research on self-directed learning, adaptive learning systems, and student autonomy in higher education further confirms the increasing maturity of the field (Mncube et al., 2026). The consistency of author contributions during this period therefore illustrates both the consolidation of research interests and the growing depth of scientific inquiry.

Entering the 2023–2025 period, publication intensity increased much more significantly. Several authors appeared repeatedly as highly productive contributors, both within single years and across consecutive years. The larger node sizes in the visualization indicate an increasing number of publications, while the continuity of author appearances demonstrates stronger sustainability of research productivity. This pattern suggests that the field has entered a stage of increasing research stability, where knowledge production is no longer dependent on incidental individual contributions but is increasingly supported by relatively stable research groups and collaborative academic networks. In bibliometric terms, the repeated presence of productive authors signifies the emergence of influential scholarly actors who contribute to shaping the direction of scientific discourse within the field.

The strengthening of author productivity also reflects broader global developments in artificial intelligence research. AI has evolved not only as a technological innovation but also as a strategic domain of epistemic competition among countries and institutions (Ge, 2025).

Consequently, the increase in publication intensity cannot be separated from the global acceleration of innovation, digital transformation, and the growing demand for technology-driven educational solutions. At the same time, the wider implementation of digital technologies across educational and professional sectors has encouraged researchers to produce more applied and solution-oriented studies (Su-Fen CHENG, 2026). This explains why recent years demonstrate stronger scientific collaboration, denser academic networks, and more consistent publication productivity.

Scientifically, the trend presented in Figure 2 confirms that AI research in education has undergone a transition from an initially fragmented and individual-based phase toward a more mature, collaborative, and globally interconnected research ecosystem. The novelty of this study lies in demonstrating the transition of AI in education from a fragmented topic into an increasingly interconnected global research field.4. Distribution of Artificial Intelligence Publications by Affiliation

Institutional involvement in publications shows a gradual yet consistent development. Prior to 2015, affiliation contributions were limited and lacked continuity; typically, only one article per year was produced by a given institution without clear research continuity. This pattern illustrates the early stage of the field’s development, when knowledge production was still dispersed and not yet institutionally organized. From a bibliometric perspective, this phase is common before the emergence of well-established research concentrations (Aria & Cuccurullo, 2017). Further details can be seen in Figure 3 below:

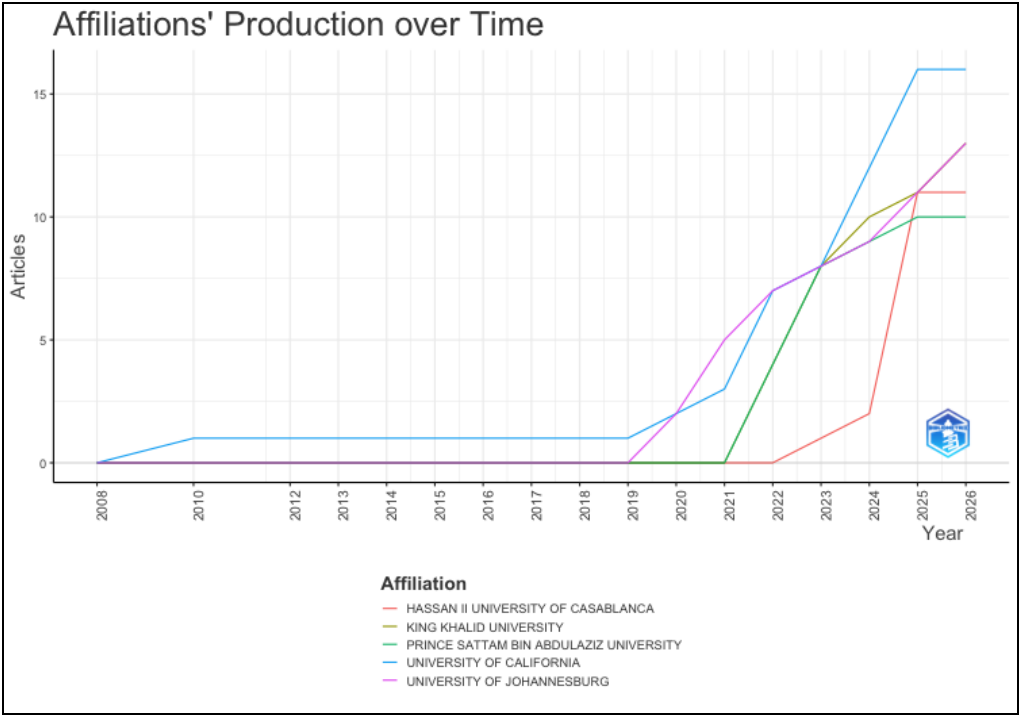


Figure 3. Affiliations Production over time

Table 3. Top Institutional Contributors in AI in Education Research (2008–2026)

| Rank | Institution                | Publication Trend                     | Research Characteristics                                                                                         |
|------|----------------------------|---------------------------------------|------------------------------------------------------------------------------------------------------------------|
| 1    | University of California   | Highest publication growth after 2021 | Strong contribution to AI-based learning systems, learning analytics, and interdisciplinary educational research |
| 2    | University of Johannesburg | Stable and continuous increase        | Focus on digital learning transformation, AI literacy, and educational innovation                                |
| 3    | King Khalid University     | Significant growth after 2023         | Increasing research productivity related to AI integration in higher education                                   |
| 4    | Prince Sattam              | Rapid publication                     | Emphasis on adaptive learning systems and                                                                        |

|   |                                    |                                               |                                                                                                |
|---|------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------|
|   | Bin Abdulaziz University           | increase during 2022–2025                     | technology-enhanced education                                                                  |
| 5 | Hassan II University of Casablanca | Emerging contributor with recent acceleration | Expanding participation in AI and digital education studies within developing-country contexts |

Table 3 complements Figure 3 by presenting the publication trajectories of the most productive institutional contributors in AI in education research from 2008 to 2026. The University of California demonstrates the strongest and most consistent growth, particularly after 2021, indicating its central role in advancing interdisciplinary AI-driven educational research. Institutions from emerging regions, such as King Khalid University, Prince Sattam Bin Abdulaziz University, and Hassan II University of Casablanca, also show notable increases in publication productivity, reflecting the expanding global diffusion of AI-related educational research. Meanwhile, the University of Johannesburg exhibits relatively stable growth, emphasizing the increasing importance of digital learning transformation and AI literacy within higher education research. Overall, these patterns suggest that AI in education research is increasingly supported by diverse institutional networks across multiple regions, indicating broader international engagement and strengthening collaborative research development.

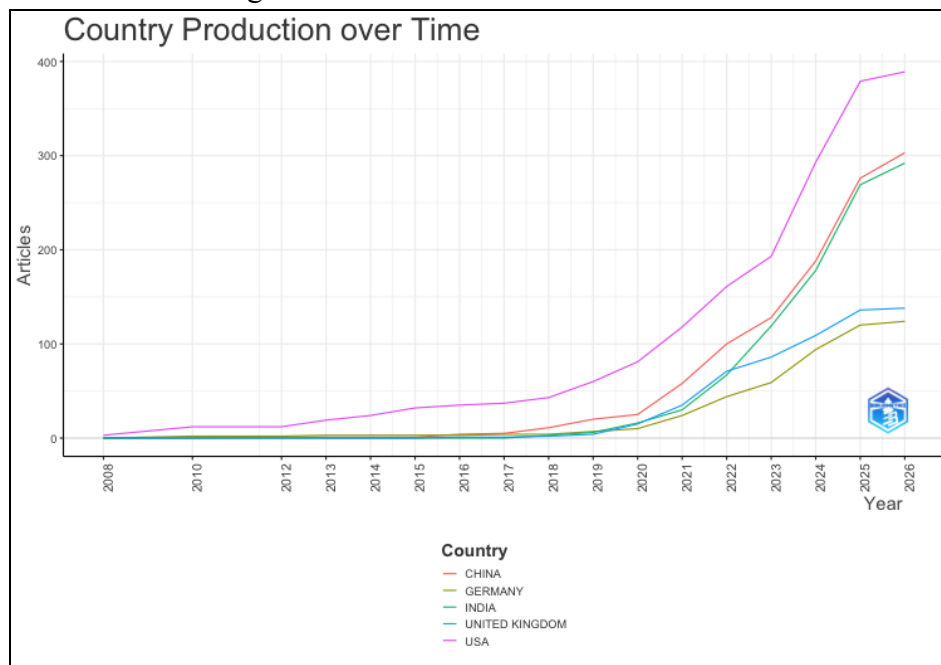
Changes began to emerge after 2018. The number of institutions involved became increasingly diverse, and publications were no longer dominated by one or two affiliations. The distribution of articles became more evenly spread across various universities, indicating that this topic had begun to be adopted as part of a broader research agenda. The most significant increase occurred during the 2023–2025 period, when several institutions showed a notable rise in the number of publications. Hassan II University of Casablanca experienced a sharp increase in contributions, while the University of California, which previously appeared sporadically, began to demonstrate a more consistent presence. This condition reflects a shift from individual initiatives toward a stronger institutional research focus.

Overall, this trend reflects the maturation process of the academic community. As more institutions become involved and demonstrate consistent publication output, this serves as an indicator that the field has entered a more stable and legitimized growth phase. Furthermore, the strengthening consolidation of affiliations also signals the emergence of knowledge production centers that play a crucial role in sustaining research development, as explained by Zupic and Čater (2015) in the context of network analysis and science mapping.

**Distribution of Artificial Intelligence Publications by Country**

The results of the visual analysis indicate that the map of country contributions has undergone a noticeable shift from an initially concentrated pattern to a more dispersed distribution. In the phase prior to 2018, country nodes in the network visualization were still limited in number and relatively small in size, with low levels of connectivity (link strength). Entering the 2019–2021 period, an expansion in the number of nodes and increased inter-country connectivity began to emerge, although citation intensity and productivity were not yet evenly distributed. The most significant surge occurred during 2023–2025, when the node sizes of several countries—particularly China and the United States expanded consistently, accompanied by the emergence of new clusters from other regions. Methodologically, this pattern indicates both an increase in productivity and more intensive international collaboration, as reflected in network density and the growth of total link strength. This trend suggests that the research topic has entered a phase of

growing international collaboration patterns, no longer dominated by a single epistemic region. Further details can be seen in Figure 4 below:



**Figure 4.** Country Production over time

**Table 4.** Top Contributing Countries in AI in Education Research (2008–2026)

| Rank | Country        | Publication Trend                                         | Research Characteristics                                                                                      |
|------|----------------|-----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| 1    | United States  | Highest and most consistent growth, especially after 2021 | Strong dominance in AI-driven educational innovation, international collaboration, and generative AI research |
| 2    | China          | Rapid acceleration after 2020                             | Supported by national AI policies and large-scale educational technology investment                           |
| 3    | India          | Significant increase after 2021                           | Focus on digital learning expansion, adaptive learning systems, and AI accessibility                          |
| 4    | United Kingdom | Stable and continuous growth                              | Strong emphasis on AI ethics, educational policy, and digital literacy                                        |

Table 3 complements Figure 4 by demonstrating the comparative contribution patterns of the most productive countries in AI in education research from 2008 to 2026. The United States shows the highest and most stable publication growth throughout the observed period, indicating its strong research infrastructure and long-standing investment in educational technology innovation. China demonstrates the most rapid acceleration after 2020, reflecting the impact of national AI development strategies and expanding digital education initiatives. Meanwhile, India, the United Kingdom, and Germany exhibit increasingly consistent publication trajectories, suggesting broader global participation in AI-driven educational transformation. Overall, the findings indicate that AI in education research is no longer concentrated within a limited number of countries but has evolved into a globally interconnected research field characterized by expanding international collaboration and growing institutional engagement.

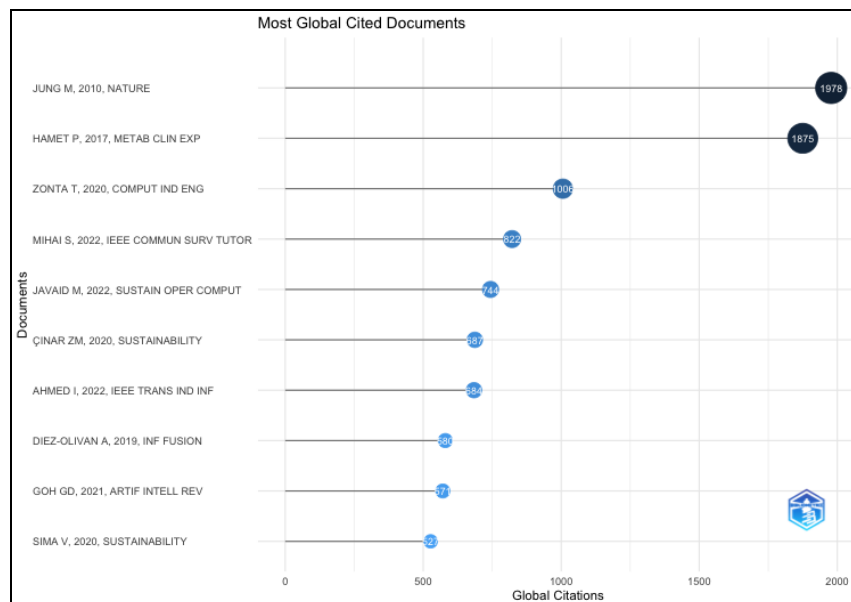
When examined more closely, the acceleration of publications during 2023–2025 does not occur in isolation but is closely linked to growing global attention toward the integration of digital technologies and artificial intelligence in education. Several recent studies confirm that AI-driven educational transformation is fostering reforms in curricula, instructional strategies, and institutional policies across various countries (Z. Hu et al., 2026; Qian et al., 2025). Moreover, the discourse on critical literacy in the era of generative AI indicates that educational institutions are responding systemically to shifts in the technological landscape (Weigelt et al., 2026). In this context, the dominance of China and the United States can be understood not merely as a quantitative advantage, but also as a reflection of research capacity, digital infrastructure, and national policies that are adaptive to educational innovation. The dominance of China and the United States can also be linked to national AI strategies and large-scale investments in educational technology innovation. China's "Next Generation Artificial Intelligence Development Plan" introduced in 2017 accelerated AI integration across education, industry, and research sectors. Similarly, the United States strengthened AI research through federal AI initiatives, digital learning programs, and collaborations between universities and technology industries. These policy-driven innovation ecosystems contributed significantly to higher publication productivity and stronger international collaboration networks. Consequently, the dominance of these countries reflects not only technological capacity but also the strategic alignment between national policy, research funding, and digital educational transformation. Thus, the growth in publications reflects underlying structural dynamics within the global research ecosystem.

Furthermore, the expansion of contributions to a broader range of countries after 2021 indicates a process of knowledge democratization. The increasing participation of developing countries in issues related to digital literacy and AI policies in schools demonstrates that this transformation is cross-contextual in nature (Ishtiaq et al., 2025; H. Liu et al., 2026). Methodologically, the consistency of annual trends and the emergence of new collaborative clusters reinforce the validity of the finding that this field has become a focal point of the international scientific community. In other words, research development is no longer sporadic but exhibits a stable and sustained growth trajectory. These findings confirm that the field under study has evolved into a global research arena characterized by increasingly dense collaboration networks, while also opening opportunities for more diverse epistemic contributions in the years to come.

### **Distribution of Artificial Intelligence Publications Based on Cited Documents**

Based on the analysis of the Most Globally Cited Documents, it is evident that the highest-cited articles are concentrated in the 2019–2022 period, a phase during which the conceptual foundations of the field began to strengthen. Visually, the citation map reveals several dominant nodes that are significantly larger than others, indicating high global citation scores. This distribution forms a core–periphery structure, in which a number of early works function as central references that support subsequent research. Methodologically, this pattern is typical of a growing field: articles that first establish transformation frameworks, learning models, or technology-based educational system designs tend to be adopted and cited more rapidly across countries. The consistency of citations over time also indicates that these works possess relatively stable theoretical and practical relevance. Further details can be seen in Figure 5 below:





**Figure 5.** Most Global Cited Documents

Substantively, the most highly cited documents generally address educational transformation in response to the artificial intelligence revolution and the digital ecosystem. For instance, studies on higher education transformation frameworks in the face of the AI revolution emphasize the importance of restructuring curricula and institutional governance to align with technological developments (Ghnemat et al., 2022). Other research on smart classroom design in the Industry 4.0 era highlights the integration of digital infrastructure, adaptive pedagogy, and technological literacy as prerequisites for future learning (Lorenzo et al., 2021). Even in the context of health education, innovative approaches such as challenge-based learning demonstrate that integrating active learning strategies with technological support can significantly enhance students' learning approaches (Tang & Chow, 2020). The high citation rates of these articles indicate that the global academic community utilizes them as both conceptual references and methodological foundations.

Meanwhile, articles published during the 2023–2025 period have begun to show an increasing citation trend, although quantitatively they have not yet surpassed the dominance of works from 2019–2022. Methodologically, this can be explained by the citation window effect, whereby more recent articles have not had sufficient time to accumulate citations optimally. Nevertheless, the emergence of newer studies with more contextual and practice-oriented approaches suggests that the field has entered a phase of deepening, rather than merely remaining at the level of conceptual exploration. Thus, the citation pattern that emerges confirms that the development of the field is strongly influenced by a set of core literature that shapes the direction of discourse, while also opening space for research innovation in subsequent phases. This structure reflects strong continuity of research development and serves as an indicator of the field's maturity within the international research landscape.

### Distribution of Artificial Intelligence Publications Based on Keywords

The most dominant keywords are directly related to the issue of technology utilization in education. The word cloud visualization shows that terms such as *artificial intelligence*, *education*, *machine learning*, and *learning* form the central core of the keyword map. The prominent font size indicates a high frequency of occurrence and highlights the primary research focus on the integration of AI in the learning process. The presence of terms such as *students*, *teachers*, *teaching*,

and *classroom* within closely connected clusters confirms that the discourse extends beyond technological development into the domain of pedagogical practice. Methodologically, the density and proximity of these keywords indicate thematic coherence, in which technology, educational actors, and learning processes form an integrated conceptual network. Further details can be seen in Figure 6 below:



**Figure 6. Most Frequently Used Keywords**

This interpretation is reinforced by literature that positions AI as part of data-driven pedagogical transformation. Chassignol et al. (2018) explain that the development of AI in education is directed toward learning support systems, performance analytics, and the optimization of learning experiences. Furthermore, the study by Baker and Inventado (2014) emphasizes the importance of educational data mining in understanding students' learning patterns and improving the quality of instructional interventions. Meanwhile, research by Roll and Wylie (2016) shows that the use of learning analytics enables teachers to monitor student progress more precisely and responsively. These references align with the high frequency of terms such as *data*, *analysis*, and *performance* in the visualization, indicating a strong shift toward evidence-based approaches in learning evaluation.

Overall, the keyword patterns illustrate that this field is developing at the intersection of technological innovation and practical pedagogical needs. The interconnected cluster structure indicates that research is not fragmented but instead forms a discourse ecosystem that integrates technology, classroom practices, and data-driven evaluation. The findings indicate a significant conceptual transition in the role of Artificial Intelligence within education. Initially, AI was primarily positioned as a technological tool designed to support instructional efficiency and automate specific educational tasks. However, recent publication trends and thematic developments demonstrate that AI is increasingly conceptualized as a broader learning environment and pedagogical ecosystem. In this paradigm, AI no longer functions merely as an assistant technology but actively shapes learning interactions, assessment mechanisms, knowledge production, and educational decision-making processes. This transformation reflects a broader epistemological shift from teacher-centered knowledge transmission toward adaptive, data-driven, and personalized learning systems. Consequently, AI is not only transforming educational technology but also

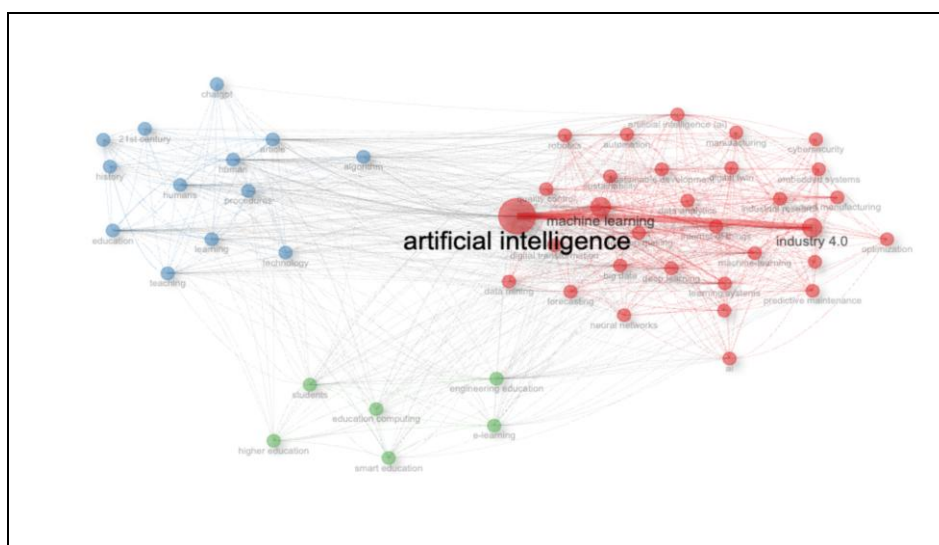
redefining how learning, teaching, and educational authority are understood in contemporary society.

Methodologically, this integration signals the maturity of the field, where AI is no longer perceived merely as a technological experiment but as part of a systematic strategy to enhance learning quality. Thus, the word cloud serves not only as a representation of term frequency but also as an indicator of the epistemic direction that places learning and educational actors at the center of digital transformation.

### Distribution of Artificial Intelligence Publications Based on Keyword Co-occurrence

The results of the co-occurrence network analysis show that the relationships among keywords form a structure that is not fragmented but systemically interconnected between technological and pedagogical dimensions. The central position of *artificial intelligence* and *education* within the network indicates that research is developing with an integrative orientation, where technology acts as an enabler of learning practices rather than merely an independent object of study. Strong connections with terms such as *machine learning*, *learning analytics*, and *students* suggest that research approaches increasingly emphasize data-driven personalized learning and the modeling of learner characteristics.

Methodologically, this pattern reflects a growing tendency toward the use of field experimental designs and human–computer interaction-based system evaluations to test the effectiveness of educational technologies in real classroom settings. Empirical studies indicate that AI-based teaching agents with multimodal interaction can enhance learning engagement while providing adaptive feedback, although challenges remain related to user trust and implementation complexity in school environments (H. Liu et al., 2026). Thus, the network visualization not only demonstrates the popularity of themes but also signals the consolidation of research approaches toward the integration of intelligent learning systems within authentic pedagogical contexts. Further details can be seen in Figure 7 below:



**Figure 7.** Keyword Interrelationships

Meanwhile, the emergence of pedagogical clusters such as *teaching*, *classroom*, and *assessment* indicates that researchers' attention is increasingly shifting toward the implementation and evaluation aspects of AI-based learning. The association with keywords such as *data* and *performance* further reinforces the indication that research is moving toward the quantitative measurement of learning outcomes through learning analytics and predictive modeling. This

approach reflects a methodological shift from conceptual studies toward evidence-based education, supported by explainable AI techniques to enhance transparency in system decision-making processes. Recent studies confirm that learner profiles automatically generated through explainable AI can assist educators in understanding individual student needs more accurately, while also improving accountability in the use of technology in education (Ouaed et al., 2026). Overall, the resulting keyword network pattern illustrates an increasingly mature research evolution, linking technological innovation, pedagogical practices, and learning performance evaluation within a comprehensive educational research ecosystem. Despite the rapid growth of learning analytics and data-driven educational systems, the findings also reveal a potential imbalance in current AI research trends. The strong emphasis on predictive analytics, automation, and performance measurement may risk marginalizing humanistic dimensions of education, including emotional interaction, ethical reflection, and students' social experiences. This tendency suggests that contemporary AI discourse in education is still predominantly technology-oriented, while the social and relational aspects of learning receive comparatively less attention. Therefore, future AI research should not only prioritize technological efficiency but also integrate more human-centered pedagogical approaches that emphasize empathy, ethical responsibility, inclusivity, and meaningful educational interaction.

## CONCLUSION

This study demonstrates that Artificial Intelligence (AI) research in education has undergone a significant transformation from a fragmented technological discourse into a globally interconnected pedagogical research ecosystem. The bibliometric findings reveal not only rapid growth in publication productivity and international collaboration but also a substantial thematic shift from viewing AI merely as an instructional support tool toward understanding it as an adaptive and data-driven educational paradigm. The increasing emphasis on machine learning, learning analytics, personalized learning, and AI-assisted assessment indicates that contemporary educational research is increasingly shaped by intelligent systems capable of influencing learning interactions, evaluation processes, and educational decision-making. At the same time, the findings highlight important challenges accompanying the expansion of AI in education, particularly regarding teacher readiness, digital inequality, ethical governance, and the potential marginalization of humanistic dimensions of learning. The dominance of data-driven approaches and predictive analytics suggests the need for a more balanced integration between technological innovation and human-centered pedagogy.

Therefore, educational institutions and policymakers should prioritize not only technological infrastructure and AI literacy but also ethical frameworks, pedagogical preparedness, and inclusive learning practices to ensure responsible and sustainable AI implementation. The novelty of this study lies in its integration of publication dynamics, collaboration structures, citation patterns, and thematic evolution within a single bibliometric framework covering the period from 2008 to 2026, including the recent expansion of generative AI discourse. Nevertheless, this study is limited by its reliance on the Scopus database and the exclusive use of journal articles, which may exclude relevant publications indexed in other databases or conference proceedings. Future studies are therefore encouraged to integrate multiple databases and comparative bibliometric approaches to provide a broader understanding of the evolving role of AI in global education.

## DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used ChatGPT to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the

author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

## AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; Investigation.

Author 3: Data curation; Investigation.

Author 4: Formal analysis; Methodology; Writing - original draft.

Author 5: Supervision; Validation.

## DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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