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TENDÊNCIAS DA IA NA EDUCAÇÃO: UMA ANÁLISE BIBLIOMÉTRICA DE CONTEXTOS EMERGENTES

AI TRENDS IN EDUCATION: A BIBLIOMETRIC ANALYSIS OF EMERGING CONTEXTS

TENDENCIAS DE IA EN EDUCACIÓN: UN ANÁLISIS BIBLIOMÉTRICO DE CONTEXTOS EMERGENTES

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Resumo

A inteligência artificial (IA) emerge como uma força transformadora na educação, impulsionando a personalização do ensino e mitigando desigualdades educacionais. Este estudo objetiva analisar, por meio de uma abordagem bibliométrica, as principais tendências da aplicação da IA na

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educação, com ênfase na produção científica associada a países em desenvolvimento e contextos com infraestrutura limitada, identificando avanços, desafios e oportunidades. A metodologia empregada foi a pesquisa bibliográfica, caracterizada pela análise sistemática da literatura. Dados foram coletados nas bases Scopus e Web of Science (WoS), abrangendo o período de 2014 a 2024. Após triagem e aplicação de critérios de inclusão e exclusão, 634 documentos foram selecionados. O gerenciamento de referências foi realizado com Zotero, e a organização e limpeza dos dados ocorreram na plataforma Rayyan. A análise bibliométrica foi conduzida com o pacote Bibliometrix no software RStudio, e o VOSviewer foi utilizado para mapeamento científico e análise de redes de coautoria e coocorrência. Os resultados revelaram um crescimento da produção científica sobre IA na educação a partir de 2019, intensificado pela pandemia de COVID-19. China, Estados Unidos e Índia se destacaram como os países com maior produção científica e impacto acadêmico no campo. Apesar dos avanços, o estudo destacou desafios como barreiras infraestruturais, viés algorítmico, falta de formação docente e riscos éticos associados à coleta e uso de dados sensíveis. Conclui-se que o uso ético, equitativo e contextualizado da IA na educação demanda políticas públicas comprometidas com a inclusão digital, formação docente contínua e investimentos em tecnologias acessíveis e sensíveis às realidades locais.

Palavras-chave: Inteligência artificial; Educação; Tecnologias emergentes; Soluções escaláveis; Desigualdades educacionais.

Abstract

Artificial intelligence (AI) is emerging as a transformative force in education, driving personalized teaching and mitigating educational inequalities. This study aims to analyze, through a bibliometric approach, the main trends in the application of AI in education, with an emphasis on scientific production associated with developing countries and contexts with limited infrastructure, and to identify advances, challenges, and opportunities. The methodology used was bibliographic research, characterized by systematic analysis of the literature. Data were collected from the Scopus and Web of Science (WoS) databases, covering the period from 2014 to 2024. After screening and applying inclusion and exclusion criteria, 634 documents were selected. Reference management was performed using Zotero, and data organization and cleaning was conducted on the Rayyan platform. Bibliometric analysis was conducted using the Bibliometrix package in RStudio software, and VOSviewer was employed for the scientific mapping and analysis of co-authorship and co-occurrence networks. The results revealed an increase in scientific production of AI in education from 2019 onwards, intensified by the COVID-19 pandemic. China, the United States, and India stood out as the countries with the most significant scientific production and academic impact in the field. Despite these advances, the study highlighted several challenges, including infrastructural barriers, algorithmic bias, a lack of teacher training, and ethical risks associated with the collection and use of sensitive data. It is concluded that the ethical, equitable, and contextualized use of AI in education requires public policies committed to digital inclusion, ongoing teacher training, and investments in accessible technologies that are sensitive to local realities.

Keywords: Artificial intelligence; Education; Emerging technologies; Scalable solutions; Educational inequalities.

Resumen

La inteligencia artificial (IA) se perfila como una fuerza transformadora en la educación, impulsando el aprendizaje personalizado y mitigando las desigualdades educativas. Este estudio busca analizar, mediante un enfoque bibliométrico, las principales tendencias en la aplicación de la IA en educación, con especial énfasis en la producción científica asociada a los países en desarrollo y a contextos con infraestructura limitada, identificando avances, desafíos y oportunidades. La metodología empleada fue una investigación bibliográfica, caracterizada por una revisión sistemática de la literatura. Los datos se recopilaron de las bases de datos Scopus y Web of Science (WoS),

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abarcando el período de 2014 a 2024. Tras la selección y aplicación de criterios de inclusión y exclusión, se seleccionaron 634 documentos. La gestión de referencias se realizó con Zotero, y la organización y limpieza de datos se realizó en la plataforma Rayyan. El análisis bibliométrico se realizó con el paquete Bibliometrix en el software RStudio, y se utilizó VOSviewer para el mapeo científico y el análisis de redes de coautoría y coocurrencia. Los resultados revelaron un crecimiento en la producción científica sobre IA en educación desde 2019, intensificado por la pandemia de COVID-19. China, Estados Unidos e India se destacaron como los países con mayor producción científica e impacto académico en este campo. A pesar de estos avances, el estudio destacó desafíos como las barreras infraestructurales, el sesgo algorítmico, la falta de formación docente y los riesgos éticos asociados a la recopilación y el uso de datos sensibles. El estudio concluye que el uso ético, equitativo y contextualizado de la IA en la educación requiere políticas públicas comprometidas con la inclusión digital, la formación docente continua y la inversión en tecnologías accesibles que se ajusten a las realidades locales.

Palabras clave: Inteligencia artificial; Educación; Tecnologías emergentes; Soluciones escalables; Desigualdades educativas.

1. Introduction

Artificial intelligence (AI) has established itself as a transformative force in education, offering innovative solutions to personalize experiences and adapt content to students' needs (Roll & Wylie, 2016). In contexts with structural limitations and scarce resources, this personalization becomes strategic for educational inclusion. According to Holmes, Bialik & Fadel (2019), AI-driven personalized learning uses adaptive algorithms and data to enhance engagement and outcomes.

However, in scenarios with limited infrastructure, low connectivity, or socioeconomic constraints, the adoption of AI faces challenges of accessibility, scalability, and ethics (Chen et al., 2021; Zawacki-Richter et al., 2019). Such contexts require solutions that are sensitive to local realities, low-cost, and capable of operating offline or with intermittent connectivity (Miao et al., 2021). Advanced technologies imported without adaptation can exacerbate inequalities, while approaches such as lightweight AI models and community-driven content show potential to overcome them (Bhutoria, 2022; Dang, Sadreddin, and Ahuja, 2024).

However, gaps still exist in understanding the appropriate use of AI in resource-limited contexts (Wang, S. et al., 2024). Much of the literature assumes robust infrastructure, ignoring internet instability, device scarcity, and lack of teacher training (UNESCO, 2019). Many studies assume advanced technology

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and stable connectivity, ignoring the challenges faced by educators and students in regions with poor infrastructure. This results in solutions that do not align with the reality of rural, peripheral, or inequality-marked educational systems. Although adaptive AI platforms are promising in high-income countries, their effectiveness in low-connectivity contexts is still underexplored, revealing a significant gap in the development of scalable and sustainable solutions (Dawadi, Goshtasbpour & Kukulska-Hulme, 2024).

The advancement of AI in education requires a systematic analysis of its potential and limitations in contexts with poor infrastructure. Ignoring the needs and constraints of these environments compromises the effectiveness of the proposed solutions. Therefore, this research seeks, through a comprehensive bibliometric analysis, to provide grounded information on how AI technologies are being adapted to these contexts, revealing trends, gaps, and opportunities for future research and innovation. To ensure comprehensive and rigorous coverage, the data for this study were obtained from two internationally recognized databases: Scopus and Web of Science (WoS). Both offer access to high-quality, peer-reviewed scientific literature, ensuring the counterpart of these proven sources. These repositories were selected due to their broad thematic coverage and rigorous indexing criteria, which allows for a robust analysis of emerging trends in the application of artificial intelligence to education (Hinojo-Lucena et al., 2019; Prahani et al., 2022; Song and Wang, 2020).

By mapping this scenario, the aim is to support the creation of technologies that broaden access to quality education, contributing to UN Sustainable Development Goal 4 (Miao et al., 2021). In this context, this work aims to bibliometrically analyze research trends in Artificial Intelligence in education from 2014 to 2024, with an emphasis on scientific production associated with developing countries and contexts with limited infrastructure, identifying the main advances, collaboration patterns, thematic concentration, and gaps related to these contexts.

2. Literature Review

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2.1 AI Applications in Education: Challenges and Opportunities in Resource-Limited Environments

The implementation of Artificial Intelligence (AI) in education faces significant challenges in resource-limited environments. These environments can be characterized by poor technological infrastructure, low internet connectivity, a shortage of computing equipment, and socioeconomic constraints that hinder access to digital education (Afzal et al., 2023).

Developing countries and rural regions frequently face barriers that make the implementation of AI-based educational solutions a major challenge. In addition, the lack of digital training for teachers and students exacerbates inequality in access to advanced technological tools (Mafara and Abdullahi, 2024). As Mubashir Moosa Panjwani (2024) also points out, "[...] limited infrastructure, funding, and staff training remain significant barriers to widespread adoption" (p. 1933, our translation).

The specific challenges for the adoption of AI in these contexts include infrastructure limitations, such as unstable or non-existent internet networks, and a lack of reliable electricity, making it difficult to adopt cloud-based technologies or those that require intensive data processing (Mubiru, Kibukamusoke, and Drake, 2024). Thus, it is noteworthy that structural barriers, in addition to hindering the technical implementation of artificial intelligence, also limit the transformative potential of these technologies in more vulnerable regions.

Inequality in access to adequate devices prevents students in areas with limited connectivity from actively participating in AI-mediated learning environments, highlighting existing educational inequalities. Brian et al. (2024) state that another impediment is the accessibility of technological devices, as many students and schools do not have access to modern computers or smartphones. This translates into increasing digital exclusion, where AI-assisted education becomes a privilege for a few (Brian, Laban, and Owin, 2024). Additionally, cultural and linguistic barriers arise, since many AI systems are trained based on data from developed countries, which makes them unsuitable for certain communities.

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In light of these difficulties, some solutions have been developed to optimize AI in contexts of low connectivity and limited infrastructure. Edge computing technologies, which allow data processing directly on the user's device without relying on cloud servers, are being explored to minimize the need for constant internet connection (Vuruma et al., 2024). Furthermore, educational platforms based on artificial intelligence are being adapted to work on offline networks, using techniques such as broadcast-store grid, which allows the prior download of educational materials for later access without internet (Dang, Sadreddin and Ahuja, 2024). Another initiative involves the use of AI in community radios and basic mobile devices, ensuring that even populations without internet access can benefit from personalized education (Haßler and Jackson, 2010). However, the representativeness of these approaches in internationally indexed scientific production is unclear, a gap that this bibliometric analysis seeks to highlight by mapping the predominant terms and thematic clusters in the literature on educational AI in emerging contexts.

However, digital equity is one of the biggest challenges in implementing AI in education in these contexts. The adoption of AI in education must be accompanied by government programs and public-private partnerships that encourage the distribution of accessible technology and the digital empowerment of teachers and students (Facer and Selwyn, 2021). Strengthening community networks and developing open-source educational software are also alternatives to democratize access to AI-based educational tools (Rachid, 2024). The extent to which these initiatives have been investigated and published in high-impact journals, as well as the countries leading this agenda, constitutes one of the central questions that this bibliometric analysis aims to answer.

2.2 Technological and digital trends and emerging innovations in the 21st century.

The 21st century has been marked by rapid technological evolution that directly impacts pedagogical practices and teaching-learning models. Among the main emerging trends, the use of educational chatbots, AI-based gamification,

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predictive analytics for educational interventions, and scalable solutions for low-infrastructure environments stand out. These technologies have been applied globally and demonstrate great potential to transform education, especially in challenging contexts (Kamalov, Santandreu Calonge and Gurrib, 2023). Through chatbots, it is possible to offer students automated answers, academic guidance, and instant feedback, providing more autonomy and student participation. Because it is a program that works with natural language algorithms, chatbots offer personalized and dynamic interaction, managing to serve a large number of students simultaneously, also reducing the overload on educators.

These systems have broadened access to information, promoting greater autonomy in learning. One point worth highlighting is the contribution to resolving doubts immediately, regardless of the time. These programs analyze student behavior patterns, identifying their difficulties and offering adaptive feedback, promoting personalized learning. Adiguzel et al. (2023) state that educational chatbots, powered by Natural Language Processing (NLP) and machine learning, are revolutionizing academic support, providing 24/7 assistance to students (Adiguzel, Kaya, and Cansu, 2023). These tools can answer frequently asked questions, offer personalized feedback, and even monitor student progress. As Kavitha and Joshith (2024) observe,

> The network visualization and overlay of the authors' keywords resulted in a distinct set of chatbots and generative AI. This indicates the growing interest in research and adoption of conversational AI models such as ChatGPT and, in general, the broader category of generative AI applications in education reform (Kavitha & Joshith, 2024, p. 394).

Despite the advances, challenges such as a lack of emotional understanding and the need for improvement in human-machine interaction still need to be overcome. Gamification with AI has also been explored to increase motivation and engagement, adapting the difficulty to the needs of students through behavior analysis and machine learning (Gawande, Badi, and Makharoumi, 2020). An example of this is platforms that integrate artificial intelligence to provide

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personalized challenges in mathematics and science, making learning more interactive and intuitive (Mageira et al., 2022). However, there are still challenges in implementing this technology, especially regarding accessibility and the costs involved in creating personalized gamification platforms.

The use of predictive analytics in education has allowed for the early identification of learning difficulties and school dropout. AI algorithms analyze data on academic performance, participation in activities, and behavioral patterns to predict which students may need additional support (Cueva et al., 2024). The use of data, statistics, and AI allows for the early identification of students at risk of dropping out or performing poorly, guiding corrective interventions by educators and administrators. Institutions that adopt these systems have reduced dropout rates and improved academic performance (Vierhauser et al., 2024). However, concerns about privacy and ethics in the use of educational data still need to be addressed to ensure that these technologies are used responsibly.

The expansion of AI in education requires attention to contexts with poor infrastructure, where there are challenges such as low connectivity, few computing resources, and energy limitations. To overcome these barriers, researchers are developing low-cost and low-consumption technologies, such as edge computing, which allows the local use of AI systems without a continuous internet connection (Vuruma et al., 2024). In this scenario, technologies such as edge computing are promising because they allow for local data processing, reducing the need for a constant internet connection, which is especially relevant in rural or peripheral areas with unstable networks. Furthermore, the use of artificial intelligence in simple mobile devices and community radios has been explored to broaden access to education in these contexts (Mubiru, Kibukamusoke, and Drake, 2024). These approaches seek to ensure that AI contributes to educational inclusion, rather than deepening inequalities.

The future of AI in education points to a scenario where adaptive technologies play a central role in personalizing teaching. Trends such as the use of generative artificial intelligence to create dynamic and personalized educational content are already on the rise and promise to further transform the learning

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process (Kavitha and Joshith, 2024). However, for these innovations to be implemented effectively, it is essential that educational policies keep pace with this evolution. Regulations aimed at data protection, teacher training, and incentives for research in AI applied to education should be prioritized (Concannon et al., 2023).

In addition to emerging technological trends, some developing countries have adopted strategic initiatives to integrate AI into education in a scalable and sustainable way. Brazil, through the Brazilian Artificial Intelligence Strategy, has invested in the application of AI for educational monitoring and combating school dropout, using data analysis to predict learning difficulties and propose early interventions (Ministry of Science, 2025). In Ecuador, an AI-based tutoring program has assisted teachers in teaching mathematics, resulting in significant improvements in student performance (Molina et al., 2024). Uruguay, in turn, has developed specific guidelines for the incorporation of AI in education, ensuring responsible adoption aligned with local needs. In addition, a recent study mapped more than 70 AI initiatives in South America, demonstrating significant growth in the use of these technologies for personalized teaching, optimization of educational processes, and expansion of access to digital education (Molina et al., 2024; Ricardo, 2025). These initiatives show that, despite infrastructure and training challenges, there is a growing movement in emerging countries to use AI as a tool for democratizing education, promoting equity and innovation in educational policies.

However, there is still no systematic mapping of the international visibility of these initiatives in the indexed scientific literature, nor of the degree of collaboration between emerging countries and high-income countries in the production of knowledge about educational AI, a gap that justifies and guides the bibliometric analysis developed in this study.

3. Methodology

This research is characterized as a bibliographic study, whose main objective is the analysis of already consolidated theoretical productions on the investigated

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topic. In this way, it is a systematic analysis of the literature related to the topic under discussion, seeking to understand and debate the different theoretical approaches available. The choice for this methodological approach is due to the need to base the study on renowned authors and previous research that helps to broaden the understanding of the problem discussed.

A bibliometric analysis was used in this study to examine research trends in the application of artificial intelligence (AI) to personalized teaching in environments characterized by limited infrastructure or low connectivity. Bibliometric analysis is a recognized method for quantitatively evaluating scientific literature, identifying the main contributors, thematic trends, and collaboration networks in a given research domain (Donthu et al., 2021).

To ensure comprehensive and relevant coverage, data were obtained from two internationally recognized databases: Scopus and Web of Science (WoS). These platforms were selected for their broad multidisciplinary coverage, robust citation tracking, and inclusion of high-quality peer-reviewed literature.

A systematic search was conducted from 2014 to 2024 to retrieve articles relevant to the application of AI in personalized teaching in environments with limited infrastructure or low connectivity. This period was chosen considering the significant advancement of the technology and its impact on the education sector in the last ten years. The search strategy was developed using a combination of controlled vocabulary and free-text terms. Boolean operators were employed to optimize the query structure, ensuring inclusion and precision. The search strategy adopted was: ("Artificial Intelligence" OR AI OR "machine learning") AND ("education" OR "teaching" OR "learning") AND ("developing countries" OR "resource-constrained environments" OR "emerging regions" OR "digital divide"). The search was iteratively refined by testing different keyword combinations to maximize relevant results, excluding irrelevant studies.

For the purposes of this study, the term 'emerging contexts' is adopted as the set of countries and regions characterized by structural constraints that condition the adoption of educational technologies, including low internet connectivity, scarcity of devices, unstable electrical infrastructure, and limitations in teacher training in

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technology. This definition is operationally delimited by the presence of the descriptors developing countries, resource-constrained environments, emerging regions, and digital divide in the search strategy, recognizing that these terms function as imperfect proxies: countries such as China and India, frequently indexed under these categories, present significant internal technological heterogeneity, with regions of high infrastructure coexisting with zones of digital exclusion. This limitation is inherent to bibliographic indexing and does not invalidate the selection, but requires that the results be interpreted as trends in the literature on educational and technological inequality, and not as a homogeneous description of a geopolitical bloc.

To ensure relevance and quality, the following inclusion criteria were applied: (1) Peer-reviewed journal articles, (2) Peer-reviewed conference papers, (3) Studies focused on AI applied to education or with some correlation. The exclusion criteria were: (1) Articles outside the educational domain or unrelated to AI, (2) Non-peer-reviewed literature, (3) Duplicates, and (4) Retracted articles.

The article selection process combined quantitative and statistical tools for analyzing the metadata of scientific articles, also supported by guidelines adapted from the PRISMA protocol (Page et al., 2021). Initially, 4,608 documents were identified. After screening by typology, 4,264 documents were selected for preliminary analysis. A total of 1,417 documents were excluded due to duplication. Additionally, 2,213 documents were excluded for not being relevant to the study topic. This is a relevant point for minimizing the possibility of bias in our bibliometric analysis. In the end, 634 unique documents remained, which were exported in .csv, .bib, and .ris formats for subsequent bibliometric analysis. The flowchart of this process is summarized in Figure 1.

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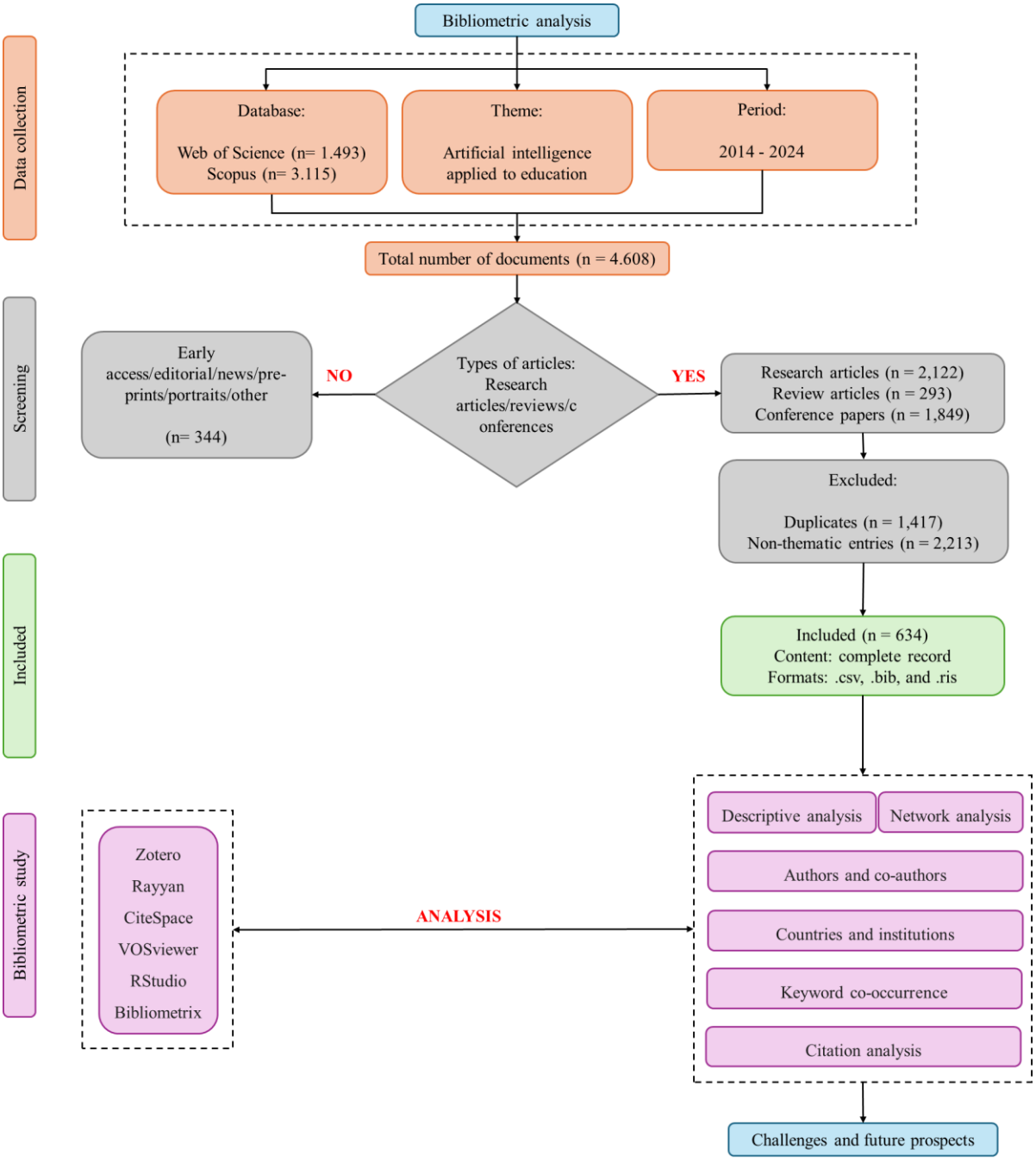
Figure 1: Flowchart indicating the selection process for bibliometric analysis.



Source: Adapted from "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews", by M. J. Page et al., 2021, PLOS Medicine, 18(3), e1003583. Copyright 2021 by The Authors, under CC BY 4.0 license.

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Bibliographic data, including author names, publication year, journal titles, keywords, and citation counts, were exported from Scopus and Web of Science (WoS) in .csv, .bib, and .ris formats, and subsequently stored in the Zotero reference manager.

The data cleaning step consisted of standardizing author names, correcting spelling variations, consolidating duplicate affiliations, and normalizing keywords to avoid semantic redundancies. This process was conducted with the support of the Rayyan platform, widely used in systematic reviews for screening and organizing bibliographic data (McKeown and Mir, 2021).

After this step, the cleaned data were imported into the Bibliometrix package in the R software to perform the bibliometric analysis. Initially, a descriptive analysis was performed, which revealed trends in the volume of publications, geographical distribution of scientific production, main journals, and temporal evolution of publications over the analyzed period. Next, network analysis is performed, aiming to map collaborations between authors and institutions, identifying co-authorship networks; analyze the co-occurrence of keywords to identify emerging themes and conceptual groupings; and highlight citation relationships, showcasing the most influential articles and authors in the field of AI applied to education.

Finally, graphical visualizations of the collaboration and co-occurrence networks were generated using the VOSviewer software (version 1.6.20), specialized in scientific mapping and bibliometric network analysis (Eck, van and Waltman, 2010).

4. Results and discussion

4.1 Descriptive analysis of scientific production

Bibliometric analysis of scientific production on AI applied to education revealed substantial growth in the volume of publications over the last decade (2014-2024), with an average growth rate of 59.45% over the last ten years. The graphical evidence of this upward trajectory, highlighting a significant evolution, especially from 2019 onwards, is presented in Figure 2.

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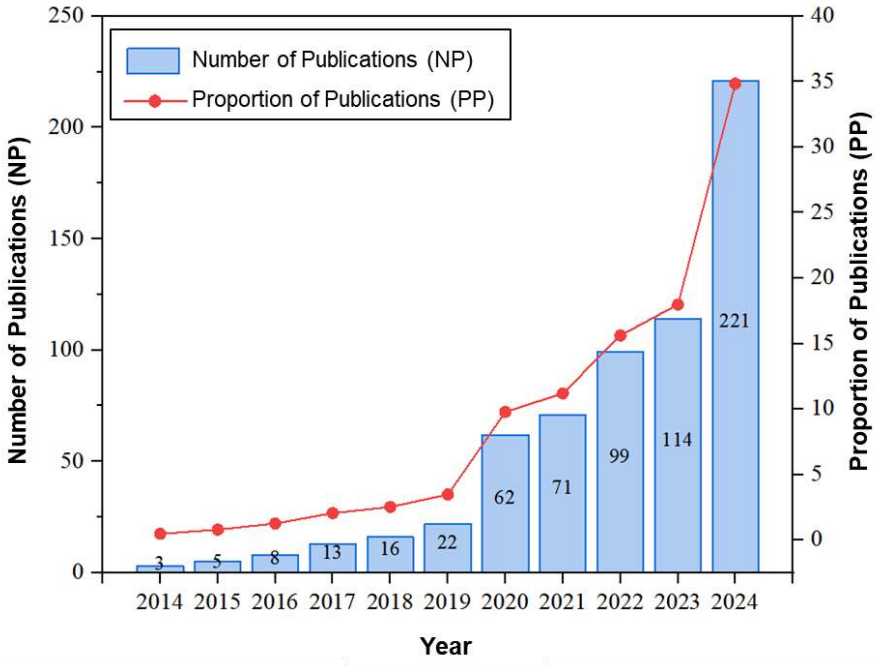
Figure 2: Annual trend in publications.



Source: Prepared by the author.

Between 2014 and 2018, a modest scientific output was observed, with linear growth (between 3 and 16 publications annually). This low volume can be attributed to an initial stage of research in the area, where the application of AI to teaching was still under development, and there was less awareness of its applicability in the educational context or in related areas (Zawacki-Richter et al., 2019).

From 2019 onwards, a significant increase was observed, with the number of publications jumping from 22 (2019) to 62 (2020), 99 (2022), and 221 (2024). Furthermore, the red line in Figure 2 (proportion of publications (PP) over time) suggests a sharp upward trend, indicating that interest in AI in education has not only increased in absolute numbers but also proportionally within the scientific community.

This increase can be attributed to several interconnected factors. Firstly, the massive adoption of AI in the education sector has driven research into the impact of machine learning technologies, intelligent tutoring systems, and big data analytics on the personalization of teaching and the optimization of educational processes (Holmes, Bialik, and Fadel, 2019). Furthermore, the COVID-19 pandemic period

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(2020-2022) accelerated the search for emerging solutions for remote and hybrid teaching, especially in regions with limited infrastructure, which intensified investigations into the role of AI in digital education and in mitigating inequalities in access to learning (Ferri, Grifoni, and Guzzo, 2020). This emergency scenario highlighted both the potential and the challenges in the applicability of AI in educational contexts; on the one hand, it showed the importance of technology as mutable platforms, and on the other hand, it highlighted structural fragility, such as digital exclusion and the scarcity of public policies that guarantee technological equality.

The growth of research in AI applied to education is also due to increased funding and international initiatives, such as those from UNESCO and the World Bank, which promote studies to reduce the digital divide and expand educational accessibility. This support has contributed to the increase in publications, especially in 2024, indicating the consolidation of the area as a strategic field of research, with advances in new approaches (Bosse, Nussbaumer and Hövel, 2024).

4.2 Geographic distribution of scientific production.

An analysis of the most influential countries in research on AI applied to education reveals a strong concentration of academic impact in a few countries, with the United States leading in the number of citations. Figure 3 illustrates a map with the ten most cited countries in the period from 2014 to 2024 in the context of the use of AI in education.

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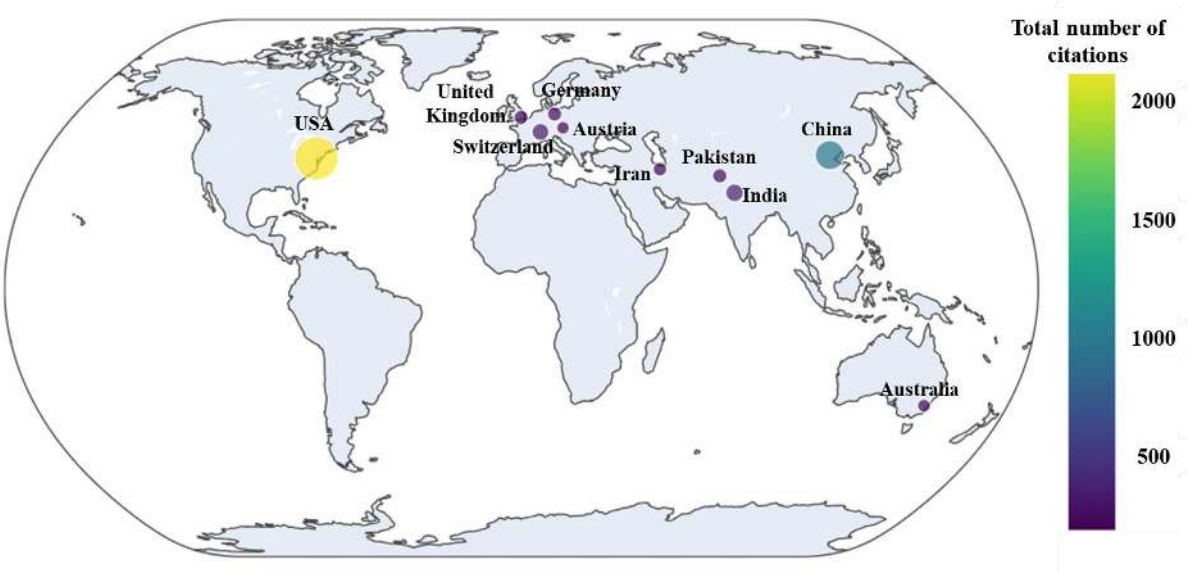
Figure 3: Citation map by country.



Source: Prepared by the author.

Figure 3 shows the United States as the leader in citations (2,184), consolidating itself as the epicenter of research in AI applied to education. This leading role stems from the research infrastructure, prestigious universities such as MIT, Stanford, and Harvard, with centers dedicated to the area (Selwyn, 2019), and strong private investment from companies such as Google, Microsoft, and IBM (Vlist, van der, Helmond, and Ferrari, 2024). Academic-business partnerships and public policies reinforce this position (Yerlikaya and Erzurumlu, 2021).

China (984 citations) occupies second place, driven by state investments, universities such as Tsinghua and Beijing Normal, and leadership in the development of educational tools in AI (Feijóo et al., 2021; Knox, 2020; Rehman et al., 2025). India (372) appears in third place, with companies such as Infosys and Tata Consultancy Services fostering scalable solutions for digital education (Srivastava, 2018).

In Europe, Switzerland (343), Germany (247), the United Kingdom (241), and Austria (197) stand out for programs such as Horizon 2020 and institutions such as ETH Zurich, the University of Oxford, and the Max Planck Institute (Groenner, 2024; Piro, Seeber, and Wang, 2024).

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Brazil, in 9th place in production, is advancing in AI for digital inclusion and adaptive education, with policies such as EBIA (Esteves et al., 2023) and research focused on low-connectivity environments (Molina et al., 2024), although it still faces limitations in international visibility.

There is, therefore, a trend indicating that China and India are consolidating themselves as fundamental centers in educational AI research, mainly in the development of scalable and accessible solutions for digital education. The analysis also suggests that the predominance of English in international publications may hinder the visibility and citation of Brazilian research.

The analysis of average citations per article reveals a significant asymmetry between production and scientific impact. Countries with a lower volume of publications, such as Switzerland (49.00 citations/article) and Austria (65.67), have a considerably higher impact per article than countries with higher absolute production, such as China (13.30) and India (7.29). This disparity suggests that centrality in the citation network does not keep pace with the growth of production in emerging countries, configuring a pattern of asymmetry between high- and low-income countries in the flow of scientific recognition. Part of this inequality can be attributed to the predominance of English as the language of international publication, which imposes visibility barriers on the production of non-Anglophone countries (Amano et al., 2023), and to the concentration of the most prestigious journals in countries of the Global North. For the emerging contexts that this study analyzes, this asymmetry has a direct implication: the solutions developed and validated in these countries circulate with less reach, reducing their influence on global research agendas in educational AI.

4.3 Distribution of corresponding authors and international collaborations.

An analysis of scientific production on artificial intelligence in education demonstrates a strong concentration in three countries: China, the United States, and India, which lead in publications in the field. This trend is evidenced in Figure 4, which distinguishes between articles authored exclusively by a single country (PUP) and international collaborations (PVP).

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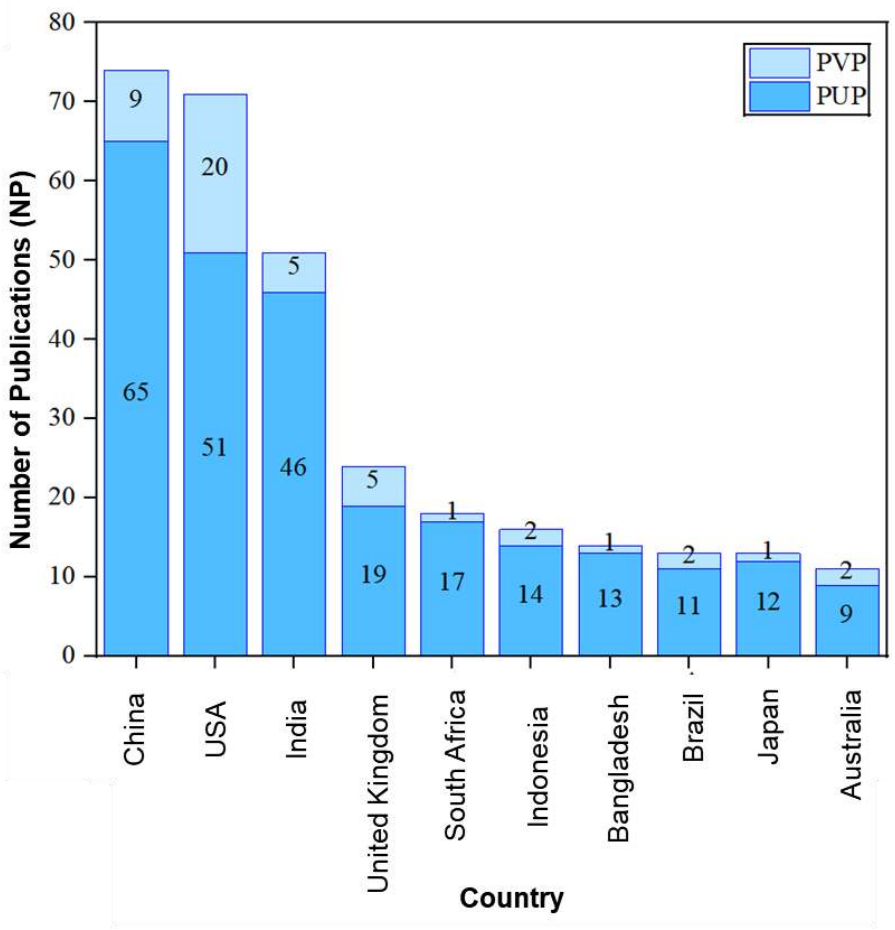
Figure 4: Countries of the corresponding authors, divided into publications from a single country (PUP) and publications from multiple countries (PVP).



Source: Prepared by the author.

The analysis showed that, although the United States leads in the total number of citations (Figure 3), China has the largest number of corresponding authors and publications. As shown in Figure 4, most Chinese publications are exclusively authored by domestic researchers (PUP), a result of consistent domestic investment policies and the work of specialized centers in AI applied to education.

The United States, in second place, maintains a balance between national publications and international collaborations (PVP), reinforcing the relevance of academic cooperation. India, although with a smaller volume, follows a similar

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pattern, consolidating itself as an emerging hub in the area.

In Brazil, production is mostly authored by nationals, signaling internal growth in the field, but still with limited international partnerships. Figure 4 shows that a greater number of publications does not necessarily imply greater scientific impact, highlighting the importance of the global circulation of knowledge.

The data on international collaboration reinforce this diagnosis. With only 12.62% of international co-authorships in the corpus analyzed, the field shows significant fragmentation. Emerging countries with the highest production, China (MCP ratio: 0.12), India (0.10), and Brazil (0.15), publish predominantly endogenously, contrasting with the US (0.28), whose international collaboration index is double the average of these countries. This pattern is not trivial: low international integration limits the transfer of methodologies, the cross-validation of results, and the insertion of solutions developed in these contexts into global citation networks. In practical terms, this means that AI research in low-connectivity contexts, developed mainly by researchers from India, Bangladesh, and Brazil, has limited reach precisely in the forums where policies and funding are decided. Strengthening collaborative networks between emerging countries and multilateral research initiatives is therefore not only an academic recommendation but a structural condition for solutions developed in these contexts to gain scale and recognition.

4.4 Distribution of the most productive authors.

A total of 2,531 authors were analyzed, of which only 55 documents were single-authored. In this analysis, the most productive authors were Chinese, as illustrated in Table 1.

Table 1: Most productive authors.

Author	Affiliation	Country	h-index (R)	NP (R)	CF
Ahmed, S.	GIK Institute Engineering Science & Technology	Pakistan	14 (5)	8 (1)	2,0
Islam, M.	Jatiya Kabi Kazi Nazrul Islam University	Bangladesh	10 (6)	7 (2)	1,7
Wang, Y.	Xi'an Jiaotong University	China	28 (2)	6 (3)	1,7
Yang, J.	Max Planck Institute for Security and Privacy	Germany	8 (7)	6 (4)	1,54

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Yang, S.	Minjiang University	China	3 (10)	6 (5)	1,5
Ahmed, A.	Kyushu University	Japan	19 (4)	5 (6)	1,3
Ahmed, M.	China University of Geosciences	China	8 (8)	5 (7)	1,28
Chen, Y.	University of Hong Kong	Hong Kong	22 (3)	5 (8)	1,25
Li, J.	Southwest Minzu University	China	6 (9)	5 (9)	1,2
Liu, Y.	Emory University	USA	97 (1)	5 (10)	1,17

Source: Prepared by the author.
Note: NP: number of publications in the analyzed corpus; R: ranking position; CF: fractional contribution, calculated as the sum of 1/n per article, where n is the number of authors, higher values indicate participation in articles with fewer co-authors; h-index: author's global h-index, obtained from Scopus and WoS databases, reflecting the accumulated impact throughout their career and not restricted to the analyzed corpus.

Researchers from Pakistan, Bangladesh, Germany, Japan, Hong Kong, and the United States have made significant contributions to research in Artificial Intelligence (AI) applied to education. Yang, J. and Liu, Y., affiliated with the Max Planck Institute for Security and Privacy and Emory University, respectively, are Chinese researchers who cooperate with international institutions, as shown in Table 1. This scenario confirms the strong participation of Asia, playing an active and fundamental role in the scientific production of the area.

All the researchers listed in Table 1 work in a multidisciplinary way, developing work that goes beyond the application of AI in education, encompassing various fields of knowledge. This approach reflects a growing trend in the global scientific landscape.

In the lead, Ahmed, S., from the GIK Institute of Engineering Science & Technology (Pakistan), has 8 publications and an h-index of 14, establishing himself as one of the most productive authors. The GIK Institute is recognized for its contributions to AI and machine learning (Faiz, 2020), with research focused on personalizing education in low-connectivity environments, a strategic area for countries with structural challenges (Sultangazina et al., 2021).

Another highlight is Islam, M., from Jatiya Kabi Kazi Nazrul Islam University (Bangladesh), with 7 publications and an h-index of 10. His output includes research on educational chatbots and adaptive learning, with the potential to improve student retention and enable large-scale teaching (Bisen et al., 2021). His collaboration factor (CF = 1.7) reflects participation in articles with a reduced

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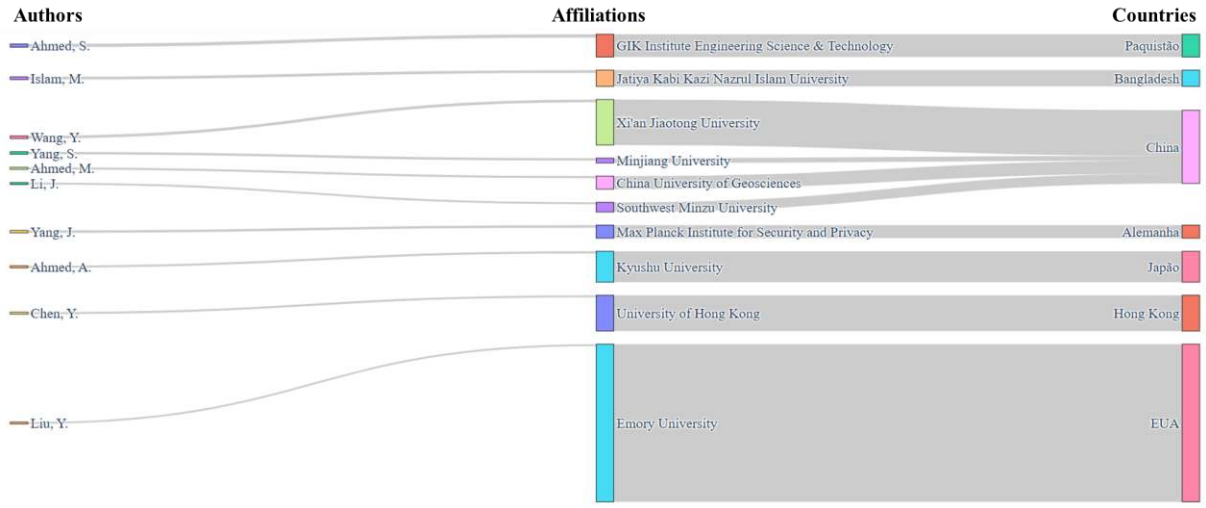
number of co-authors, suggesting a greater individual contribution to each publication.

In China, four institutions stand out: Xi'an Jiaotong University, Minjiang University, China University of Geosciences, and Southwest Minzu University. Xi'an Jiaotong University is recognized for its studies in predictive learning and modeling (Peng and Xiaohong, 2018; Wang et al., 2024). The others have invested in internationalization and national strategies for integrating AI into education (Huang et al., 2023; Knox, 2020).

The Max Planck Institute for Security and Privacy conducts research in AI and security, with implications for the protection of educational data (Shoukat, 2024). Figure 5 presents the Sankey diagram weighted by CF and h-index, connecting authors, affiliations, and countries, allowing visualization of interactions and scientific impact.

Figure 5: Sankey diagram with three fields (Author → Affiliation → Country).



Source: Prepared by the author.
Note: The thickness of the edges is proportional to the combined weight of the author's overall h-index and fractional contribution (FC), simultaneously reflecting the accumulated academic impact and the intensity of authorial participation in the publications of the analyzed corpus.

It is noteworthy that Emory University (USA) appears separately in the analysis, strongly linked to Y. Liu, indicating his independent academic impact in the field. Even when adding the impact of other Chinese researchers, Liu's is superior. It is worth remembering that, although Liu is Chinese, he works in the USA.

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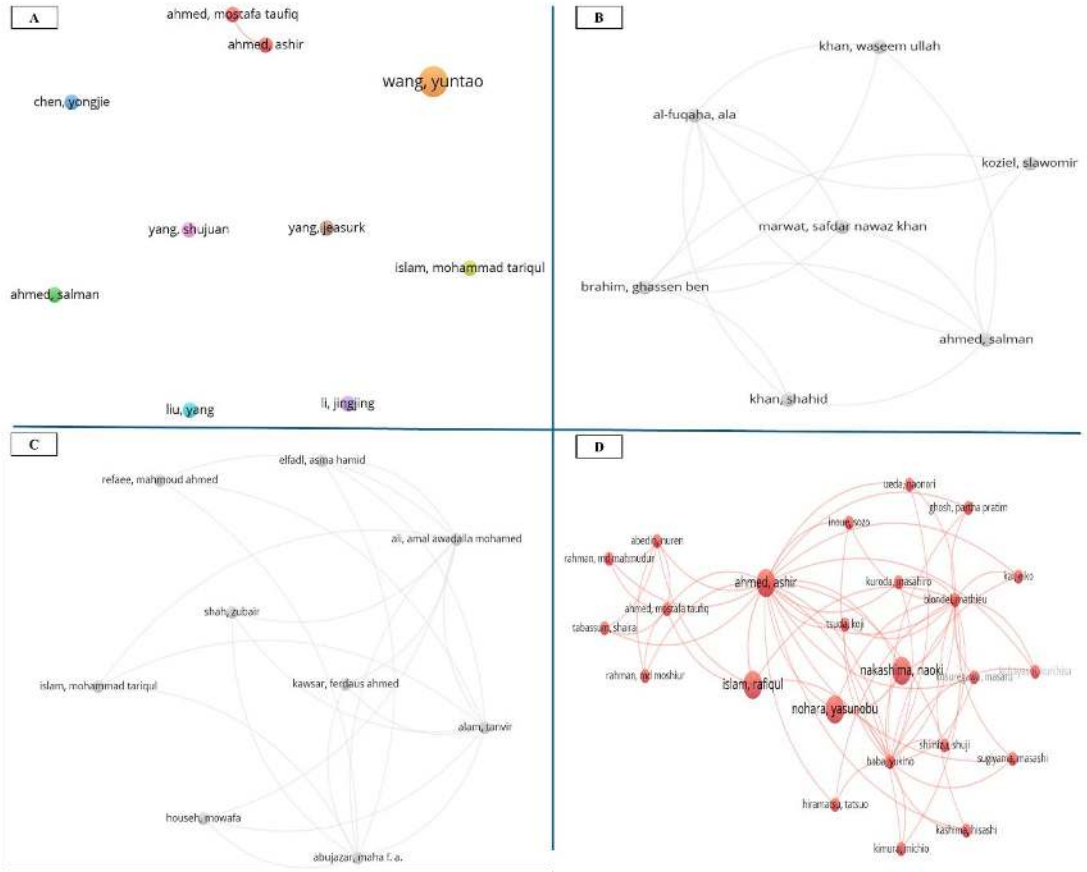
4.5 Analysis of co-authorship networks.

The co-authorship networks related to the topic of this work were analyzed in their entirety. Figure 6 illustrates the most relevant co-authorship networks among the authors analyzed.

Figure 6: Co-authorship networks in research on AI applied to education: (A) Most productive authors, (B) Co-authorship network of the most productive author, (C) Co-authorship network of the second most productive author, and (D) Co-authorship network among authors with the strongest collaborative link.



Source: Prepared by the author.

Figure 6 (A) shows the co-authorship network of the most productive authors, highlighting Wang, Yuntao as the most representative, a result of his significant production and academic impact. Other relevant researchers include Ahmed, Salman and Islam, Mohammad Tariqul. The dispersion of nodes indicates that,

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although some authors have high productivity, the field still presents fragmentation in scientific collaborations.

Figure 6 (B), which represents Ahmed, Salman's co-authorship network, reveals a compact configuration, with connections restricted to six collaborators. Despite being the most productive author, his network shows low international and interinstitutional diversity, suggesting a specific thematic focus and less interdisciplinarity.

Figure 6 (C), referring to Islam, Mohammad Tariqul, shows a more decentralized and diversified network, involving eight collaborators. This configuration indicates greater academic diversity, favoring the circulation of knowledge and the integration of different perspectives in AI research applied to education. Finally, Figure 6 (D), which presents the network of Ahmed, Ashir and Ahmed, Mostafa, shows a dense and highly interconnected structure, with strong scientific collaboration between researchers from multiple areas. This characteristic points to a potential for broader and multidisciplinary academic impact, going beyond the field of educational AI.

4.6 Keyword co-occurrence analysis.

Considering keywords with at least 15 occurrences, a network of 33 terms was formed, divided into three thematic clusters (Figure 7). The blue cluster groups terms related to education, such as e-learning and digital exclusion; the green cluster focuses on the application of AI in developing countries, including machine learning and sustainable development; and the red cluster addresses human aspects of AI, such as algorithms and prediction. This division highlights the main research areas in AI in education, encompassing technological advances, educational impacts, and socioeconomic dimensions. Figure 7, showing the keyword co-occurrence analysis, is presented below.

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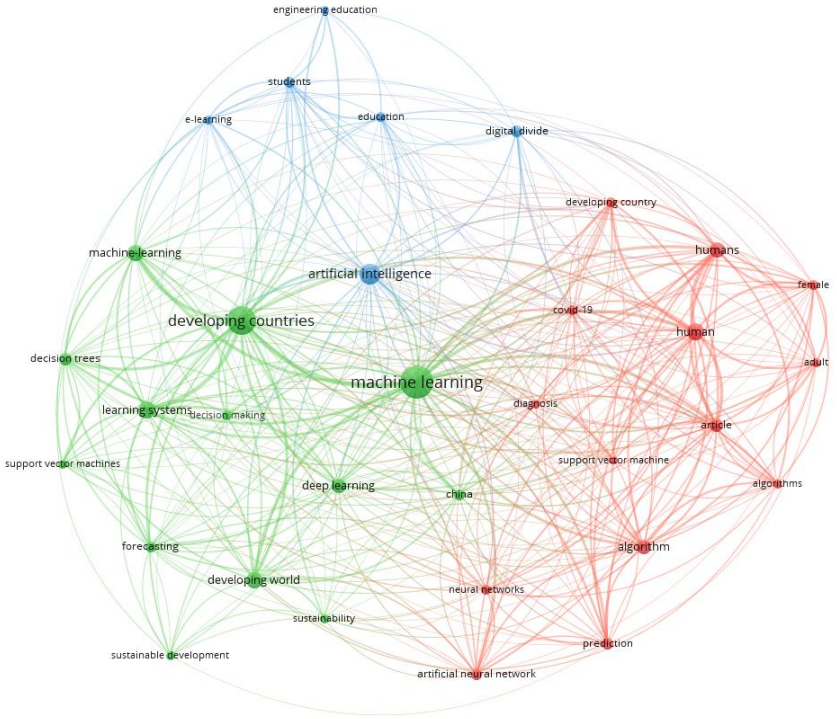
Figure 7. Keyword co-occurrence analysis.



Source: Prepared by the author.

The blue cluster highlighted the consolidation of AI as an institutional response to digital exclusion, bringing together terms such as e-learning, digital divide, and engineering education. Its centrality in the network suggests that reducing the digital divide is the organizing problem of research on educational AI, not just a peripheral concern. For the emerging contexts analyzed in this study, this is significant: it indicates that the literature recognizes inequality of access as a structural variable, and not just as a technical limitation to be overcome by connectivity solutions. The presence of engineering education in this cluster also points to a thematic concentration in technical higher education, to the detriment of other levels of education more vulnerable to digital exclusion, such as basic education in rural areas.

The green group highlighted the use of AI in developing countries, bringing

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together terms such as machine learning, developing countries, developing world, and sustainable development. In addition to the qualitative analysis of the clusters, the frequency data of the Keywords-Plus allow us to quantify the presence of the emerging contexts in the set of documents analyzed. The term "developing countries" appears in 136 documents (21.5% of the 634), while "developing world" occurs in 48 documents. Considering also the digital divide (32 occurrences in the authors' keywords), it is estimated that approximately 180 to 200 articles, between 28% and 32% of the total examined, present explicit markers of emerging contexts or developing countries. This percentage indicates that, although the production on AI in education is dominated by high-income countries (USA, China, Europe), there is a substantial proportion of the literature that specifically addresses the structural challenges of regions with limited infrastructure, justifying the scope adopted in this study. The concentration of these terms in the green cluster, and their relative absence in the others, suggests that research on emerging contexts constitutes a distinct thematic front within the field, with its own agenda focused on scalability, digital inclusion, and sustainable development.

The red cluster is the most relevant for interpreting the impact of the pandemic on the field. The co-occurrence of COVID-19, human, algorithm, and prediction indicates that the pandemic not only accelerated scientific production, as evidenced in Section 4.1, but also repositioned the debate on the relationship between automation and human agency in education. The abrupt growth of remote learning between 2020 and 2022 exposed the dependence on algorithms trained on data from high-infrastructure contexts to make decisions in radically different environments, such as schools without stable connectivity. The presence of prediction in this cluster points to the use of predictive models of dropout and performance, tools whose potential is widely documented, but whose validity in contexts of low data quality is questionable. This is an ethical and methodological issue that the literature still addresses in an incipient way, configuring a relevant gap for future research.

4.7 Most influential periodicals.

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The analysis identified the ten most relevant journals in research on Artificial Intelligence applied to education, ranked according to the number of publications, the Journal Citation Indicator (JCI – 2023), and the Journal Impact Factor (JIF – 2023). These indicators allow for the evaluation of the impact and scientific relevance of publications in the field of study.

The JCI corresponds to the average Category Normalized Citation Impact (CNCI) of articles and reviews published by a journal in a recent three-year period. An average JCI in a category is 1, and journals with a JCI of 1.5 have 50% more citation impact than the average in that category. This metric can be used in conjunction with the JIF to support the evaluation of journals (Gazarian, 2023).

The JIF is one of the most widely used metrics for measuring impact and is generated by Clarivate's Journal Citation Reports (JCR). Their calculation consists of dividing the number of citations of articles published in a given year, referring to the two previous years, by the total number of citable publications in that same period (Moussa, 2023).

Table 2 illustrates the ten most influential journals in research on Artificial Intelligence applied to education, ranked by number of publications, JCI, and JIF.

Table 2: Most influential journals.

Journals	NP (R)	JCI - 2023 (R)	JIF - 2023 (R)
Sustainability (Switzerland)	44	0.68 (7)	3.3 (5)
Scientific Reports	28	1.05 (3)	3.8 (2)
Plos One	21	0.88 (5)	2.9 (8)
Water (Switzerland)	9	0.67 (8)	3.0 (7)
Heliyon	8	0.82 (6)	3.4 (4)
Expert Systems with Applications	5	1.60 (2)	7.5 (1)
Frontiers in Public Health	5	1.02 (4)	3.0 (6)
International Journal of Scientific and Technology Research	5	NA (10)	0.12 (10)
Environment, Development and Sustainability	4	NA (9)	0.89 (9)
Humanities and Social Sciences Communications	4	4.68 (1)	3.7 (3)

Source: Prepared by the author.
Note: JCI: Journal Citation Indicator; (2) JIF: Journal Impact Factor; (3) NA: Not available.

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Among the journals analyzed, Expert Systems with Applications stood out as the most influential, with a JIF of 7.5 and a JCI of 1.60, reflecting its relevance in applied artificial intelligence, including education. With a technical and specialized profile, it addresses machine learning, neural networks, and decision support algorithms, justifying its high academic impact. Other relevant journals include Scientific Reports (JIF 3.8; JCI 1.05) and PLOS ONE (JIF 2.9; JCI 0.88), both open access and multidisciplinary in scope.

Journals such as International Journal of Scientific and Technology Research and Environment, Development and Sustainability presented JCI scores not reported, suggesting lower visibility, but still play a relevant role in disseminating educational AI, especially in emerging contexts. Humanities and Social Sciences Communications stood out with the highest JCI in the table (4.68) and a JIF of 3.7, reinforcing its importance in interdisciplinary research between technology, education, and social sciences. Despite the relevance of these journals, the most cited articles belong to other highly prestigious periodicals: Proceedings of the National Academy of Sciences – PNAS (JIF 9.4; JCI 2.4), with “Scaling up behavioral science interventions in online education” (114 citations), and Science (JIF 44.8; JCI 9.90), with “Fighting poverty with data” (94 citations). Science, ranked second globally in the JCI for multidisciplinary sciences, maintains a strong international impact, notably with contributions from the University of California System (USA).

Data availability

The underlying content of the research text is contained in the manuscript.

5. Conclusions

Bibliometric analysis revealed that Artificial Intelligence (AI) plays a growing role in education, particularly in personalizing teaching and reducing the digital divide. Tools such as chatbots, AI-based gamification, and predictive analytics show potential for adapting content to learning pace and expanding access in contexts

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with low connectivity, aligning with UN Sustainable Development Goal 4 (SDG 4). However, some limitations should be considered when interpreting the results. The reliance on databases such as Scopus and Web of Science reduced the diversity of studies, excluding publications in other languages and contexts. The use of the term "developing countries" as a proxy to delimit emerging contexts presents limitations inherent to the heterogeneity of indexing between databases, potentially including distinct technological and economic realities within the same category. Geographic bias was also observed, with a predominance of the USA, China, and India, as well as thematic bias, favoring areas such as adaptive learning and chatbots over topics such as ethics and the social impacts of AI. To overcome these challenges, it is recommended to broaden the variety of sources, languages, and contexts analyzed, as well as to consider non-peer-reviewed publications, content analysis of abstracts, and complementary techniques such as bibliographic coupling and co-citation, which would allow the identification of research fronts and schools of thought within the field. Public policies aimed at teacher training and the expansion of digital infrastructure, coupled with public-private partnerships, are fundamental to ensuring an equitable and sustainable application of AI in education.

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