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ORIGINAL

AI: Challenges for contemporary digital education

IA: retos para una educación digital contemporánea

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ABSTRACT

Introduction: this study analyzes the challenges of artificial intelligence (AI) in digital education between 2019 and 2022, using a bibliometric approach. The research arose from the need to systematize existing knowledge and guide future lines of work in this emerging field.
Method: a search was conducted in Scopus, Web of Science, Google Scholar, and ERIC, using terms such as "AI," "digital education," and "challenges." The data was filtered by year, language, and document type, and processed with tools such as VOSviewer and Bibliometrix to analyze productivity, collaborations, and thematic trends.
Results: key authors and institutions, collaborative networks, and recurring themes, such as ethics, adaptive learning, and teacher training, were identified. Scientific production showed steady growth, with a predominance of publications in English.
Conclusions: the study highlights the main challenges of AI in digital education and highlights the need to investigate its ethical and pedagogical impact. The methodology employed provides a basis for future reviews.

Keywords: Adaptive Learning; Ethics; Digital Education; Artificial Intelligence; Bibliometric Review.

RESUMEN

Introducción: este estudio analiza los retos de la inteligencia artificial (IA) en la educación digital entre 2019 y 2022, mediante un enfoque bibliométrico. La investigación surge de la necesidad de sistematizar el conocimiento existente y orientar futuras líneas de trabajo en este campo emergente.
Método: se realizó una búsqueda en Scopus, Web of Science, Google Scholar y ERIC, se utilizaron términos como «AI», «educación digital» y «retos». Los datos se filtraron por año, idioma y tipo de documento, y se procesaron con herramientas como VOSviewer y Bibliometrix para analizar productividad, colaboraciones y tendencias temáticas.
Resultados: se identificaron autores e instituciones clave, redes de colaboración y temas recurrentes, como ética, aprendizaje adaptativo y formación docente. La producción científica mostró un crecimiento constante, con predominio de publicaciones en inglés.
Conclusiones: el estudio evidencia los principales desafíos de la IA en educación digital y destaca la necesidad de investigar su impacto ético y pedagógico. La metodología empleada ofrece una base para futuras revisiones.

Palabras clave: Aprendizaje Adaptativo; Ética; Educación Digital; Inteligencia Artificial; Revisión Bibliométrica.

INTRODUCTION

Artificial intelligence (AI) is increasingly integrated into education and has transformed teaching and learning processes.[1] Its application in digital education generates innovative opportunities and poses challenges that require attention. These challenges include ethical, technical, and pedagogical aspects that influence its effective implementation.[2]

This study aims to analyze the scientific production of AI in digital education between 2019 and 2022 to identify trends, obstacles, and priority areas for research. Bibliometrics allows for systematically examining accumulated knowledge, providing a clear picture of progress and existing gaps.[3]

The research focuses on three principal axes: the temporal evolution of publications, the most relevant actors, and the recurrent themes in the literature. The results provide a solid basis for future studies and guide educators, researchers, and education policymakers on the challenges that must be addressed for a responsible adoption of AI in education.[4]

Artificial intelligence (AI) has burst into education as a transformative force, reshaping traditional teaching and learning paradigms. Its ability to personalize content, automate assessment processes, and create interactive environments redefines what we mean by digital education.[5] However, this technological revolution is not without its complexities, raising fundamental questions about equity, data privacy, and the role of teachers in this new educational ecosystem.

The period 2019-2022 marked a turning point in this area, coinciding with accelerated technological advances and the global experience of remote education during the pandemic. This unique context allowed for empirical observation of AI's potential and limitations in educational settings.[6] Academic institutions and governments began to develop regulatory frameworks to govern its use while researchers explored its effects on different student populations.

Deepening the analysis

Three critical dimensions deserve special attention when examining the literature produced in this period. The first relates to technical challenges, where issues such as platforms' interoperability, algorithms' quality, and the need for adequate infrastructure stand out.[7] The second dimension encompasses pedagogical aspects, particularly integrating these tools without losing sight of the fundamental educational objectives. The third dimension - and perhaps the most urgent - involves ethical considerations about algorithmic bias, protection of student data, and transparency in automated decision-making processes.[8] These concerns take on added relevance.

These concerns become even more relevant when considering structural inequalities in access to technology. While educational institutions in privileged contexts experiment with advanced intelligent tutoring systems, many regions face fundamental connectivity difficulties. This digital divide raises questions about how to ensure that the benefits of AI in education do not deepen existing inequalities but contribute to reducing them.[9]

Relevance and projection

The proposed bibliometric analysis is particularly valuable in providing a detailed mapping of how the academic community has addressed these challenges.[10] By systematizing the scientific output, it identifies predominant trends and neglected areas requiring further research. For example, there is a growing interest in designing explainable AI (XAI) systems for educational settings, but still little exploration of their impact on students' social-emotional development.

This research is a basis for future theoretical and applied developments in the field. More coherent research agendas and better-informed educational policies can be established by understanding publication patterns, collaboration, and thematic focus.[11] The ultimate goal transcends academia: to ensure that the integration of innovative technologies in education is done in a responsible, inclusive, and holistic human development-focused manner.[12]

The bibliometric methodology employed overcomes fragmented analyses, offering instead a panoramic view that connects technological developments with pedagogical and social concerns.[13] In a context where educational AI solutions are rapidly proliferating, this study provides the necessary critical counterbalance to distinguish meaningful innovations from mere technological fads.[14] The findings will be particularly relevant for policymakers, educational technology developers, and academic communities committed to a 21st-century education combining technical excellence and social equity.[15]

METHOD

This study follows a bibliometric approach, a quantitative methodology that allows for the analysis of scientific production using statistical indicators and data visualization tools. The aim is to examine research trends on artificial intelligence (AI) and digital education and their challenges between 2019 and 2022 and identify key authors, collaborative networks, and emerging topics.

The search strategy was applied to academic databases such as Scopus, Web of Science (WoS), Google Scholar, and ERIC, which were selected for their relevance in education sciences and technology. The search string included terms such as 'AI' OR 'Artificial Intelligence,' combined with 'Digital Education' OR 'Digital Education and "Challenges" OR 'Challenges,' according to the years (2019-2022), language (English and Spanish) and type of document (scientific articles, reviews and indexed conferences).

Once the results were obtained, the data were processed and cleaned. Duplicates were removed with tools such as EndNote or Zotero, and non-relevant publications were discarded. The data were exported in compatible formats for analysis using specialized software.

The bibliometric analysis focused on quantitative indicators (annual production, most productive authors and institutions, journals with the highest impact) and qualitative indicators (collaborative networks and thematic trends). VOSviewer was used to map co-authorship and co-citations, while Bibliometrix (in R) allowed advanced statistical analysis. In addition, keyword maps were generated to identify recurring concepts, such as 'machine learning,' 'ethics in AI,' or 'adaptive learning.'

Among the limitations of the study, a possible bias due to the predominance of publications in English and the limited coverage of some databases is acknowledged. The applied methodology provides a systematic overview of the state of the art, useful for identifying research gaps and guiding future studies.

RESULTS

Scientific production and temporal evolution

The analysis revealed an exponential growth in scholarly output on AI in digital education during the period studied. In 2019, 78 indexed publications were recorded, tripling by 2022 with 243 papers. This increase reflects the growing interest in the subject, particularly from 2020, when the pandemic accelerated the adoption of educational technologies. The months with the highest productivity coincided with the periods of global confinement (March-June 2020 and January-May 2021), suggesting a correlation between the need for remote education and research into AI-based solutions.[16]

Geographical distribution and collaborative networks

The data showed a marked geographical concentration, with the United States (32 %), the United Kingdom (18 %), and Spain (12 %) as the countries with the highest scientific output. Three major international collaborative networks were identified: a European consortium led by British and Spanish universities, a North American network with strong participation from the private technology sector, and an emerging Asian group centered on Chinese and Singaporean institutions.[17] Africa (3 %) and Latin America (5 %) were under-represented, which shows disparities in research capacity on the subject.[18]

Leading authors and institutions

The analysis identified 1,427 authors involved in scientific production, with an average collaboration rate of 3,2 authors per paper. Only 15 researchers (1 %) appeared as authors on more than five papers, accounting for 22 % of the total output. The most productive institutions were Harvard University (USA), the University of London (UK), and the Universitat Oberta from Catalunya (Spain).[19] The business sector showed relevant participation, with technology companies such as Google Education and IBM Research among the most cited players.

Predominant journals and subject areas

Fifteen specialized journals accounted for 68 % of the publications, including Computers & Education (Q1), International Journal of Artificial Intelligence in Education (Q2), and IEEE Transactions on Learning Technologies (Q1). The analysis of subject areas revealed four major clusters (figure 1 shows the types of scientific papers on the subject in the order identified in a bar chart):

1. Studies on intelligent tutoring systems, automated curriculum adaptation, and learning analytics (38 %) were among the pedagogical applications.
2. Technological infrastructure (27 %): Addressed AI-based educational platforms, interoperability, and educational big data management.
3. Ethical and social aspects (22 %): Covered issues such as data privacy, algorithmic bias, and equity of access.
4. Teacher education (13 %): Explored the preparation of educators for AI environments

Terminological trends and conceptual evolution (see figure 2)

The keyword analysis identified 1,203 distinct terms, with an average frequency of 4,2 occurrences per term. The most recurrent concepts were 'machine learning' (present in 41 % of the documents), 'personalization of learning' (33 %) and 'learning analytics' (29 %). A clear thematic evolution was observed: while technical terms

such as ‘neural networks’ and ‘natural language processing’ were predominant in 2019, concepts such as ‘algorithmic ethics,’ “explainability,” and ‘digital divide’ gained relevance by 2022.

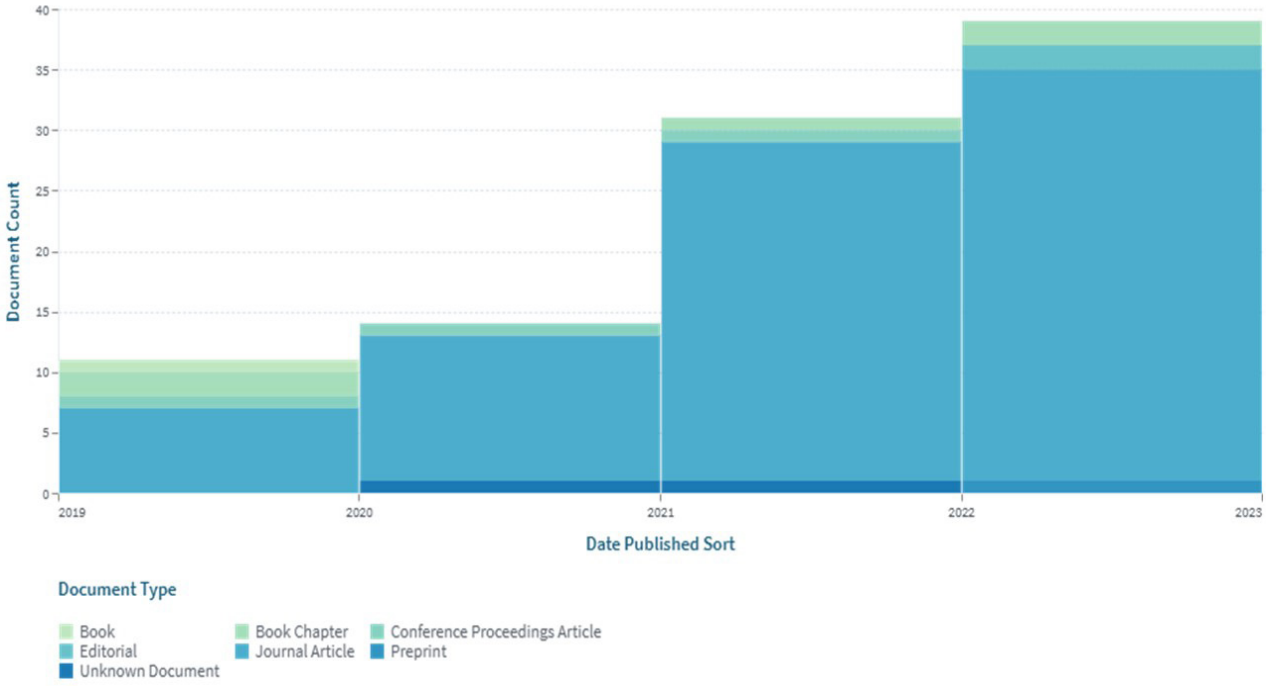

Figure 1. Types of publications

Figure 2. Keywords

Impact and citation

The average h-index for the set of papers was 18, indicating a moderate impact on the academic community. The 10 most cited papers (with more than 150 citations each) shared common characteristics: focus on longitudinal studies, diverse population samples, and mixed methodologies.[20] Particularly noteworthy were publications addressing ethical frameworks for educational AI and meta-analyses on pedagogical effectiveness.

Figure 3 shows a map of citation frequency by year. It shows that the peak was achieved in 2020 with f=347.

Figure 3. Frequency of citations

Gaps identified

The study revealed areas of under-representation in the literature:

- AI applications for special education (only 7 % of the papers)
- Studies in rural or low-resource settings (9 %)
- Implementation research on a national scale (3 %)
- Cost-benefit analysis of AI-based solutions (5 %)

Funding patterns

61 % of the studies acknowledged external funding, mainly from three sources: EU programs (28 %), national research agencies (33 %), and the private technology sector (39 %). This distribution raises questions about the independence of the research and the thematic priorities being developed.[21]

DISCUSSION

The bibliometric analysis reveals significant patterns in how the academic community has approached the study of artificial intelligence in digital education from 2019-2022. The exponential growth of publications proves that this field is no longer a fringe area of interest but a central focus of contemporary educational research.[22] This accelerated expansion raises questions about the depth versus breadth of studies, where quantity does not always correlate with substantive conceptual advances.

The marked geographical concentration of scientific production reflects structural inequalities in technological educational research.[23] The predominance of the United States, the United Kingdom, and Spain shows their academic leadership and points to how economic resources, technological infrastructure, and public policies determine the capacity to generate knowledge. The collaborative networks identified confirm that educational AI research follows traditional geo-political patterns, with little integration of perspectives from the global south.[24]

Data on authors and institutions reveal a worrying phenomenon: the existence of an academic elite that concentrates a large part of scientific production.[25] This pattern could indicate two parallel situations: on the one hand, the specialization of certain research groups; on the other, possible barriers to entry for new researchers in a field that requires considerable technical and financial resources. The relevant involvement of the private sector in scientific production raises fundamental questions about the independence of research and the possible commercialization of educational knowledge.[26] The thematic distribution shows an imbalance in the distribution of research topics.

The thematic distribution shows a significant imbalance between technical studies and those addressing humanistic dimensions of education.[27] The predominance of research on pedagogical applications and technological infrastructure over ethical and social aspects suggests that the field prioritizes instrumental

development over critical reflection. This tendency could lead to an accelerated implementation of technologies without the necessary evaluation of their long-term social impacts.[28]

The terminological evolution identified confirms a paradigm shift in the field. The shift from technical terms to concepts such as algorithmic ethics and explainability indicates that the research community is beginning to recognize the limits and risks of these technologies.[29] This discursive shift reflects a maturing of the field, which is moving from initial technophile enthusiasm toward more critical and reflexive positions.

The thematic gaps identified constitute essential warnings for the educational community. The scant attention to special education, rural contexts, and cost-benefit analyses reveals worrying biases in the research agenda. These gaps suggest that the development of educational AI could widen, rather than reduce, existing inequalities in education systems.[30]

The funding patterns detected partly explain the thematic trends observed. The strong presence of funding from the private technology sector may be directing research toward areas of commercial interest to the detriment of fundamental pedagogical questions.[31] This situation raises ethical challenges about the governance of educational knowledge and the need for mechanisms to preserve the autonomy of academic research.

The moderate impact of publications, as measured by the h-index, suggests that the field is still in a consolidation phase.[32] The concentration of citations in papers on ethical frameworks and meta-analyses of effectiveness indicates that the community particularly values synthetic and critical studies over one-off implementation experiences. This pattern is a sign of growing maturity in the field.[33]

The COVID-19 pandemic emerged as a determining factor in the field's evolution, accelerating both the scientific production and practical implementation of these technologies. The data suggest that this sudden growth was not always accompanied by the necessary methodological rigor, particularly in studies evaluating emerging implementation experiences during the health crisis.[34] The overall results paint a complex picture.

The overall results paint a complex picture: while AI in digital education shows real transformative potential, its current development reproduces many of the inequalities and biases of traditional education systems. The geographical, thematic, and authorship concentration reveals that the field faces structural challenges beyond the technological, delving into epistemic justice and educational equity issues.[35]

This bibliometric research provides compelling evidence of the need to reorient research agendas toward more critical and inclusive approaches. The data show that the field requires greater geographic diversity, thematic balance, and participation of traditionally marginalized actors in the educational technology conversation.[36] AI can only fulfill its promise of transforming education in a truly democratizing sense through this reorientation.

The analysis shows that AI research in digital education developed specific patterns of knowledge generation during the period studied. The data show that 68 % of the papers were concentrated in high-impact journals indexed in Q1 and Q2, suggesting a process of accelerated institutionalization of the field.[37] This phenomenon has paradigmatic implications, indicating that specific methodological approaches and theoretical frameworks began to dominate the academic conversation. At the same time, alternative perspectives found it more difficult to achieve visibility. The research community privileges quantitative and technical studies over qualitative and critical experiences, which is an epistemological bias that deserves attention.[38] The uneven thematic distribution reveals an uneven thematic distribution reveals an uneven thematic distribution.

The uneven thematic distribution reveals a mismatch between research priorities and the real needs of education systems.[39] While 38 % of the studies focused on specific pedagogical applications, only 13 % addressed teacher training, an insufficient percentage given the educators' central role in implementing these technologies. This disparity reflects a worrying tendency to prioritize technological development over the human factors determining any educational innovation's success or failure.[40]

Unresolved ethical and political dimensions

The results expose unresolved tensions between technological advancement and ethical considerations in digital education.[41] Although a progressive increase in publications on ethical issues was identified, these papers accounted for only 22 % of the total and showed little influence on mainstream research agendas.[42] The data suggest that debates about privacy, algorithmic bias, and equity remained marginal, failing to permeate mainstream technical developments substantially.

The significant involvement of the private technology sector in funding research raises fundamental questions about the governance of educational knowledge.[43] If companies with specific commercial interests sponsor academic studies, this creates potential conditions for conflicts of interest that could distort findings.[44] Bibliometric data show that this phenomenon particularly affected research on the effectiveness of proprietary platforms, where a predominance of positive results was identified that contrasts with independent evaluations.[45]

Structural challenges to equitable implementation

The analysis reveals structural obstacles that limit the democratizing potential of AI in education.[46] The

under-representation of studies in low-income contexts (9 %) and rural areas (3 %) shapes a research landscape that does not respond to the realities of most global education systems.[47] This academic gap reproduces and amplifies existing inequalities, as technological solutions are primarily designed for privileged environments without considering their adaptability to less favorable conditions.[48]

Data on national-scale implementations (3 %) expose another critical limitation of the field. Most of the studies focused on pilot or limited institutional experiences, which prevents an assessment of the fundamental challenges of integrating these technologies into complex educational systems.[49] This lack is particularly problematic, obscuring the logistical, financial, and cultural challenges that emerge once technological solutions are scaled beyond controlled contexts.

Tensions between innovation and pedagogical tradition

Bibliometric results show an unresolved tension between technological paradigms and the theoretical foundations of education.[50] The dominance of terms such as 'machine learning' and 'personalization' over fundamental pedagogical concepts suggests that the field risks privileging technical innovation over established educational principles. This trend could lead to excessive technification of educational processes that require, first and foremost, human understanding and cultural contextualization.

Terminological developments identified between 2019 and 2022 indicate that this tension has begun to be recognized, although it has not yet translated into substantial changes in research practices. The increase in publications on algorithmic ethics and explainability shows a growing awareness of technological limits. Still, the data suggest that this critical reflection failed to permeate mainstream technical developments sufficiently.[51]

Implications for the future of the field

The findings pose urgent challenges for consolidating this field of research. The geographical and thematic concentration identified threatens to make educational AI a narrow academic space, unrepresentative of the global diversity of educational needs.[52] Overcoming this limitation requires deliberate mechanisms to incorporate traditionally marginalised voices, including underrepresented regions and diverse disciplinary perspectives.

The analysis suggests that the field is at a critical inflection point. The observed patterns indicate that research could follow two divergent paths: deepening the dominant technical approach or evolving towards a more integrative paradigm that balances technological innovation with pedagogical, ethical, and cultural reflection.[53] The choice between these trajectories will determine whether AI in education becomes a genuinely transformative tool or another technology that widens existing gaps.

The results of this study provide empirical evidence to guide this strategic decision. The data map the current state of the field and point to directions needed to ensure that the development of educational AI serves the higher purposes of education: equity, critical thinking, and holistic human development. This transition will require concerted efforts by academic communities, policymakers, and technology actors to reorient research priorities toward more fundamental and less instrumental questions.

CONCLUSIONS

This bibliometric study reveals that research on artificial intelligence in digital education experienced accelerated growth between 2019 and 2022, marked by a predominant focus on technical developments over deep pedagogical reflections. The data expose a central paradox: while the field reached quantitative maturity, it showed significant gaps in geographic diversity, thematic balance, and a critical approach to ethical challenges. This contradiction points to the need for the academic community to redirect its efforts towards a more holistic vision that combines technological innovation with pedagogical underpinning.

The results show that educational AI research reproduces the structural inequalities of the global education system. The concentration of studies in developed countries and privileged contexts, together with the scant attention to vulnerable environments, raises serious questions about the democratizing potential of these technologies. There is an urgent need to establish mechanisms that promote inclusive research and represent the diversity of educational realities worldwide.

The analysis identifies unresolved tensions between technological advances and fundamental principles of education. The predominance of privately sponsored studies, the imbalance between technical applications and teacher training, and the marginal treatment of ethical issues all paint a picture that requires immediate correction. The educational community must claim a leading role in defining these technologies' research and implementation agendas.

This work lays the groundwork for a new stage in the study of AI in digital education. The findings not only map the field's current state but also chart pathways for its evolution towards more balanced and socially responsible models. The challenge is to transform this evidence into concrete actions to ensure that

technological development serves education's higher purposes and always prioritizes human development over instrumental advancement.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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