Id: 1559629

Participatory Educational Research (PER)
Vol.11(Prof. Dr. H. Ferhan Odabaşı Gift Issue), pp. 95-113, December 2024
Available online at http://www.perjournal.com
ISSN: 2148-6123
http://dx.doi.org/10.17275/per.24.96.11.6

Advances in Artificial Intelligence in Education: Leading Contributors, Current Hot Topics, and Emerging Trends

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Article history

Received:
01.10.2024

Received in revised form:
12.11.2024

Accepted:
11.12.2024

Key words:
artificial intelligence; bibliometrics; education; network analysis; performance analysis; science mapping

Artificial Intelligence (AI) has emerged as a burgeoning field in education, characterized by rapid growth and diverse research interests. This study employs bibliometric analysis to explore the landscape of AI research in education, focusing on studies indexed in the Web of Science (WOS) database. A comprehensive search identified 1383 articles published between 1981 and 2024, which were analysed using the Bibliometrix R package. The analysis encompassed performance analysis, science mapping, and network analysis, yielding visualizations such as annual scientific production trends, most cited documents, and thematic maps. Key findings reveal a substantial increase in AI research from 2022 onwards, underscoring a shift towards longitudinal studies to track AI's evolution and impacts in educational contexts. Ethical considerations, data privacy, and societal implications emerged as critical areas requiring further investigation. While early studies focused on intelligent tutoring systems, contemporary research highlights topics like ChatGPT, machine learning, and higher education. The interdisciplinary nature of AI in education is evident through its publication in journals spanning educational technology and related fields. Future research directions emphasize the need for comprehensive studies addressing ethical frameworks and guidelines for responsible AI integration in education. Bridging technological advancements with pedagogical strategies is essential for developing integrative models that enhance personalized learning and educational outcomes. Ongoing bibliometric analyses will play a pivotal role in identifying emerging trends and guiding future research endeavours in AI and education.

Introduction

The integration of artificial intelligence (AI) in the education sector induces significant transformation (Qu et al., 2022). This transformation enhances education in terms of accessibility, efficiency, and engagement (Kasneci et al., 2023). AI is regarded as a pedagogical tool with the capacity to facilitate effective learning experiences for both educators and students (Loeckx, 2016). However, the implementation of AI in education also brings challenges, including concerns related to data privacy, accuracy, and ethics (Fyfe, 2023; Li et al., 2023).

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On the positive side, AI research in education addresses issues such as improving student feedback, interaction, providing adaptive learning, and supporting gamification (Zhai et al., 2021). Moreover, machine learning and AI-based analytical techniques, which are subfields of AI, are employed as methodologies in educational research (Emin et al., 2024; Tsai et al., 2020).

As evidenced, critical research topics for AI in education include optimizing AI for more effective learning, mitigating potential negative impacts, and the methodological application of AI. The introduction of ChatGPT 3, a generative AI, in November 2022 (Bower et al., 2024), has significantly increased interest and thus related research in AI applications within education. The rapid proliferation of academic publications poses challenges for researchers to keep abreast of the latest academic trends and advancements (Briner & Denyer, 2012). For newly developing and high-interest areas, it is crucial to identify which topics warrant further research, which variables have gained significance or reached maturity, and which authors, publications, and journals are pivotal. Bibliometrics, as a method of analysing trends and relationships in scientific literature using data such as publications and citations (Broadus, 1987), emerges as a valuable tool. Employing bibliometric analysis to determine trends in the use of AI in education is particularly important given the nascent nature of this field.

Previous bibliometric studies and systematic reviews on the educational use of artificial intelligence (e.g., Amarathunga, 2024; Guo et al., 2024; Hinojo-Lucena et al., 2019; Lin & Yu, 2024; Pradana et al., 2023; Wang et al., 2024) differ from this research in terms of data sources, timeframes, AI tools examined (e.g., ChatGPT), educational contexts (e.g., higher education), and bibliometric methods, leading to distinct findings. The potential contributions of this study, which uses bibliometric analysis to map research on the use of AI in education, are believed to be multifaceted. Firstly, the study reveals the expansion of the field over the years. It discusses the key development stages of AI in education, examines the reasons behind these developments, and explores how to respond to them. Additionally, it analyses productive authors, globally most-cited studies, and significant scientific journals, providing guidance to researchers on where to begin their investigations. This information paves the way for new research directions and methodologies, creating a foundation for future studies. The study also examines which topics within the field have been explored, which have been discussed together, and how these topics have evolved over time, offering valuable insights to researchers on the direction and focus of their studies. Following these trends is crucial for the future of AI research in education, guiding researchers on the gaps in the field. Based on the findings, the study suggests future research directions, highlighting hot topics, trends, and research gaps. This aims to inspire new research by revealing innovative approaches, important variables, and effective methodologies necessary for the field. Overall, this study provides a holistic perspective on AI research in education, offering valuable information on the past, present, and future of the field. The research aims to bibliometrically analyse AI studies in education to determine the current state of the field and establish a scientific basis for guiding future research. To this end, the study seeks to answer the following research questions:

(1) What is the annual publication status of AI studies in the field of education?
(2) Which journals publish the most on AI studies in the field of education?
(3) What are the most cited articles in AI studies in the field of education?
(4) What are the hot topics according to keywords in AI studies in the field of education?
(5) How is the thematic map according to keywords in AI studies in the field of education?
(6) How is the trend according to keywords in AI studies in the field of education?
(7) How is the co-occurrence network according to keywords in AI studies in the field of education?

Literature Review

Artificial intelligence in education

AI refers to the science and engineering of creating systems that can perform tasks typically associated with intelligent beings, such as learning, judgment, and decision-making (Xu et al., 2021). Due to its capabilities, such as automating tasks, processing large amounts of data, and providing predictive insights, AI is driving significant change across various fields (Yang, 2022). One such field is education (Qu et al., 2022). AI can be applied in education in several ways, including student-oriented AI (intelligent tutoring systems), educator-oriented AI (automatic grading support), and institution-oriented AI (identifying students at risk) (Luckin et al., 2022). The use of AI in education enables task assignment based on individual competence, facilitates human-computer interaction, analyses student tasks for feedback, and enhances adaptability and interaction in digital environments (Chiu et al., 2023). The introduction of ChatGPT in education has particularly sparked discussions about the potential effects of AI on education. ChatGPT is a variant of the AI language model developed by OpenAI (Brown et al., 2020). Large Language Models (LLM), a type of generative AI, produce human-like language (OpenAI, 2023), and ChatGPT, as a generative AI derivative, is built on LLM. ChatGPT employs deep learning techniques to understand, process, and generate natural human language with significant accuracy and usability despite high complexity (Haque et al., 2022). These features have garnered the attention of researchers and practitioners since its release. Consequently, the academic community has produced substantial research on generative AI in education. According to these studies, generative AI offers several opportunities for education, including increasing access to information, providing individualized learning, facilitating complex learning, and alleviating teacher burdens (Farrokhnia et al., 2023). However, the use of generative AI in education also raises ethical, privacy, and equity concerns (Lameras & Sylvester, 2022). Issues such as freedom of expression, data ownership, misuse of information, bias, and trust in science are particularly relevant to the use of AI in educational contexts (UNESCO, 2019).

Technological advancements such as machine learning and neural networks have sparked extensive debate over the definition and scope of AI. Within the computer science and information technology community, AI is typically characterized by techniques such as theorem proving, neural networks, Bayesian networks, data mining, deep learning, and natural language processing, among others, leading to the creation of various subfields (Wang, 2019). These subfields underscore the application of AI in educational environments, as well as its utility as a methodological and analytical tool in educational research. Hence, the utilization of AI in analytical processes and its integration into learning processes are pivotal areas of interest.

Despite the widespread adoption of AI in both educational practices and research, it is often characterized as the "Cinderella of the AI story," highlighting its underdeveloped and frequently overlooked status within education (Seldon & Abidoye, 2018). Therefore, understanding the current state of AI in education is crucial, including an assessment of existing academic contributions, ongoing research endeavours, and identifying key variables that will shape future research directions.

Bibliometrics

Bibliometrics serves various purposes, including identifying emerging trends in scientific publications, collaboration patterns, research components within a field, and the

intellectual structure of the field (Donthu et al., 2021; Verma & Gustafsson, 2020). Well-executed bibliometric studies:

- Provide an overview of the field,
- Aid in identifying research gaps,
- Facilitate the acquisition of new information for research,
- Enable researchers to situate their contributions within the field (Donthu et al., 2021).

According to Cobo et al. (2011), bibliometric methods are primarily utilized for two main purposes: performance analysis and science mapping. Performance analysis is intended to assess the research and publication outputs of individuals and institutions. On the other hand, science mapping aims to uncover the structure and dynamics of scientific fields (Figure 1).

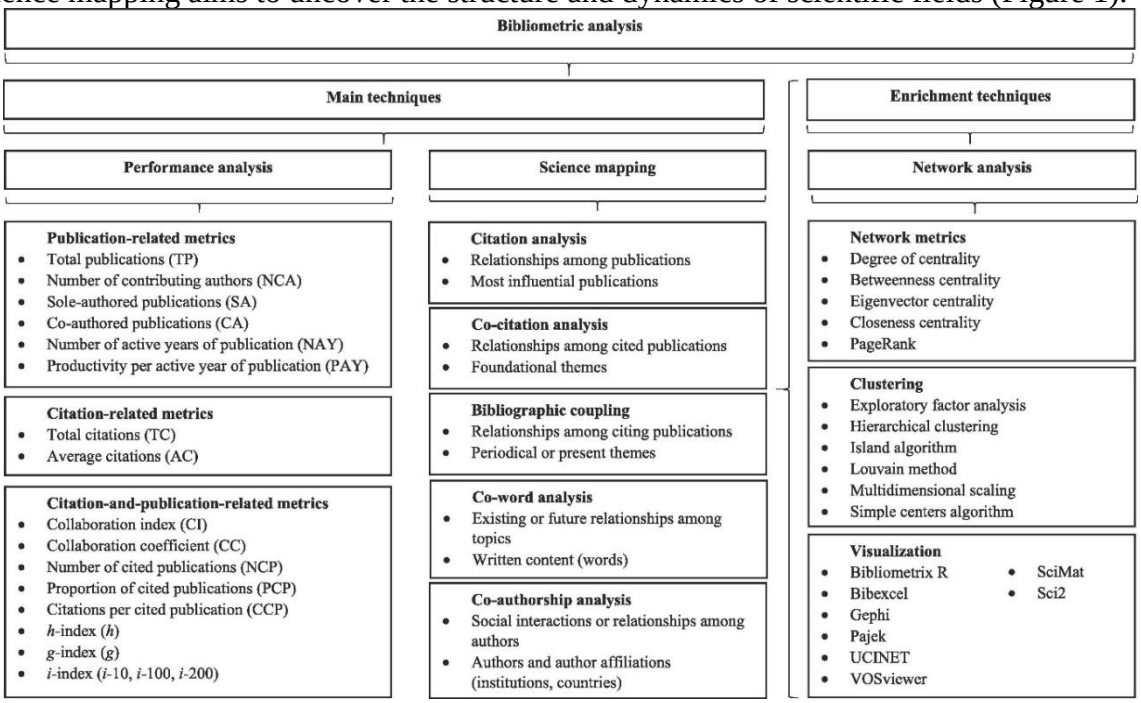

Figure 1. The techniques for bibliometric analysis (Donthu et al., 2021)

Figure 1 illustrates that performance analysis enables the extraction of descriptive statistics regarding publication numbers and citation counts. Conversely, science mapping allows for the exploration of relationships among publications, citations, and authors. Network analysis, a common tool in bibliometric studies, enriches the discourse on research domains, thereby enhancing the validity of bibliometric assessments (Andersen, 2019; Donthu et al., 2021). This study employs performance analysis, science mapping, and network analysis to investigate bibliometric data on AI usage in education. Through these methods, the study aims to elucidate current trends in the field and forecast its future directions.

Methodology

Study design

The research employs a descriptive approach using bibliometric methods. Bibliometrics, which utilizes statistical techniques to analyse publication patterns, plays a crucial role in assessing the evolution and trends within a specific field, as well as identifying

key themes, influential authors, and significant publications (Mao et al., 2021; McBurney & Novak, 2002; Moral-Muñoz et al., 2020; Qian & Zhong, 2023). In conducting the bibliometric analysis, the study adhered to the five-step process recommended by Zupic and Čater (2015): (i) study design, (ii) data collection, (iii) analysis, (iv) visualization, and (v) interpretation.

Data collection

The research data comprises articles indexed in the Social Science Citation Index (SSCI) within the Education/Educational Research category on Web of Science (WOS), accessed on July 11, 2024. The articles were retrieved using the search terms "artificial intelligence" OR "chatgpt" and filtered by WOS category, index, and language (English). After evaluating the relevance of the retrieved articles to the research topic, a total of 1383 articles were included for analysis. This dataset, characterized by its comprehensiveness and quality sourced from a reputable platform, forms a robust basis for exploring the landscape of AI research in education spanning from 1981 to 2024. Detailed features of the dataset are presented in Table 1.

Table 1. Features of articles

Timespan	1981-2024
Sources	166
Annual Growth Rate %	13.98
Document Average Age	3.39
Authors	3513

Analysis

The articles obtained were saved in BibTeX format and analysed using the Bibliometrix R package (Aria & Cuccurullo, 2017), a robust software tool for bibliometric analysis. Bibliometrix offers extensive functionalities, including data importation and conversion to R format, bibliometric analysis, matrix creation, network analysis, multiple correspondence analysis, factorial analysis, and visualization (Arruda et al., 2022). Therefore, it serves as a powerful tool for conducting performance analysis, science mapping, and network analysis, as mentioned earlier.

Visualization

In the visualization phase of the analysed data, several visual representations were generated using the Bibliometrix software. These include:

- Annual scientific production chart,
- Most relevant sources chart,
- Most globally cited documents chart,
- Word cloud,
- Thematic map,
- Trend topics,
- Co-occurrence network.

These visualizations help to provide insights into the trends, key sources, influential documents, thematic areas, emerging topics, and relationships among keywords in the field of AI research in education based on the bibliometric analysis.

Interpretation

The visual outputs generated from the data analysis were interpreted using descriptive statistics provided by Bibliometrix. Throughout the interpretation process, emphasis was placed on elucidating the relationships among the identified structures in alignment with the research objectives. This approach facilitated a comprehensive understanding of the patterns, trends, and dynamics within the field of AI research in education, as revealed through the bibliometric analysis.

Results and Discussion

Annual publications

AI research in the field of education commenced in 1981 (Figure 2). In 2020, there were 48 studies on this topic, which doubled to 96 studies in 2021. From 2022 onwards, a notable surge occurred, with 127 studies conducted that year. This trend escalated dramatically to 365 studies in 2023 and further to 555 studies in 2024.

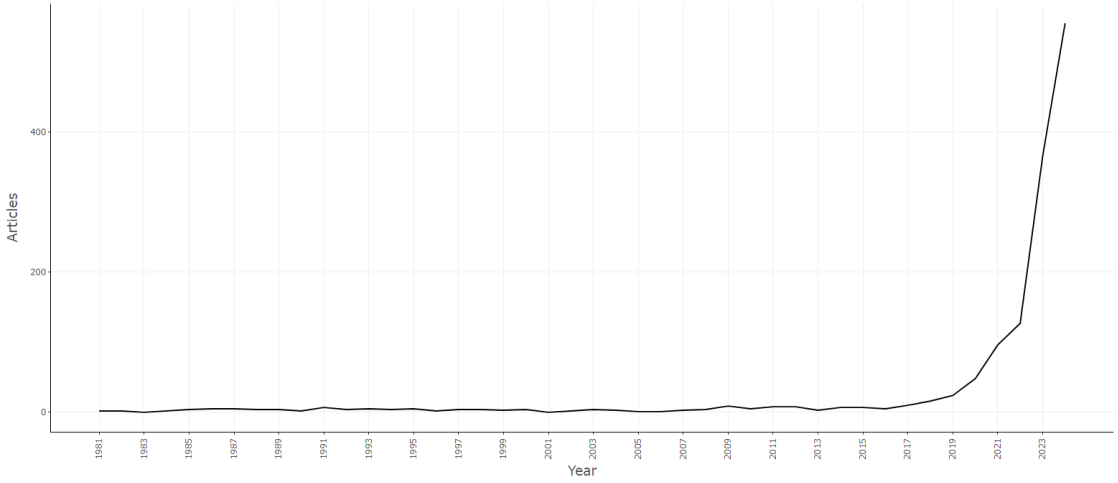

Figure 2. Annual publications of research on AI in education

The release of ChatGPT 3 by OpenAI in November 2022 marks the advent of a transformative era characterized by powerful and readily accessible generative AI capabilities. ChatGPT can undertake tasks ranging from writing stories, offering life advice, composing poems, to coding computer programs (Scharth, 2022). Moreover, generative AI facilitates translation, content generation, text summarization, serves as a chat companion, and aids in article production (Cotton et al., 2024; Transformer et al., 2022). The anticipated availability of such versatile software by 2022 has propelled generative AI into the forefront of research agendas within this year. Consequently, an increase in AI research within education is expected by 2022. The overall growth trajectory of AI literature underscores a promising future characterized by an expanding community and heightened scientific output (Chen et al., 2021).

Top journals and most cited articles

The most published SSCI indexed journals for AI studies in education are as follows (Figure 3): Education and Information Technologies (n = 218), IEEE Transactions on Learning Technologies (n = 85), Interactive Learning Environments (n = 80), British Journal of Educational Technology (n = 78), Computers & Education (n = 67), Educational Technology

& Society (n = 60), International Journal of Educational Technology in Higher Education (n = 45), Journal of Computer Assisted Learning (n = 45), BMC Medical Education (n = 45), Journal of Educational Computing Research (n = 28).

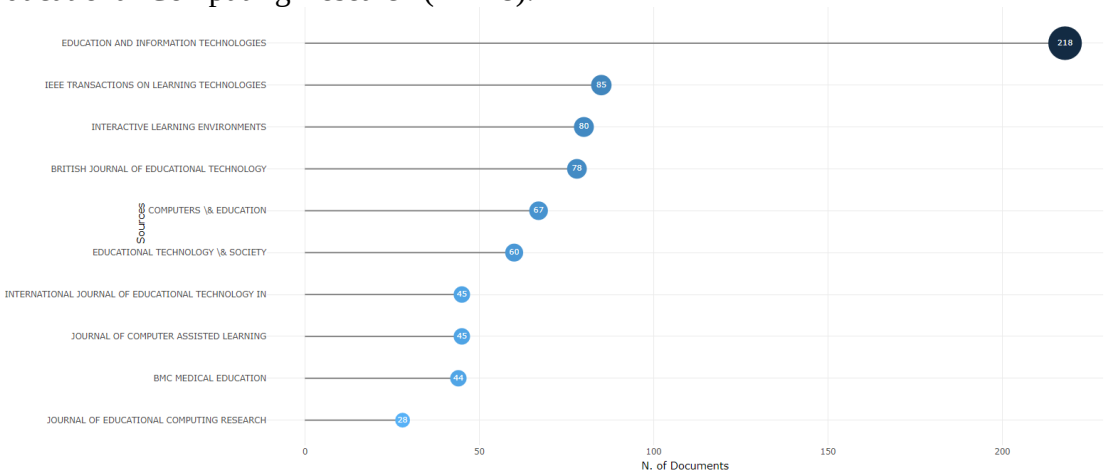

Figure 3. Publishers of research on AI in education

The scientific journals with the highest number of publications on the use of AI in education predominantly belong to interdisciplinary fields focused on instructional technology. These journals publish studies that explore the intricate relationships between technology and education, such as educational data mining (e.g., IEEE Transactions on Learning Technologies), adaptive systems (e.g., Interactive Learning Environments), intelligent tutoring and mentoring systems (e.g., International Journal of Educational Technology in Higher Education), and learning analytics (e.g., Journal of Computer Assisted Learning). The prevalence of AI-based topics in these journals reflects their emphasis on advancing technological applications in educational contexts. The concentration of publications in these journals is not coincidental; it aligns with findings from previous studies highlighting the close association between AI and computer science (Chen et al., 2021; Tang et al., 2021; Zawacki-Richter et al., 2019). This correlation underscores the pivotal role of interdisciplinary journals in advancing research at the intersection of AI and education.

AI research in the field of education is represented in Figure 4 based on the most cited studies. These studies, ranked by the number of citations, are as follows: Cotton et al. (2024) (n = 269), García et al. (2007) (n = 256), Azevedo et al. (2007) (n = 224), Hwang (2003) (n = 184), Farrokhnia et al. (2023) (n = 167), Goralski and Tan (2020) (n = 166), Cooper (2023) (n = 158), Lim et al. (2023) (n = 150), Kessler (2018) (n = 141), Chou et al. (2003) (n = 127).

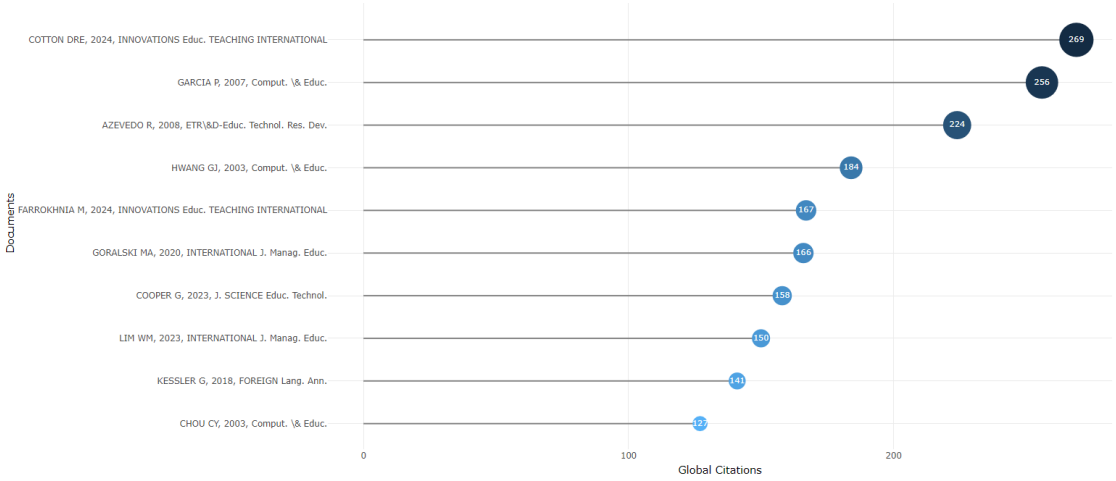

Figure 4. Most global cited articles on AI in education

Cotton et al. (2024) explores the opportunities and challenges associated with integrating ChatGPT into higher education, addressing both the potential risks and benefits of this technology. The prominence of these current issues in generative AI discussions has contributed significantly to the citation count of this publication. García et al. (2007) aimed to identify students' learning styles using Bayesian networks, an AI-based analysis method. This methodological approach leveraging AI likely enhances the citation potential of their study. Azevedo et al. (2007) investigated the impact of dynamic adaptive scaffolding on student learning within a hypermedia environment. Adaptive learning, facilitated by personalized tools grounded in AI, underscores the enduring interest in AI's role in educational enhancement. Hwang (2003) proposed a concept map model for intelligent tutoring systems, highlighting AI's application in education. The sustained interest in studies involving adaptive learning environments and intelligent tutoring systems reflects AI's enduring significance in educational contexts. Farrokhnia et al. (2023) conducted a SWOT analysis to assess the strengths, weaknesses, opportunities, and threats posed by ChatGPT in education. This reflective analysis on the implications of generative AI has garnered attention within the academic community. Goralski and Tan (2020) examined the impact of AI on sustainable development from business strategy and public policy perspectives. Their study's inclusion among the highly cited articles indicates a growing interest in understanding AI's broader implications beyond education. Cooper (2023) employed a self-study approach to evaluate ChatGPT's use in science education, offering recommendations for its effective implementation while mitigating potential risks. This practical application-focused study contributes to discussions on leveraging generative AI in educational settings. Lim et al. (2023) critically analysed debates surrounding generative AI's use in education, highlighting diverse perspectives on its implications. Such critical analyses are pivotal in shaping the discourse on AI's integration into educational practices. Kessler (2018) discussed leveraging technology for student benefit, particularly in comprehensive language practice, emphasizing AI's role in creating personalized learning environments. This underscores AI's significance in language education research. Chou et al. (2003) explored educational agents, rooted in AI, reflecting longstanding discussions on the benefits and challenges of AI in education. Their study contributes to the foundational understanding of AI's role in educational environments.

As observed from the analysis of the most cited publications, research focusing on the opportunities and risks of integrating generative AI into education has garnered significant attention among researchers in this field. Additionally, foundational applications of AI such as

intelligent tutoring systems, adaptive learning environments, and educational agents have consistently been topics of interest over time. Moreover, studies exploring AI's implications in specific domains like science and language education have also garnered notable interest. Furthermore, discussions around AI's impact on sustainability underscore a growing curiosity regarding how AI will influence economic, environmental, and social outcomes in the future.

Hot topics, trends, and co-occurrence network

The word cloud presented in Figure 5 displays the most frequently utilized keywords in research related to AI in education. The top keywords, ranked by their frequency of use, are as follows: AI (n = 387), ChatGPT (n = 148), education (n = 126), learning (n = 87), higher education (n = 61), and machine learning (n = 53). These keywords underscore the primary areas of interest and focus within the research landscape, highlighting significant attention on AI applications, particularly through ChatGPT, across educational contexts ranging from general education to higher education, and emphasizing learning processes and machine learning methodologies.

Figure 5. Word cloud based on keywords

The word cloud provides a quick overview of the prominent themes and concepts within the field of AI in education. AI emerges as the most frequently used term, encompassing descriptive studies (e.g., Goralski & Tan, 2020), experimental studies (e.g., Vázquez-Cano et al., 2021), survey studies (e.g., Chai et al., 2021), and qualitative studies (e.g., Jeon, 2024). This indicates a diverse methodological approach to studying AI's application in education. Following AI, ChatGPT stands out as the second most utilized keyword among authors (e.g., Yan, 2023). Despite its relatively recent introduction, the revolutionary capabilities of generative AI are a major focus of research attention. Education (e.g., Chatterjee & Bhattacharjee, 2020) and learning (e.g., Liu et al., 2022) are also frequently mentioned keywords, underscoring the extensive exploration of AI's integration into educational and learning contexts. The frequent appearance of higher education (e.g., Cotton et al., 2024) highlights a significant focus on research targeting university-level education. Additionally, machine learning (e.g., Tsai et al., 2020) is prominently featured, indicating extensive research into both the foundational mechanisms of AI and its methodological applications. Overall, the word cloud reflects a comprehensive exploration of AI in education, encompassing diverse research methodologies and emphasizing its broad impact across educational settings.

The thematic map categorizes keywords in AI research within education into motor themes, basic themes, emerging or declining themes, and niche themes based on their respective levels of development (density) and relevance (centrality) (Cobo et al., 2011) (Figure 6). Motor themes exhibit both high development and relevance, indicating a mature area of study within the field. Basic themes display high relevance but relatively low development, suggesting

foundational concepts that require further exploration. Emerging or declining themes show low levels of both development and relevance, signifying either nascent or less connected topics in the field. Niche themes demonstrate high development but low relevance, indicating specialized areas with substantial depth of knowledge yet limited integration with broader research trends.

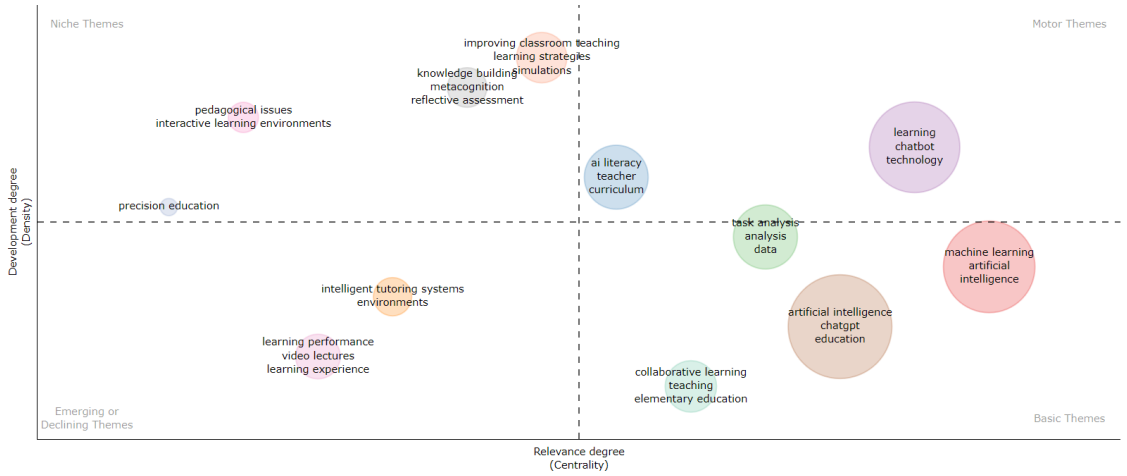

Figure 6. Thematic map of keywords

The motor themes quadrant encompasses keywords such as learning, chatbot, technology, AI literacy, teacher, and curriculum in AI research within education. These keywords exhibit a mature level of development and strong connections with other topics in the field, stemming from extensive historical study (e.g., Halff, 1986; Hwang, 2003). Therefore, they are considered well-established and relevant within educational AI research. Chatbot and AI literacy, introduced following the emergence of generative AI, also reside in this quadrant due to their frequent exploration and interconnectedness with established themes (e.g., Chocarro et al., 2023; Kong et al., 2021). Keywords like AI, ChatGPT, education, machine learning, collaborative learning, teaching, task analysis, and data are situated in the basic themes quadrant. These terms demonstrate significant relevance to the field but still lack sufficient depth of study and developmental maturity, partly attributed to the recent introduction of generative AI technologies and evolving methodologies such as machine learning (Chen et al., 2021). The emerging or declining themes quadrant includes keywords such as learning performance, video lectures, learning experience, and intelligent tutoring systems. These topics exhibit lower levels of relational and developmental maturity, indicating either nascent exploration or decreasing relevance within current research trends. The inclusion of Intelligent tutoring systems (e.g., Chou et al., 2003) in this quadrant may reflect its earlier prominence in AI research and subsequent diminished focus with the advent of generative AI. These findings align with prior research insights (Chen et al., 2021). Lastly, the niche themes quadrant encompasses keywords such as improving classroom teaching, learning strategies, simulations, knowledge finding, metacognition, pedagogical issues, and interactive learning environments. While these topics demonstrate a high degree of developmental maturity, they exhibit limited integration with broader research trends within the field of educational AI. Thus, researchers are encouraged to explore and integrate these themes more deeply into current discourse to enhance their relevance and connectivity within the field.

Figure 7 illustrates the longitudinal changes in keyword frequencies across articles focusing on AI in education from 2004 to 2024. This visualization highlights the trends where some topics have increasingly established their significance over the years, while others are emerging as

new areas of study within the field.

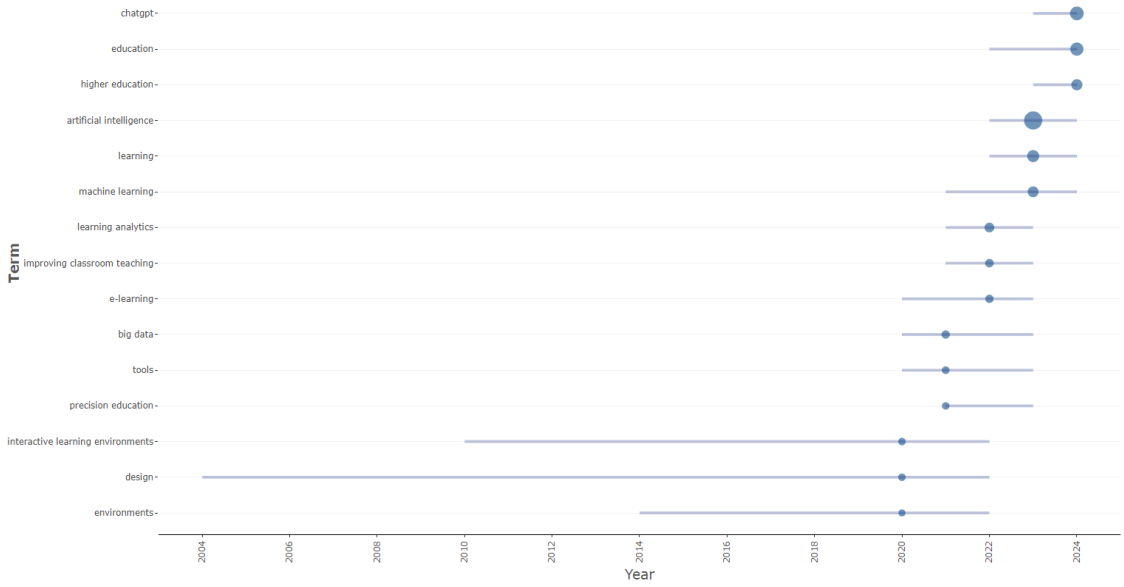

Figure 7. Trend topics by keywords

“AI” has been identified as a keyword 387 times by researchers. With a median year of 2023, this keyword has been prominently studied in recent years. Following closely is “ChatGPT” with a frequency of 148, and a median year of 2024 for this keyword, considering its release by OpenAI in November 2022, indicating its immediate and significant impact in the field of AI in education (Bower et al., 2024). The keywords "education" and "learning" have frequencies of 126 and 87, respectively. These keywords began to see increased usage starting in 2022. While studies on AI in education date back to 1981, the heightened frequency of these keywords in recent years is notable, possibly linked to the emergence of generative AI. The oldest keyword in terms of median year is "cooperative/collaborative learning" (e.g., Faria et al., 2009; Mitnik et al., 2009). Considering the emergence of generative AI and its capability to provide personalized environments (Seldon & Abidoye, 2018), this shift from collaborative processes to personalized processes can be observed in the research field.

It appears that Figure 8 depicts a co-occurrence network where lines represent the associations between keywords, and the size of each node indicates how frequently these keywords co-occur. According to this visualization, the keywords used by researchers are grouped into two main clusters based on their connections. The blue cluster predominantly focuses on keywords like "education" and "student," while the red cluster is centred around keywords related to "technology" and "AI." This indicates that the network reveals relationships between two main clusters: one emphasizing technological aspects and the other pedagogical aspects, highlighting their interconnections.

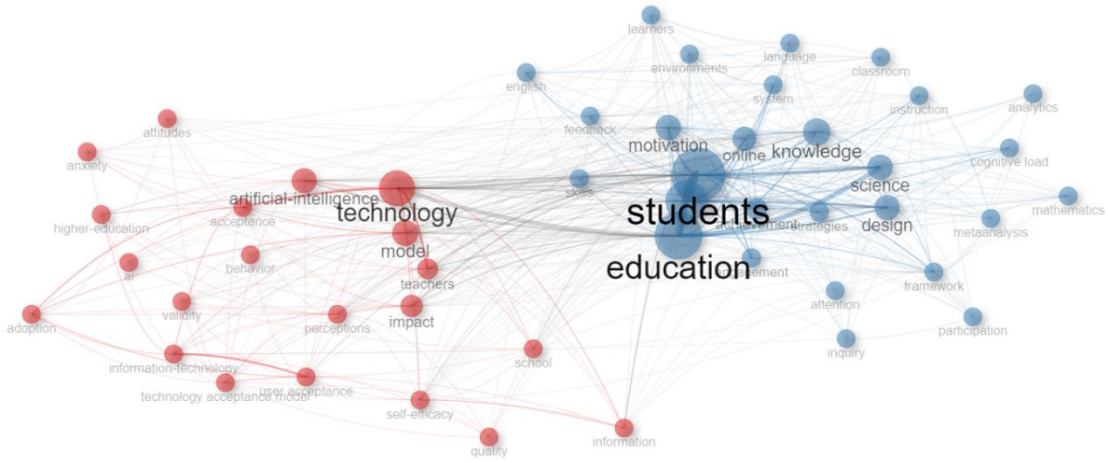

Figure 8. Co-occurrence network

In the blue cluster of the co-occurrence network depicted in Figure 8, keywords such as "students," "education," "motivation," "science," "design," and "knowledge" are frequently interconnected. These terms collectively illuminate aspects of the educational domain within AI research. It suggests that studies clustered here are primarily concerned with exploring how AI can enhance learning and teaching processes. For instance, research by Vázquez-Cano et al. (2021) and Yan (2023) likely delve into the integration of AI technologies to improve student learning outcomes and educational methodologies. Conversely, the red cluster predominantly features keywords like "technology," "AI," "model," and "impact." This cluster signifies studies that are more oriented towards the technological aspects of AI deployment. Here, researchers likely investigate various models and frameworks that leverage AI technologies in educational contexts. For example, works by Chatterjee & Bhattacharjee (2020) and Strzelecki (2023) are likely exploring how AI models impact educational practices and learning environments. In essence, the co-occurrence network delineates two distinct thematic clusters: one focusing on the educational applications of AI, emphasizing student engagement and pedagogical strategies, and the other centred around the technological aspects of AI, highlighting models and frameworks influencing AI adoption in education.

Limitations

While this review identifies significant trends and potential research directions in A) within education, it is subject to several limitations. Primarily, the articles analysed in this study were sourced exclusively from the SSCI index of the WOS database, excluding other databases such as SCOPUS and EI, as well as alternative sources. Moreover, the search conducted in WOS was constrained to the terms 'AI' and 'ChatGPT', which could be broadened by incorporating additional keywords. Another primary limitation of bibliometric analysis is its reliance on quantifiable metrics, which may not comprehensively capture the maturity or saturation of a field (Donthu et al., 2021). As this study aims to provide a systematic overview of AI in education, it does not assess the effect size of the variables studied, unlike a meta-analysis. Hence, our investigation should be interpreted within this context. Importantly, bibliometric analysis does not intend to assess the quality of studies; therefore, our research is confined to quantitative analysis of bibliometric data.

Conclusion and Future Research

The objective of this study is to conduct a bibliometric analysis of AI research within the field of education. The study utilized the WOS database with a search query comprising "artificial intelligence" OR "chatgpt," filtered by parameters including SSCI indexing, article type, English language, and the Education/Educational Research category. A total of 1383 articles published between 1981 and 2024 were subjected to performance analysis, science mapping, and network analysis using the Bibliometrix R package. The findings were visualized through graphs depicting annual scientific production, most relevant sources, most globally cited documents, as well as through a word cloud, thematic map, trend topics, and co-occurrence network analyses.

The annual publications chart highlights a significant uptrend in research on AI in education since 2022, indicating growing interest and exploration by researchers in this field. There is a recognized need for longitudinal studies that can systematically track the development of AI applications and their enduring impacts over extended periods. Such studies are essential for gaining deeper insights into the long-term advantages and challenges associated with the integration of AI within educational contexts. Additionally Educational frameworks should incorporate the principles of generative AI to address its capabilities for personalization, engagement, and scalability. Theoretical models such as the Technology Acceptance Model (TAM) can be expanded to include constructs specific to generative AI, such as trust and creativity, to better explain its adoption in educational contexts. Publications on AI in education predominantly appear in scientific journals focusing on educational technology and interdisciplinary themes. Future research endeavours should prioritize fostering interdisciplinary collaborations, aiming to innovate solutions that integrate technical, pedagogical, and psychological perspectives. These collaborative efforts hold potential for advancing the effective implementation of AI in educational practices.

The most cited publications underscore the dual aspects of leveraging AI in education, focusing on both its potential benefits and risks. There is a pressing need for comprehensive research that addresses ethical considerations, data privacy concerns, and the broader societal impacts of AI adoption in educational settings. Future studies should prioritize developing guidelines and frameworks to ensure the responsible deployment of AI technologies in education. Descriptive, experimental, survey, and qualitative research methodologies are frequently employed in investigating AI's role in education, highlighting the diverse research approaches in the field. The prominence of keywords such as ChatGPT, machine learning, and higher education reflects current focal points in AI research within education. Early AI concepts like intelligent tutoring systems are declining in prominence as newer technologies such as chatbots and advanced machine learning methods gain traction. Nonetheless, a detailed historical analysis of intelligent tutoring systems' impact and limitations can offer valuable insights for current and future AI implementations in educational contexts. Future research endeavours should delve deeper into specific applications, effectiveness assessments, and pedagogical implications of these evolving technologies. Comparative studies that evaluate the performance of different AI tools across diverse educational environments hold particular promise in advancing our understanding and optimizing the use of AI in education.

The application of AI in education is categorized into two primary clusters: technological and pedagogical. While the pedagogical dimension predominantly investigates AI's integration into learning and teaching processes, the technological dimension focuses on modelling studies that identify variables influencing AI utilization. Future research should endeavour to bridge these clusters by developing integrative models that encompass both technological advancements and

pedagogical strategies. There is a critical need for studies exploring how AI can facilitate personalized learning, enhance teaching methodologies, and improve educational outcomes. As AI's role in education continues to evolve, new research models must be devised to capture the dynamic interplay between AI technologies and educational practices. These models should consider factors influencing AI implementation, including user engagement, learning efficacy, and accessibility. Additionally, ongoing bibliometric analyses should be conducted periodically to track emerging trends and anticipate future research trajectories. This will enable scholars and practitioners to remain abreast of the latest developments and adapt their research and educational practices accordingly.

To ensure effective integration of AI tools like ChatGPT in education, educators require specialized training that focuses on developing skills for leveraging these technologies in their pedagogical practices. Such training should encompass techniques for lesson personalization, AI-assisted content creation, and enhancing student engagement. Schools and universities need to invest in AI-powered platforms designed for intelligent tutoring systems, adaptive learning environments, and comprehensive learning analytics. These platforms should align with specific educational goals, enabling tailored solutions that support diverse learning contexts. Policymakers and educational institutions must collaborate to establish ethical guidelines for AI usage in education. These guidelines should address concerns such as data privacy, algorithmic bias, and responsible utilization to maintain trust and integrity in AI applications. A multi-stakeholder approach is essential, involving educators, technologists, and policymakers working together to ensure AI tools are developed and implemented to meet the actual needs of educational environments. Practical initiatives, such as pilot programs and collaborative research projects, can provide valuable insights into the real-world effectiveness of AI solutions, fostering scalable and sustainable integration into education systems.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors

Ethics Statements

This study does not contain any studies with human participants and/or animals performed by any of the authors.

Conflict of Interest

We have no conflict of interest.

Data availability

The raw data supporting the conclusions of this article will be made available by the authors.

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