

Artificial intelligence in education: a bibliometric analysis of emerging trends

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ABSTRACT

This study investigates the transformative potential of artificial intelligence (AI) in education through a bibliometric analysis of 291 scholarly works retrieved from the Web of Science (WoS) database. Traditional methods of instruction are under threat from the growing demand for individualized and equitable education, particularly in underserved communities. This study looks at how AI innovations, like virtual assistants and adaptive learning platforms, can enhance learning outcomes and the efficacy of instruction in order to address these concerns. The methodology used co-occurrence and co-citation analyses to map research trends and find educational and AI thematic clusters. Pedagogical frameworks, medical education innovations, ethical governance, generative AI applications, and AI acceptance are the five main research areas highlighted in the findings. With 5,246 citations and an H-index of 42, the data show how widely used AI is in both academia and industry. Adaptive learning models, moral dilemmas, and AI literacy are emerging themes. According to this research, AI has the potential to improve accessibility, equity, and quality in education while tackling issues like algorithmic bias and digital divides. This is in line with sustainable development goal 4 (quality education). Teachers, legislators, and technologists can use this study's thorough intellectual landscape to gain practical insights on how to responsibly incorporate AI into educational systems for more sustainable innovation.

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1. INTRODUCTION

By improving teaching and learning procedures, artificial intelligence (AI) is revolutionizing a number of industries, including education. Education can become more individualized, effective, and accessible with the help of AI, which includes tools like chatbots, machine learning, and intelligent systems [1]. Among them, generative AI technologies – like ChatGPT and AI-generated content tools – have attracted a lot of attention lately due to their potential to transform educational assessment, creativity, and instruction

while posing serious questions regarding ethical use and academic integrity. Over the past decade, AI has been incorporated into applications like intelligent tutoring systems, virtual teaching assistants, and automated grading platforms to address the needs of individual students and overcome the drawbacks of traditional methods [2]. However, to comprehend AI's entire influence, difficulties, and future development potential, a critical analysis of its position in education is necessary [3].

A major challenge in contemporary education is addressing the diverse needs of learners. Traditional teaching approaches often apply a uniform method to all students, neglecting individual differences in learning pace, styles, and capabilities. Factors such as large class sizes, limited resources, and overburdened educators exacerbate this issue, reducing the level of personalized support provided to students [4]. Furthermore, marginalized or under-resourced communities face significant barriers in accessing quality education, and online learning has further exposed gaps, including a lack of engagement and inadequate feedback mechanisms [5].

By using data-driven strategies to improve teaching and learning, AI offers encouraging answers to these problems. Large amounts of educational data are analyzed by AI-powered systems to find learning gaps and trends in student performance, allowing teachers to offer more focused help [6]. A more customized learning experience is promoted by adaptive learning platforms, which modify the pace and information to suit each learner's strengths and shortcomings [7]. AI-powered chatbots and virtual assistants are examples of tools that offer 24/7 support, improving student engagement and guaranteeing prompt assistance [8]. Additionally, by automating administrative duties like scheduling and grading, AI frees up teachers' time to concentrate on important teaching activities [9].

AI is important for education because of its potential to increase quality, equity, and accessibility. AI-enabled individualized learning allows students to progress at their own speed, which enhances comprehension and retention of the subject matter [10]. AI also promotes inclusiveness by providing assistive technologies, such as voice recognition software, to students with disabilities [11]. AI provides educators with valuable data-driven insights that improve instructional strategies and curriculum design [12]. Policymakers can use AI-generated data to inform their decisions and develop policies aimed at improving educational institutions [13].

Notwithstanding its benefits, incorporating AI into education is fraught with difficulties. Given that AI systems handle sensitive student data, worries about data security and privacy are critical [14]. Further sustaining educational disparities, algorithmic bias in AI systems can produce unfair or erroneous results [15]. Furthermore, the digital divide could expand if under-resourced places do not have equal access to AI-driven technology [3]. Effective AI application is further hampered by instructors' resistance to change and a lack of digital skills [4].

AI has the ability to improve accessibility and learning outcomes while addressing a number of current issues in education. Therefore, the purpose of this study is to use bibliometrics to gain a thorough understanding of the body of literature on "AI in education". To achieve this, the study looks at the literature on AI in the classroom. Using two distinct bibliometric approaches, this study closes a large gap in the literature and provides valuable insights into the past, present, and future directions of research on the ways AI is transforming educational systems. This entails having a fair grasp of both the advantages—like more individualized instruction, more participation, and administrative effectiveness—and the drawbacks—like data privacy threats, moral dilemmas, and adoption resistance. These are the study's goals, which correspond with the particular bibliometric analyses: i) to analyze current trends in AI in education through co-citation analysis and ii) to identify emerging keyword trends in AI in education through co-occurrence analysis.

2. METHOD

Bibliometric analysis is a vital tool in academic research as it provides a systematic and quantitative method to evaluate large bodies of scholarly work. By analyzing citations, collaborations, and publication trends, bibliometric analysis enables researchers to identify key contributions, emerging themes, and the overall structure of a research field [16]. In the context of AI in education, bibliometric analysis plays an essential role in mapping the development of the field, synthesizing existing knowledge, and identifying areas for future exploration. It allows researchers to track the progression of scholarly activity and understand the influence of specific studies, institutions, and authors over time [17].

Co-occurrence and co-citation analysis reveal significant connections in the literature, which enhance bibliometric research. By analyzing the frequency of citations between two texts, co-citation analysis can identify developing research clusters, fundamental studies, and thematic links. According to Polat *et al.* [18], AI in education offers valuable perspectives on the field's intellectual framework. However, the correlations between terms in research articles are the main focus of co-occurrence analysis. It provides

a greater comprehension of new themes and potential paths by highlighting research gaps, trends, and subjects that are currently popular in academic conversations [19].

Using an adaptation of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework, Figure 1 shows the document selection procedure used in this bibliometric analysis. A targeted keyword term, (TI="artificial intelligence" OR TI="AI") AND TI="educat*", was used to get 3,017 documents from the Web of Science (WoS) database to start the identification stage. Because of this, articles that specifically address AI in educational settings were certain to be included. Results were restricted to English-language, peer-reviewed journal articles published between 2015 and 2024 after records were filtered according to inclusion and exclusion criteria throughout the screening and eligibility phase.

After filtering, 946 pertinent studies were found. To guarantee subject relevance and analytical suitability, all 946 papers underwent a full-text review as part of the final inclusion step. A thorough and superior dataset for the next co-citation and co-occurrence analysis was guaranteed by this methodical record-narrowing procedure, using VOSviewer version 1.6.20. In the co-citation analysis, a minimum citation threshold of 60 was applied to filter the most influential documents. For the co-occurrence analysis, a minimum keyword occurrence threshold of 5 was set to identify the most significant terms. The fractional counting method was employed for both analyses to ensure balanced representation of sources.

Out of the 946 relevant articles that were obtained from the WoS database, 291 papers were chosen for the paper's comprehensive study of the literature on AI in education. These 291 papers were selected to ensure representation of key advancements and prominent works in the field based on factors such as contribution significance, theme alignment with educational AI, and citation relevance. With 5,246 citations overall and 5,001 citations after removing self-citations, these articles obtained an average of 18.03 citations per article. The total number of citing articles decreases to 3,525 when self-citations are removed. This implies that the study of AI in education has attracted a lot of scholarly attention and widespread recognition. The determined H-index of 42, which indicates that at least 42 articles have each been mentioned at least 42 times, further demonstrates the impact of the publications. The productivity and effect of the research field are vitally represented by this measure.

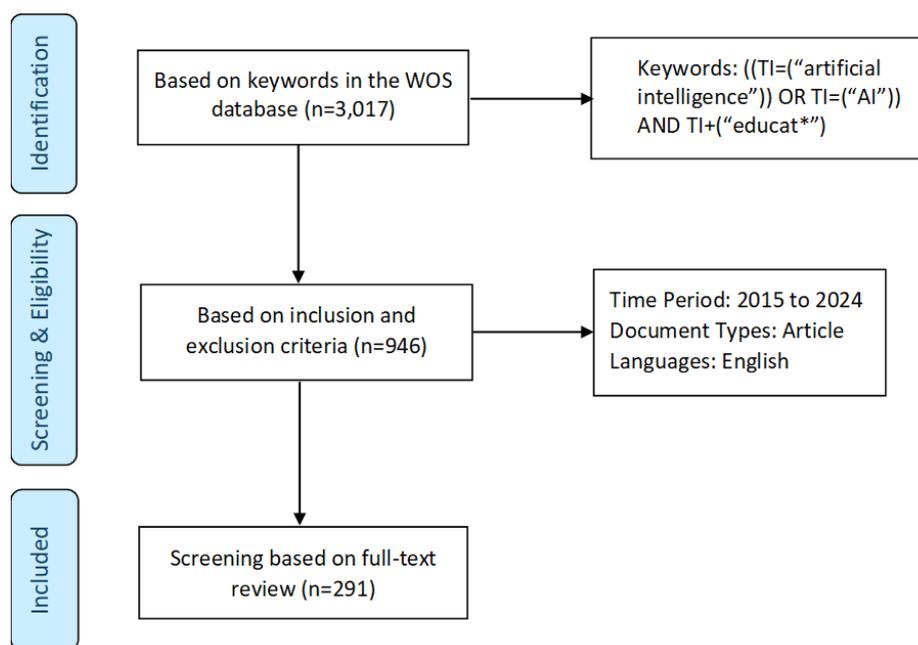


Figure 1. PRISMA flowchart

3. RESULTS AND DISCUSSION

3.1. Co-citation analysis

The co-citation analysis identifies five different clusters (as shown in Table 1) that deal with conceptual frameworks, ethical governance, generative AI, systematic reviews, and medical education. Together, the clusters highlight important areas of concentration, difficulties, and prospects for further research, demonstrating the depth and breadth of AI research in education. The analysis in Figure 2 connects

key papers to offer a thorough intellectual landscape map, pointing researchers toward important gaps and new subjects in AI education research.

Cluster 1 focuses on the opportunities, challenges, and implications of generative AI, particularly tools like ChatGPT, in educational settings. Key publications, such as Dwivedi *et al.* [20] and Kasneci *et al.* [21] explore the transformative potential of large language models while addressing ethical and practical concerns. Cooper [22] highlights generative AI's role in science education, offering insights into its application and challenges. Similarly, Crompton and Burke [23] examine the state of AI in higher education, analyzing its current use and future potential. This cluster reflects the increasing academic attention on generative AI technologies and their integration into teaching, learning, and assessment processes.

Cluster 2 is devoted to the fundamental reviews, frameworks, and difficulties of AI in education. Chen *et al.* [24] summarize technological developments and obstacles in their study of AI applications. The functions of AI in education and its potential research avenues are covered by Hwang *et al.* [25]. Meanwhile, Popenici and Kerr [26] investigate the wider effects of AI on instruction and learning, pointing out its disruptive potential in higher education. The conversation is expanded by several studies [27], [28], which address big data, smart classrooms, and emerging paradigms. The emphasis on creating methodical frameworks to handle AI's potential and constraints in education is evident in this cluster.

Cluster 3 focuses on the governance and ethical issues surrounding AI use in education. The absence of educator involvement in AI development is highlighted by Zawacki-Richter *et al.* [29], who advocate for inclusive AI frameworks. A community-wide ethical framework for AI in education is put forth by Holmes *et al.* [30], addressing issues of fairness and transparency. In a similar vein, other studies [31], [32] examine moral dilemmas in K–12 contexts and the necessity of policy formation. Jobin *et al.* [33] emphasize the significance of regulations to control AI applications and further highlight global trends in AI ethics. This cluster emphasizes how ethical AI implementation is necessary to prevent bias and guarantee equity.

Cluster 4 focuses on AI applications in medical education and the acceptance of AI technologies by users. Sit *et al.* [34] and Santos *et al.* [35] explore attitudes toward AI among medical students, indicating both enthusiasm and concerns regarding AI's role in clinical practice. Wartman and Combs [36] advocate for a shift in medical education to integrate AI capabilities, addressing emerging technological demands. Additionally, Venkatesh *et al.* [37] provide a foundational framework for user acceptance of new technologies, applicable across educational and professional domains. This cluster highlights AI's role in professional education, particularly in fields requiring advanced technical knowledge.

Cluster 5 highlights conceptual analyses and rigorous studies of AI applications in education. Fairness and accountability are highlighted in Nguyen *et al.* [38] discussion of ethical considerations for AI integration. While Celik *et al.* [39] examine the potential and difficulties of AI for educators, Chiu *et al.* [40] conduct a comprehensive evaluation of AI prospects, problems, and research objectives. With an emphasis on AI literacy, study by Ng *et al.* [41] offer a conceptual framework for fostering AI competencies in both teachers and students. This cluster highlights the necessity of a methodical strategy to guarantee the moral, useful, and significant incorporation of AI in education.

Table 1. Co-citation cluster on AI in education

Cluster no and color	Cluster labels	No. of articles	Representative publications
Cluster 1 (red)	Generative AI and its impact on education	17	[20]–[23], [42]–[45]
Cluster 2 (green)	AI frameworks, challenges, and future directions	16	[24]–[28], [46]
Cluster 3 (blue)	Ethical issues and AI governance in education	10	[29]–[33]
Cluster 4 (yellow)	AI in medical education and user acceptance	8	[34]–[37]
Cluster 5 (purple)	Systematic reviews on ethical and practical AI applications	7	[39]–[41], [47]

3.2. Co-occurrence analysis

The co-occurrence analysis identifies six thematic clusters highlighting the various uses, difficulties, and developments of AI in education, as shown in Figure 3. These clusters focus on important topics such as attitudes and perceptions of AI, its educational uses, ethical issues, performance enhancements, data-driven analytics, and creative solutions. When taken as a whole, this gives a thorough grasp of the state of the field and insightful information for educators, researchers, and policymakers who want to use AI in education responsibly and efficiently, as seen in Table 2.

Cluster 3 focuses on how AI affects students and how it may be used to improve learning models and assess performance. Keywords such as “students”, “model”, “deep learning”, “impact”, and “performance” are indicative of studies that measure how well AI improves student results. Research in this area focuses on creating deep learning models to evaluate educational data and enhance the learning experience. The assessment of AI tools’ effects on learning outcomes, student engagement, and general academic achievement is referred to as “impact”. This cluster demonstrates how AI may improve student-centered learning through performance evaluations and sophisticated predictive models.

Cluster 4 highlights the implications of generative AI technologies, such as ChatGPT, for higher education. “Ethics”, “academic integrity”, and “higher education” are among the keywords that indicate growing worries regarding the ethical usage of AI and its effect on academic honesty. Talks about striking a balance between the advantages of AI – such as automating learning procedures and offering immediate support – and its drawbacks, like plagiarism and abuse, are reflected in this cluster. “ChatGPT’s” existence indicates the growing impact of massive language models in educational contexts, igniting discussions on moral principles, rules, and responsibility. The significance of tackling ethical issues while guaranteeing the responsible application of generative AI in education is generally highlighted by this cluster.

Cluster 5 focuses on the technology infrastructure that enables AI in education. Big data, learning analytics, digital transformation, and models are some of the keywords that highlight AI’s capacity to evaluate enormous educational data sets in order to guide decision-making and enhance learning procedures. In order to better analyze student behavior, tailor learning experiences, and improve institutional performance, research in this cluster focuses on using AI-driven analytics. AI’s wider role in updating educational systems, encouraging innovation, and moving toward data-driven, technologically enhanced learning environments is signaled by the term “digital transformation”.

Cluster 6 focuses on the adoption and innovative applications of AI. Keywords like ‘artificial-intelligence,’ ‘acceptance,’ ‘chatbot,’ and ‘innovation’ highlight studies exploring the acceptance and usability of AI tools, such as chatbots, in education. This cluster addresses factors influencing educators’ and students’ willingness to adopt AI technologies, including ease of use, perceived benefits, and institutional support. The emphasis on ‘innovation’ reflects AI’s capacity to introduce novel teaching and learning solutions, transforming traditional educational practices.

Table 2. Co-word analysis of AI in education

Cluster no and color	Cluster label	Number of keywords	Representative keywords
1 (Red)	AI perceptions, teaching, and learning processes	14	‘AI,’ ‘technology,’ ‘perceptions,’ ‘knowledge,’ ‘attitudes,’ ‘teaching,’ ‘learning,’ ‘self-efficacy’
2 (Green)	AI, machine learning, and pedagogical applications	14	‘artificial intelligence,’ ‘education,’ ‘machine learning,’ ‘artificial intelligence (AI),’ ‘medical education,’ ‘AI literacy’ ‘pedagogy,’ ‘children’
3 (Blue)	Students, models, and performance outcomes	10	‘students,’ ‘model,’ ‘deep learning,’ ‘impact,’ ‘performance’
4 (Yellow)	Generative AI, ethics, and academic integrity	8	‘generative AI,’ ‘higher education,’ ‘ChatGPT,’ ‘ethics,’ ‘academic integrity’
5 (Purple)	Big data, learning analytics, and digital transformation	7	‘big data,’ ‘learning analytics,’ ‘digital transformation,’ ‘models’
6 (Turquoise)	Innovation and AI acceptance	6	‘artificial-intelligence,’ ‘acceptance,’ ‘chatbot,’ ‘innovation’

3.3. Discussions

The bibliometric analysis of AI in education reveals critical theoretical and practical implications. Theoretically, by highlighting important themes, frameworks, and research clusters, it improves our comprehension of AI’s revolutionary role in education. This study illustrates how AI applications – from learning analytics to generative AI – reshape conventional practices and educational paradigms [48]. Deeper understanding of AI’s impact on learning theories and institutional practices is fostered by the research’s analysis of co-citation and keyword occurrences, which highlights new ideas like adaptive learning models, ethical AI governance, and AI-driven pedagogical strategies [49]. In line with constructivist theories of personalized learning, for instance, the incorporation of AI into education highlights the transition from teacher-centered to learner-centered approaches [50]. Furthermore, the concentration of research on ethical issues highlights the necessity of strong frameworks to direct the integration of AI in education, guaranteeing equity, openness, and inclusivity [51].

This analysis has important practical effects on educators, legislators, and technologists, among other stakeholders. AI-powered resources for teachers, like chatbots, virtual assistants, and adaptive learning platforms, improve productivity and allow for individualized instruction based on each student’s needs [38].

By addressing issues like big class sizes, scarce resources, and a range of learner abilities, these technologies increase educational accessibility and equity [52]. The study gives policymakers a data-driven basis on which to build regulations that encourage the responsible adoption of AI, reduce risks like algorithmic bias and data privacy issues, and close the digital divide in communities with limited resources [4]. The findings of this study can be used by policymakers to create frameworks for regulations that guarantee the moral application of AI while encouraging creativity [53].

Technologists and developers gain practical guidance from this study on addressing gaps and user needs. According to Aggarwal [54], the emphasis on user acceptance and innovation underscores the significance of creating AI tools that are scalable, context-specific, and easy to use in a variety of educational contexts. The focus on ethics and governance also recommends incorporating accountability and bias detection mechanisms into AI systems to improve dependability and trust [55]. This analysis provides recommendations for future research directions, such as investigating the long-term effects of AI on student outcomes, tackling issues of digital equity, and creating interdisciplinary frameworks that combine AI with cutting-edge educational technologies [56].

The findings strongly suggest that educators, technologists, and legislators should work together to optimize AI's potential while ensuring that development aligns with educational values and societal demands. One noteworthy unexpected conclusion was that, despite AI's extensive use across domains, cross-disciplinary research was underrepresented. This finding aligns with earlier observations that the absence of educator involvement in AI design limits the integration of diverse disciplinary perspectives [29], [31]. Similarly, Allen and Kendeou [50] emphasize the need for interdisciplinary frameworks that merge technological innovation with educational theory, underscoring a vacuum in integrative educational models that warrants further investigation.

4. CONCLUSION

The bibliometric study of AI in education has shed light on the opportunities, problems, and current status of the field. This study emphasizes AI's revolutionary role in transforming education through personalized learning, adaptive technologies, and creative teaching strategies by looking at important publications, co-citation networks, and keyword trends. The analysis emphasizes how crucial it is to address ethical issues like algorithmic bias, data privacy, and equitable access in order to guarantee the responsible and inclusive application of AI in educational settings.

The clustering of research topics around generative AI, ethical governance, and educational applications shows how technological developments and their real-world effects on teachers, students, and legislators interact dynamically. Although AI has a lot to offer in terms of improving student engagement, teaching effectiveness, and institutional decision-making, issues with digital equity and adoption resistance are still important topics for further research. Aligned with sustainable development goal 4 (quality education), this study underscores the potential of AI to advance equitable and inclusive educational opportunities for all learners, particularly those in marginalized communities. By addressing systemic barriers and leveraging AI-driven innovations, stakeholders can create transformative solutions that close learning gaps and enhance educational outcomes globally. This analysis ultimately provides a basis for promoting AI-driven innovation and guaranteeing long-term advancement in the field of education, ensuring alignment with broader sustainability objectives.

While this study provides a thorough bibliometric mapping of AI in education, several limitations should be acknowledged explicitly. First, the scope was restricted to English-language publications, WoS-indexed articles, and the Social Sciences Citation Index (SSCI), which may have left out important contributions from research with a regional focus or non-English speaking participants. Second, relying just on co-citation and co-occurrence analysis provides a broad perspective, but it may ignore intricate empirical or methodological details from other studies. Qualitative content analysis should be incorporated into future studies to enhance the thematic comprehension. Additionally, longitudinal research could track the development of particular subthemes including multidisciplinary applications in actual classroom settings, ethical AI use, and AI literacy. Furthermore, cross-database comparisons (e.g., Scopus, Dimensions) and the incorporation of grey literature should be advantageous for future studies in order to increase the scope and depth of AI educational research visibility and impact.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Fatin Syamilah Che Yob	✓		✓			✓			✓		✓		✓	
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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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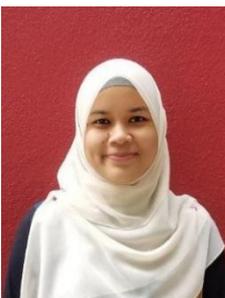
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