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Artificial Intelligence in Education: A Bibliometric Analysis of Research Trends and Future Directions

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ABSTRACT

This study aims to explore the research trends, intellectual structure, and emerging themes in Artificial Intelligence (AI) applications in education through a bibliometric approach. As AI adoption in education accelerates, understanding these patterns is essential for guiding future research and practical implementation. To achieve this, a bibliometric analysis was conducted on 3,441 documents published between 2010 and 2025, retrieved from major academic databases. Using VOSviewer, the study applied network, density, and overlay visualization to identify co-authorship networks, keyword co-occurrence, and thematic clusters. The findings reveal that machine learning and deep learning dominate the field, forming the core of research themes, while clusters highlight topics such as personalized learning, decision-making, ethical issues, and emerging technologies like generative AI. Early studies focused on foundational methods such as expert systems and fuzzy logic, whereas recent research emphasizes human-centered concerns, including privacy, fairness, and responsible AI use. The integration of AI with big data, IoT, and advanced analytics for educational management also shows significant growth. These insights provide valuable guidance for educators, policymakers, and researchers in promoting the ethical, inclusive, and effective application of AI in education.

1. Introduction

The integration of Artificial Intelligence (AI) in education is poised to experience significant growth in the coming years. According to a HolonIQ report (2020), global spending on AI in education was projected

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to reach $6 billion by 2025, reflecting rapid adoption by educational institutions. Recent market analyses indicated compound annual growth rates (CAGR) of 36 – 43% for AI-driven EDTech solutions between 2019 and 2027 (HolonIQ, 2020; MarketsandMarkets, 2020). This growth is driven by the increasing demand for personalized and adaptive learning experiences, as well as the need to improve educational outcomes (Strielkowski et al., 2025; Sumathy & Navamani, 2024).

The application of AI in education has been the subject of research for over three decades (Baillifard et al., 2025; Ekin et al., 2025). Today, AI is transforming the education sector in numerous ways. It is helping identify gaps in teaching and learning, increasing the proficiency of education, and driving efficiency, personalization, and the streamlining of administrative tasks (Singh et al., 2025; Wongmahesak et al., 2025). By combining the strengths of machines and teachers, better student outcomes can be achieved (Alwakid et al., 2025). AI can also help create customized learning plans for each student, based on their interests, skills, and learning style (Dei, 2025; Strielkowski et al., 2025).

One of the most significant advantages of AI is personalized learning. AI-powered systems analyze student performance, identify learning gaps, and deliver tailored recommendations (Vadivel et al., 2025). This improves academic outcomes and fosters engagement and motivation. Moreover, AI supports administrative automation, reducing teachers' workload and allowing them to focus on higher-value educational activities (Bhardwaj & Kumar, 2025; Molina & Medina, 2025; Xu, 2025). AI also promotes inclusivity by providing accessibility solutions such as real-time translation, subtitles, and adaptive content for students with disabilities (Ahmed et al., 2025; Farhah et al., 2025). Virtual learning environments further enhance flexibility and interactivity, offering immersive experiences with real-time feedback and assessments (Velmurugan et al., 2026; Wang & Huang, 2025). Beyond classrooms, AI-powered chatbots and virtual tutors provide on-demand academic support (Kavitha et al., 2025), while teacher development benefits from ai-driven feedback and professional resources (Singh et al., 2025; Yadav, 2025).

Despite these benefits, several challenges remain. Traditional teaching methods often fail to meet the diverse needs of learners, but the implementation of AI-driven solutions is not yet universal. Barriers such as limited resources, lack of technical expertise, and high deployment costs hinder widespread adoption. Additionally, the use of generative AI tools like ChatGPT introduces risks, including misinformation, over-dependence, academic integrity concerns, and data privacy issues. If AI systems are trained on biased data, their decisions can perpetuate inequities rather than eliminate them. These issues highlight the need for ethical frameworks, clear guidelines, and institutional readiness to ensure responsible AI integration in education.

The future of education is increasingly shaped by AI, with expectations of continued innovation in accessibility, personalization, and immersive learning environments (Fauziddin et al., 2025; Luckin, 2025). As AI technologies advance, educational institutions and companies are expected to increasingly adopt AI-powered solutions, making learning more accessible, personalized, and effective. Despite the growing interest in AI applications in education, there is limited understanding of the overall research landscape, thematic evolution, and emerging trends. To address this gap, this study employs a bibliometric approach to analyze existing literature and answer the following research questions:

RQ1: How can tools such as machine learning and deep learning enhance personalized learning and improve student performance?

RQ2: What challenges and risks arise from the use of AI tools like ChatGPT in education, and how can these be managed to ensure fairness and safety?

RQ3: How can AI technologies support educational institutions in making informed and effective decisions?

2. Literature Review

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2.1 *Personalized Learning through AI*

The integration of AI in education has revolutionized personalized learning, offering adaptive solutions that address individual learner needs. AI-powered systems such as intelligent tutoring platforms and adaptive learning technologies have demonstrated the ability to improve student engagement, motivation, and academic performance (Karmakar & Das, 2024). Large-scale implementations involving thousands of students report significant improvements in learning outcomes when AI tools are incorporated into instructional design (Nyamwange, 2025; Yaseen et al., 2025). Furthermore, AI technologies enable customized learning paths by analyzing learner strengths and weaknesses, thereby creating more inclusive and effective educational experiences (Cota-Rivera et al., 2024). These personalized approaches not only address diverse learning styles but also help in narrowing educational gaps.

2.2 *Ethical Challenges and Risks of AI in Education*

Despite its benefits, AI integration in education raises important ethical and governance challenges. Generative AI tools, such as ChatGPT, have sparked debates over academic integrity, as students increasingly rely on AI-generated content, raising concerns about plagiarism and the authenticity of academic work (Medina et al., 2024; Perkins, 2023). Recent studies show that nearly 79% of students report using AI tools for academic purposes (Gonsalves, 2025) and surveys indicate that 90% of students are aware of ChatGPT, with 89% admitting to using it for assignments, highlighting the growing prevalence of AI-assisted academic task (Austa & Caukin, 2024). These findings underscore the urgency for institutions to address AI-related ethical conduct through clear policies, academic integrity frameworks, and appropriate assessment strategies to mitigate potential risks of plagiarism and misuse.

Beyond academic integrity, AI technologies raise issues of algorithmic bias, privacy and fairness. If models are trained on biased datasets, they may perpetuate inequities in education (Hanna et al., 2025). Furthermore, the vast amounts of personal data required by AI systems increase the risk of data breaches and misuse (Murdoch, 2021). The lack of clear policies and guidelines on AI usage in education further complicates these ethical challenges. Many institutions are still grappling with establishing frameworks that ensure responsible and equitable AI integration (Chan et al., 2025).

2.3 *AI in Educational Decision-Making*

Beyond personalized learning, AI has the potential to enhance decision-making processes within educational institutions. AI-driven analytics can assist in identifying at-risk students, optimizing resource allocation, and improving administrative efficiency (Babu et al., 2025; Funda & Francke, 2024). For example, AI tools are being used to streamline tasks such as lesson planning, grading, and data collection, thereby reducing the administrative burden on teachers and allowing them to focus more on instruction (Olafare, 2024; Zhang, 2024). However, the effectiveness of AI in decision-making is contingent upon the quality of data and the transparency of algorithms (Chaudhary, 2024; Rinaldi et al., 2023). Concerns about algorithmic opacity and the potential for biased decision-making underscore the need for robust oversight and ethical considerations in deploying AI for institutional purposes.

3. **Methodology**

This study employed a bibliometric analysis to explore the research trends, influential works, and thematic evolution of Artificial Intelligence (AI) in education. The analysis was conducted using a dataset comprising 3,441 documents published between 2010 and 2025. These documents were retrieved from indexed academic databases and included both journal articles (n – 2,100) and conference papers (n = 1,341). The selection was limited to publications written in English to maintain consistency in analysis and interpretation.

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To ensure relevance, inclusion criteria focused on studies explicitly addressing the application of AI in educational contexts, such as personalized learning, educational decision-making, and ethical implications. Exclusion criteria were applied to remove duplicates, off-topic papers, and non-scholarly content. After refining the dataset, the final sample accounted for a total of 88.755 citations, resulting in an average of 25.79 citations per document, indicating a high level of scholarly interest in this field.

The timespan of analysis was deliberately set from 2010 to 2025 to capture both foundational developments and recent innovations in AI-driven educational technology. Bibliometric data was analyzed using VOSviewer, a widely recognized tool for visualizing co-authorship, keyword co-occurrence, and citation networks.

Table 1. Methodology

Description	Result
Initial Research	
Life Span	2010 – 2025
Number of Documents	3441
Applying Exclusion Criteria	
Timespan	2010 - 2025
Documents Type	- Article - Conference Paper
Language	English
Article	2100
Proceeding	1341
Total Number of Citations	88755
Average Citations per Documents	25.79

4. **Findings**

4.1 Network Visualization

The network visualization offers a comprehensive view of the current research landscape on Artificial Intelligence (AI) in education. This visual map displays clusters of frequently co-occurring terms extracted from academic publications, with each color representing a distinct thematic group. The size of each note reflects the frequency of the term, while the proximity and linkage between nodes indicate their degree of co-occurrence. Based on the visualization, several key research areas and thematic trends emerge.

At the core of the network are the terms “machine learning” and “deep learning”, which appear as the most prominent and central elements. Their central positioning suggests that the majority of AI-related research in education revolves around these technologies. These tools are widely used to create intelligent learning environments, develop adaptive learning systems, and analyze large datasets to enhance educational outcomes. Surrounding this central theme are multiple thematic clusters. The green cluster emphasizes decision-making, innovation, technology adoption, ethics, and higher education. This indicates a strong focus on how AI impacts institutional and classroom-level decision-making. AI tools in this domain support data-driven decisions, outcome predictions, and strategy recommendations for educators and administrators. Ethical issues such as fairness, privacy, and bias are also prominent in this cluster, reflecting a growing concern about the responsible and transparent use of AI in education.

The yellow cluster highlights the application of AI to enhance student engagement and improve learning outcomes. Keywords such as students, teaching, language model, and generative AI point to the increasing influence of tools like ChatGPT and other large language models. These technologies support personalized learning pathways, generate feedback, and provide on-demand tutoring, demonstrating a shift toward student-centered AI applications tailored to individual needs. The red cluster centers on technical topics

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such as classification, feature extraction, ensemble learning, and neural networks. These elements represent the computational backbone of AI applications in education. Researchers in this area are developing and refining algorithms for analyzing student performance, predicting learning difficulties, and enhancing adaptive systems. The inclusion of terms like support vector machines and random forests suggests that both traditional and modern machine learning methods are actively used.

The purple cluster focuses on the application of AI in domain-specific education, particularly in healthcare, diagnosis, and clinical research. Terms such as diagnosis, clinical research, and convolutional neural networks suggest that AI tools are also widely adopted for medical and professional education, where diagnostic modelling and training simulations are common. The blue cluster reveals an intersection between AI and broader technological trends. Topics such as Internet of Things (IoT), big data, e-commerce, and social networking indicate the integration of AI with real-time data collection and analysis platforms. AI is being used to monitor learner behavior, personalize digital learning environments, and enhance informal education through social media platforms. Additionally, there is significant representation of management-related terms such as knowledge management, management science, and decision theory, emphasizing AI's role in educational administration. These terms suggest that AI is also being deployed to support institutional management, streamline operational processes, and forecast trends in student enrolment and academic performance.

Overall, the network visualization demonstrates that AI in education is a multidimensional and rapidly evolving field. The research themes are highly interconnected, showing overlap between technological developments, ethical concerns, pedagogical practices, and institutional innovation. For example, personalized learning systems often combine machine learning with ethical safeguards, while administrative tools integrate decision theory with data analytics.

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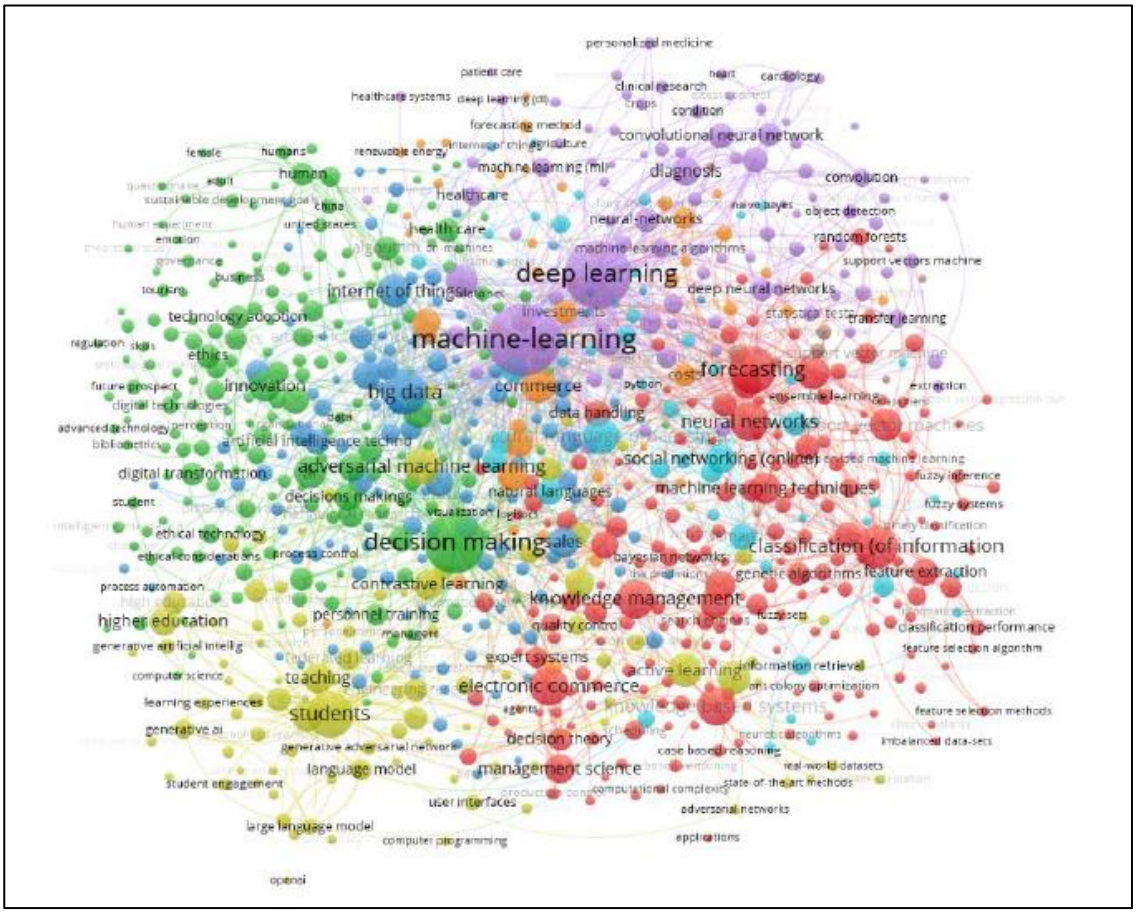

Figure 1. Network Visualization

4.2 Density Visualization

The density visualization map illustrates the temporal evolution of key research topics in the application of Artificial Intelligence (AI) in education. Each term on the map represents a research keyword or concept, with color gradients indicating the average publication year in which these terms appeared most frequently. The color scheme ranges from blue and purple tones (older research focus, ~2014) to yellow tones (recent focus, ~2022), allowing a chronological understanding of thematic development within the field.

At the center of the map, the most prominent and frequently studied terms include machine learning, deep learning, decision-making, and natural language processing. These concepts have consistently served as the foundation for AI in education. Machine learning is widely adopted for its ability to improve learning systems through data-driven personalization, while deep learning is an advanced subset of machine learning, has become increasingly prevalent for tasks such as automated grading, learning analytics, and performance prediction. In earlier years, depicted in blue and purple, research predominantly focused on foundational AI techniques such as classification, expert systems, fuzzy logic, and knowledge management. These topics reveal an initial emphasis on developing basic AI-based systems to support data organization, content recommendation, and instructional decision-making. For example, expert systems were designed to provide tutoring advice or aid teachers in pedagogical decisions, while fuzzy logic was explored for its ability to handle uncertainty in student learning assessments.

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Between 2017 and 2020, as significant shift in research focus is observed, marked in green. This period saw growing interest in more sophisticated topics such as neural networks, forecasting, natural language processing, and online social networking. These advances reflect a move toward understanding learner behavior through AI-driven platforms, supporting natural language interactions, and analyzing online learning environments. Tools such as chatbots and automated writing assistants emerged during this phase, enhancing language learning and feedback generation. In the most recent (highlighted in yellow), the emergence of topics like generative AI, large language models, federated learning, technology adoption, ethics, and student engagement indicate the field's growing maturity. Generative AI technologies such as ChatGPT are now being used to create educational content, including quizzes, instructional texts, and writing prompts. While these tools offer opportunities for personalized support and instructional efficiency, they also raise critical concerns regarding academic integrity, plagiarism, and the evolving role of the teacher.

The increasing attention to federated learning shows a parallel emphasis on data privacy, where AI systems are trained without transferring sensitive student data, thereby supporting ethical compliance. In tandem, keywords related to fairness, trust, and human-centered AI suggest that contemporary research is placing greater improvements on responsible AI implementation in education. Additionally, recurring terms such as management science, automation, and decision theory indicate that AI is being utilized not only for instructional enhancement but also for administrative and institutional planning. For instance, AI models are now being employed to predict student dropout risks, recommend interventions, and optimize school resource planning.

In summary, the density visualization demonstrates how AI research in education has evolved over the past decade, from foundational technologies toward sophisticated, ethical, and human-centered applications. The shift from technology-centric to people-centric research highlights the field's progression toward designing AI tools that are not only innovative but also aligned with student's needs, values, and rights. As AI continues to evolve, future research will likely focus on ensuring educational AI is equitable, transparent, and supportive of long-term learning outcomes.

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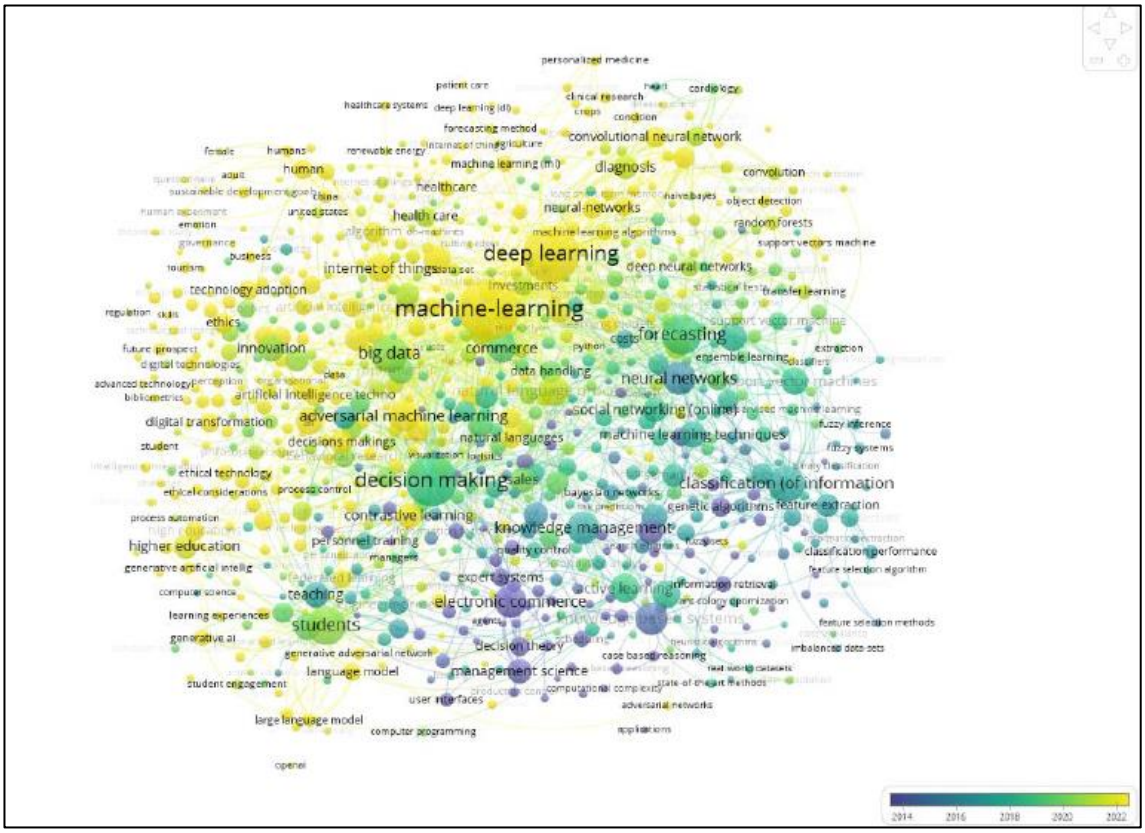

Figure 2. Density Visualization

4.3 Overlay Visualization

The overlay visualization map provides a temporal dimension to the bibliometric landscape of Artificial Intelligence (AI) in education. It highlights how research themes have evolved over time, based on the average publication year associated with each keyword. In this map, brighter colors such as yellow represent more recent research activity, while darker shades such as blue and green reflect earlier periods of scholarly focus.

At the core of the visualization, keywords such as machine learning, deep learning, students, and higher education appear prominently in bright hues, indicating sustained and growing interest in these areas. These terms suggest a strong emphasis on applying AI technologies to enhance personalized learning experiences, develop intelligent tutoring systems, automate assessments, and support student-centred pedagogical models. The presence of advanced techniques such as natural language processing and neural networks further indicates the application of sophisticated AI methods to address educational challenges.

Terms such as decision-making, forecasting, and management are also highly visible, reflecting the growing role of AI in educational administration and strategic planning. AI-driven decision support systems are increasingly being explored to forecast student performance, optimize resource allocation, and enhance institutional operations.

Additionally, the visualization underscores a notable shift toward learner-centric and ethical considerations. Keywords such as teaching, curricula, students, federated learning, ethics, and technology adoption suggest that researchers are increasingly attentive to issues of fairness, data privacy, and

responsible AI implementation. Emerging themes like generative AI, blockchain, contrastive learning, and active learning reflect the integration of cutting-edge technologies in educational contexts.

Importantly, terms associated with new trends such as ChatGPT, large language models, and blockchain are positioned in the brighter, more recent regions of the overlay. These developments signal a transition in AI research from purely technological innovation to applications that directly support human learning processes, while simultaneously addressing ethical, social, and governance challenges.

In summary, the overlay visualization illustrates a dynamic and maturing research field. While foundational AI methods remain central, there is a clear trajectory toward more holistic, ethical, and learner-centred applications. This evolution highlights the need for future research to not only explore technical advancements, but also to critically examine how these tools can be deployed safely, fairly, and effectively within educational systems.

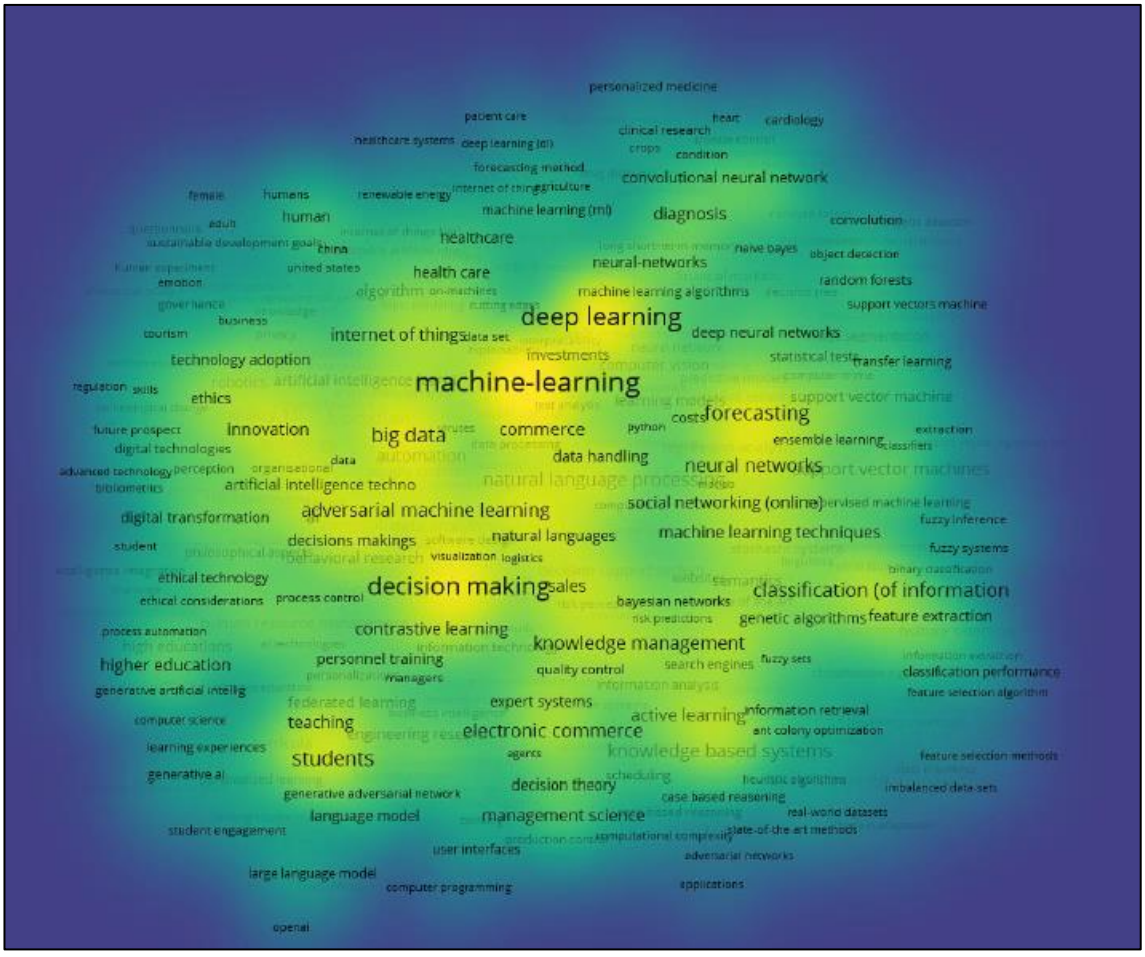

Figure 3. Overlay Visualization

5. Findings

The findings presented above offer a comprehensive mapping of the research landscape on Artificial Intelligence (AI) in education. The network visualization reveals several prominent clusters, indicating thematic concentrations and interdisciplinary overlaps within the field. Central to the network are high-

frequency terms such as machine learning and deep learning, underscoring their pivotal role in advancing educational technologies. These methodologies are fundamental to the development of adaptive learning systems, intelligent tutoring, automated assessments, and predictive analytics demonstrating their foundational presence in the literature. Surrounding these core terms, multiple clusters illustrate specialized but interconnected domains. The green cluster, for example, highlight's themes related to decision-making, technology adoption, innovation, ethics, and higher education. This suggests that researchers are not only focused on the technical development of AI, but also actively exploring its implementation, ethical considerations, and systematic impact. Notably, concerns such as data privacy, algorithms bias, and transparency are increasingly significant in educational contexts, where vulnerable populations such as students are directly affected by AI deployment. Research attention on technology adoption further emphasizes the challenge institutions face in integrating AI within traditional educational models. The yellow cluster places emphasis on learner-centric approaches, comprising terms such as students, teaching, language model, and generative AI. This reflects a paradigmatic shift from teacher or system-centric tools to more personalized, student-driven applications. Generative AI tools like ChatGPT are being increasingly explored for their potential to facilitate writing, dialogue, and interactive learning, signifying a growing interest in natural language generation for educational use. In contrast, the red cluster highlights the technical foundations of AI, with terms such as classification, feature extraction, ensemble learning, and neural networks. This indicates ongoing efforts to enhance model performance for educational analytics. Despite the rise of deep learning, traditional machine learning techniques such as support vector machines and random forests remain relevant and widely applied. The purple cluster extends the scope of research into domain-specific applications, particularly in healthcare, clinical education, and diagnostic systems. This demonstrates a convergence between educational AI and professional training, particularly in disciplines requiring high cognitive and procedural competencies. Meanwhile, the blue cluster integrates AI into broader technological ecosystems, including IoT, big data, and e-commerce. These links signify the embedding of Ai-driven educational environments into smart systems that enable real-time data collection and analysis. In addition, the presence of administrative and institutional keywords such as knowledge management and decision theory reflects AI's expanding role in educational governance. Institutions are leveraging AI to optimize operational processes, improve decision-making, and support strategic planning. These developments affirm that the influence of AI in education extends beyond pedagogy into institutional and administrative spheres. Taken together, the network visualization illustrates that AI in education is a dynamic and multifaceted research domain, characterized by strong interconnections among technical innovation, ethical considerations, pedagogical design, and institutional transformation. These thematic clusters are not isolated but are part of an integrated research ecosystem, reinforcing the need for collaborative input from educators, data scientists, policymakers, and ethicists to ensure holistic and impactful AI applications in education.

The density visualization further elucidates the temporal evolution of research priorities in the AI-education nexus from 2014 to 2022. The color gradient from dark purple (older terms) to bright yellow (more recent terms), captures the progression of the field from foundational concepts to more sophisticated and human-centered applications. In the early period (2014 – 2017), terms such as classification, expert systems, fuzzy logic, and knowledge management were dominant, reflecting initial attempts to apply basic AI techniques to structure and interpret educational data. Expert systems, for instance, were designed to simulate domain-specific instructional guidance, while fuzzy logic enabled the handling of uncertain or imprecise data, common challenges in assessing learning outcomes. Between 2017 and 2020, the field underwent a phase of technological expansion, marked by increased usage of terms like neural networks, forecasting, natural language, and social networking. This shift indicated a growing interest in leveraging AI for broader and more complex educational tasks. Natural Language Processing (NLP) became a key enabler in this period, supporting tools such as automated essay scoring, conversational agents, and intelligent language tutors. From 2020 onwards, the density map highlights emerging interests in generative AI, federated learning, ethics, technology adoption, and student engagement. Generative AI represents a significant leap in functionality, allowing for dynamic content creation, interactive support, and personalized learning interventions. Federated learning, by contrast, addresses increasing concerns around

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data privacy by enabling decentralized model training without requiring data centralization, an especially important development for educational institutions managing sensitive student information. This period also marks a broader transition from tool-centric to human-centric concerns. The increasing frequency of terms such as ethics, fairness, privacy, and student engagement reflects a growing emphasis on responsible AI use. These themes align with global efforts to promote trustworthy AI that upholds equity, inclusiveness, and transparency in educational settings. A renewed interest in the student-teacher dynamic is also apparent. Terms like learning experiences, personal training, teaching, and curricula highlight an evolving focus on the practical pedagogical, and emotional aspects of AI integration in classroom. Simultaneously, administrative terms such as management science and automation underscore AI's emerging role in institutional governance, optimizing resource allocation, forecasting student performance, and enabling data-informed decision-making. Collectively, the density visualization reveals a maturing field transitioning from basic technical innovation to ethically grounded and pedagogically meaningful AI implementations. The trajectory reflects increasing convergence between technological advancement and the real-world needs of educators and learners.

The overlay visualization offers an additional perspective by identifying dominant and emerging research trends. Prominent and brightly colored terms such as machine learning, deep learning, and students indicate central areas of focus. These technologies are applied across various domains, including smart tutoring, automated grading, and personalized instruction. Advanced techniques such as natural language processing and neural networks further support instructional design and adaptive learning systems. Decision-making is another critical application area. Keywords such as forecasting and management suggest that AI is aiding school leaders in improving operational efficiency and enhancing educational outcomes through data-informed strategies. Ethical considerations are increasingly salient, as evidenced by keywords like ethics, governance, and privacy. The adoption of federated learning reflects efforts to uphold data sovereignty and protect student privacy. Emerging technologies such as generative AI and blockchain are also gaining traction. While generative AI can assist students with writing and content creation, it raises concerns regarding misuse, plagiarism, and academic integrity. Meanwhile, blockchain technology presents a novel approach to secure and transparent record-keeping in educational institutions. In summary, the overlay visualization confirms that AI in education is both a well-established and rapidly evolving research domain. The findings emphasize the importance of balancing innovation with ethical responsibility. As AI tools become increasingly powerful and pervasive, future research must ensure that these technologies are implemented in ways that are fair, inclusive, secure, and beneficial for all stakeholders in the educational ecosystem.

6. Conclusions

This bibliometric study highlights the transformative role of Artificial Intelligence (AI) in the education sector, particularly in enhancing learning, teaching, and institutional management. Central to these advancements are machine learning and deep learning, which drive a wide range of educational technologies, including adaptive learning systems, intelligent tutoring platforms, automated assessment tools, and predictive analytics. These technologies form the foundation of contemporary innovations in educational AI.

The analysis reveals diverse thematic areas that reflect the broad and interdisciplinary impact of AI in education. Emerging themes such as ethics, decision-making, and technology adoption underscore the need to address challenges related to data privacy, algorithmic fairness, and institutional preparedness for AI integration. Learner-centric innovations such as generative AI and tools like ChatGPT are increasingly enabling personalized, interactive learning experiences tailored to individual student needs. Concurrently, technical developments in neural networks, data classification, and algorithmic performance continue to refine the reliability and scalability of AI systems.

Moreover, the convergence of AI with other domains such as healthcare, professional training, the Internet of Things (IoT), and big data demonstrates the expanding influence of AI on real-time, data-rich

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educational environments. Institutions are also adopting AI for administrative decision-making, strategic planning, and resource optimization, signaling a shift in its role beyond pedagogy.

Over time, the research trajectory has shifted from the development of basic AI tools toward more advanced, human-centered applications. The increasing focus on ethical use, privacy protection, and fairness highlights a growing recognition of the societal responsibilities accompanying AI deployment in education. Emerging technologies such as federated learning, blockchain, and generative AI offer promising opportunities but also raise important considerations regarding misuse, transparency, and accountability.

In summary, the findings suggest that AI is poised to make education more intelligent, adaptive, and inclusive. However, future research and practice must ensure that these technologies are implemented in ways that are ethical, equitable, and aligned with the needs of learners, educators, and institutions.

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Conflict of interest statement

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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