

Digital and Intelligence Education in Medicine: A Bibliometric and Visualization Analysis Using CiteSpace and VOSviewer

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Abstract This study provides a comprehensive bibliometric analysis of the development and current status of digital and intelligence education in medicine over the past decade, with a focus on the integration of digital technologies in professional training. Using bibliometric methods, we analyzed publications between 2015 and 2024, identifying key research themes, emerging technologies, and the contributions of leading institutions and countries. The results show a steady increase in publications, particularly from 2022 to 2024, reflecting a growing global interest in digital and intelligence education in medicine, driven by technological advancements and the COVID-19 pandemic. Key themes identified include artificial intelligence-powered personalization, virtual reality in training, deep learning for medical imaging, and the use of language models for interactive teaching. However, challenges such as disparities in global research capacity, data privacy concerns, ethical issues, and resource inequality are also highlighted. Notably, the integration of intelligent digital platforms in education has been found to be transformative, particularly in clinical training, adaptive learning, and medical diagnostics simulation. The study concludes that while digital and intelligent technologies have the potential to revolutionize medical education, addressing ethical, technical, and resource-based challenges is crucial for equitable global implementation. Future research should focus on fostering international

collaboration, developing standardized frameworks, and creating inclusive, low-cost digital tools to democratize medical education, thereby improving healthcare outcomes worldwide.

Keywords digital technologies, artificial intelligence, medical education, bibliometrics, CiteSpace, New Medicine

1 Introduction

The rapid advancement of digital and intelligent technologies has profoundly impacted various sectors, including education. In particular, medical education is undergoing a significant transformation, driven by these technological innovations (Aydinlar et al., 2024). Digital tools, such as online learning platforms, virtual simulations, and artificial intelligence (AI)-powered systems, are reshaping traditional educational paradigms, providing unprecedented opportunities for personalized learning, efficient delivery of content, and improved assessment methods (Kleib et al., 2024; McIntosh et al., 2022). AI, in particular, has opened new innovative approach for enhancing student learning experiences, automating teaching evaluations, and accurately assessing learners' behavior, skills, and knowledge acquisition (Chan & Zary, 2019). These advancements enable medical educators to tailor educational content and assessments to meet the diverse needs of students, fostering more efficient and

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effective learning environments (Rabie, 2023). In China, the concept of “New Medicine” has emerged as part of a national strategy to modernize medical education, with a particular emphasis on the integration of digital and intelligent technologies (Ma et al., 2024). This initiative aims to cultivate medical professionals equipped with the necessary skills to navigate the rapidly evolving healthcare landscape.

While digital and intelligent technologies possess transformative potential for medical education, their full integration and effective application continue to face significant challenges. These challenges are observed globally, while there is growing enthusiasm for these technologies, particularly AI, their successful implementation in medical curricula has been inconsistent (Ba et al., 2024). One of the primary obstacles is the resistance to change from traditional teaching methods (Zhao et al., 2023). Many educators and institutions are still reliant on conventional, instructor-led teaching approaches, which may hinder the adoption of more innovative, technology-driven learning models. Furthermore, the readiness of medical educators to incorporate digital tools into their pedagogical practices varies significantly, with some expressing concerns about the efficacy and reliability of AI-driven assessments and learning solutions (McGee et al., 2024).

Despite the growing body of literature on the integration of digital technologies in medical education (Boscardin et al., 2024), limited research has focused on the systematic analysis of the trends, key themes, and emerging frontiers in the field, especially within the context of “New Medicine.” Existing studies often focus on the application of individual technologies or specific case studies, but a comprehensive, field-wide analysis is lacking (Civaner et al., 2022; Masters, 2019). Moreover, while many studies have highlighted the benefits of digital and intelligence education in medicine, there is a notable gap in understanding the broader implications of these technologies, including ethical concerns such as data privacy, algorithmic fairness, and transparency in AI-driven assessments (Kashyap et al., 2024; Weidener & Fischer, 2023). Given these gaps, there is a need for an in-depth investigation into the current state of medical education in the digital age. Specifically, it is essential to identify the prevailing trends, core research areas, and emerging frontiers in the use of digital and intelligent technologies in medical curricula. A thorough understanding of these issues will not only inform the design of future medical education programs but also contribute to the ethical and practical integration of these technologies into the healthcare education system.

To address these gaps, this study aims to systematically analyze published literature on the integration of digital and intelligent technologies in

medical education. Using bibliometric methods such as CiteSpace and VOSviewer, the research will map key trends, emerging themes, and collaborative networks in the field of digital medical education. The study will provide insights to navigate the challenges of incorporating advanced technologies into medical curricula and driving innovation in medical education for the digital age.

2 Methods

2.1 | Data Source and Literature Search Strategy

For this study, Web of Science (WoS) was chosen as the primary database due to its comprehensive coverage of over 34,000 academic journals and its established reputation for bibliometric analysis (Birkle et al., 2020). Compared to other databases such as Scopus and PubMed, WoS provides the most comprehensive and reliable resource for academic research (Yeung, 2019). A literature search was conducted in the WoS Core Collection on January 1, 2025, using all available database versions. The search strategy, developed collaboratively by all authors in consultation with senior literature search experts, utilized the search terms outlined in Table 1. To ensure the quality and relevance of the data, only peer-reviewed journal articles written in English and published from the inception of the database to 2025 were included, while conference proceedings, book chapters, editorials, letters, and non-English articles were excluded. Complete records, including cited references, were extracted and saved in plain text format for subsequent analysis.

Table 1 Search strategy

Set	Search query
#1	(((TS = (digitization)) OR TS = (Artificial Intelligence)) OR TS = (big data)) OR TS = (digital intelligence) OR TS = (intelligentize) OR TS = (AI)
#2	TS = (medical education)
#3	#1 and #2

Notes. TS: topic; AI: artificial intelligence.

2.2 | Software for Bibliometric Analysis

The search results were subsequently analyzed using CiteSpace and VOSviewer. CiteSpace, a visual analysis software (Chen & Chen, 2005; Synnestevedt et al., 2005) was employed to analyze the publication volume, temporal trends, keyword frequency, and centrality

within the research field. This tool facilitated a systematic and intuitive exploration of the structure, patterns, and distribution of knowledge. By generating scientific knowledge maps, CiteSpace helped identify key research hotspots, track knowledge evolution, and assess the current state of the field. The complete records extracted from WoS included metadata such as the titles, authors, keywords, abstracts, journal names, publication years, and cited references. These elements were included to provide a comprehensive view of the research trends, authorship patterns, and the evolution of key topics in the field.

Additionally, VOSviewer (van Eck & Waltman, 2010), a software tool designed for document data processing, was used to analyze bibliometric aspects such as countries, institutions, authors, journals, and keywords. VOSviewer enabled the creation of co-occurrence knowledge graphs, which illustrated relationships between countries, institutions, journals, and documents.

This software enabled the construction of co-occurrence knowledge graphs, visually depicting the interconnections between different entities. In these graphs:

- Each node represented a unique entity (e.g., a country, institution, or keyword).
- The width of the connections between nodes indicated collaboration strength.
- Node size reflected the publication volume, with larger nodes representing more frequently occurring elements.

A key metric used in these analyses was total link strength, which refers to the overall strength of connections between nodes. In bibliometric networks, total link strength quantifies the number of shared co-occurrences or citations between two entities (such as authors or keywords). A higher total link strength indicates stronger relationships, which helps identify central topics and high-impact collaborations within the field.

3 Results

3.1 | Annual Publications

Figure 1 illustrates the publication trends over the past decade, with a total of 2,328 papers published on digital and intelligence education in medicine between 2014 and 2025. As the data were retrieved from a single database (WoS) using predefined inclusion criteria, no ineligible or duplicate records were identified during the selection process. The overall trend demonstrates a steady increase, with a significant surge from 2022 to 2024, peaking in 2024.

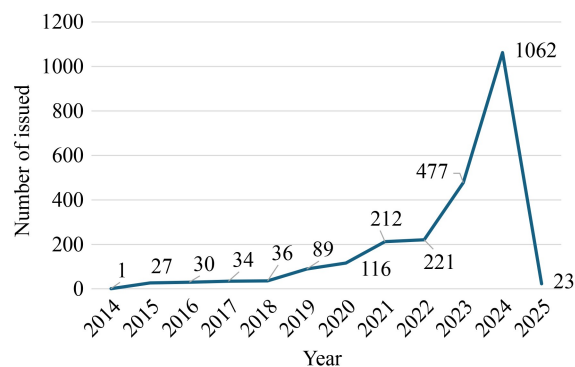


Figure 1 Chart of the number of years issued.

3.2 | Analysis by Country

A comprehensive national analysis from 2014 to 2025 (Tables 2–4) reveals contributions from 53 countries exploring the digital and intelligence education in medicine. The USA leads with 908 publications, establishing itself as the most active contributor in this field. Other top contributors include China (including the Chinese mainland, Hong Kong, Macao, and Taiwan), the United Kingdom, Germany, etc. Figure 2 highlights the prominent role of the USA in adopting

Table 2 Top 10 publications of countries

Rank	Document	Country
1	908	USA
2	307	China
3	221	UK
4	202	Germany
5	182	India
6	171	Canada
7	119	Australia
8	95	Italy
9	87	Saudi Arabia
10	83	Türkiye

Table 3 Top 10 citations of countries

Rank	Citation	Country
1	12,073	USA
2	3,902	UK
3	3,292	China
4	2,904	Canada
5	2,616	Germany
6	1,809	Singapore
7	1,467	India
8	1,234	Poland
9	1,202	Austria
10	1,102	Australia

Table 4 Top 10 centrality of countries

Rank	Total link strength	Country
1	581	USA
2	418	UK
3	249	Germany
4	227	Italy
5	218	Canada
6	213	Australia
7	211	Netherlands
8	173	China
9	166	Switzerland
10	151	Spain

digital and intelligence education in medicine, as well as its collaborative research efforts with other nations.

3.3 | Analysis by Institutions

Institutional analysis reveals that 46 institutions have engaged in digital and intelligent research in medical education from 2014 to 2025 (Tables 5–7). Figure 3

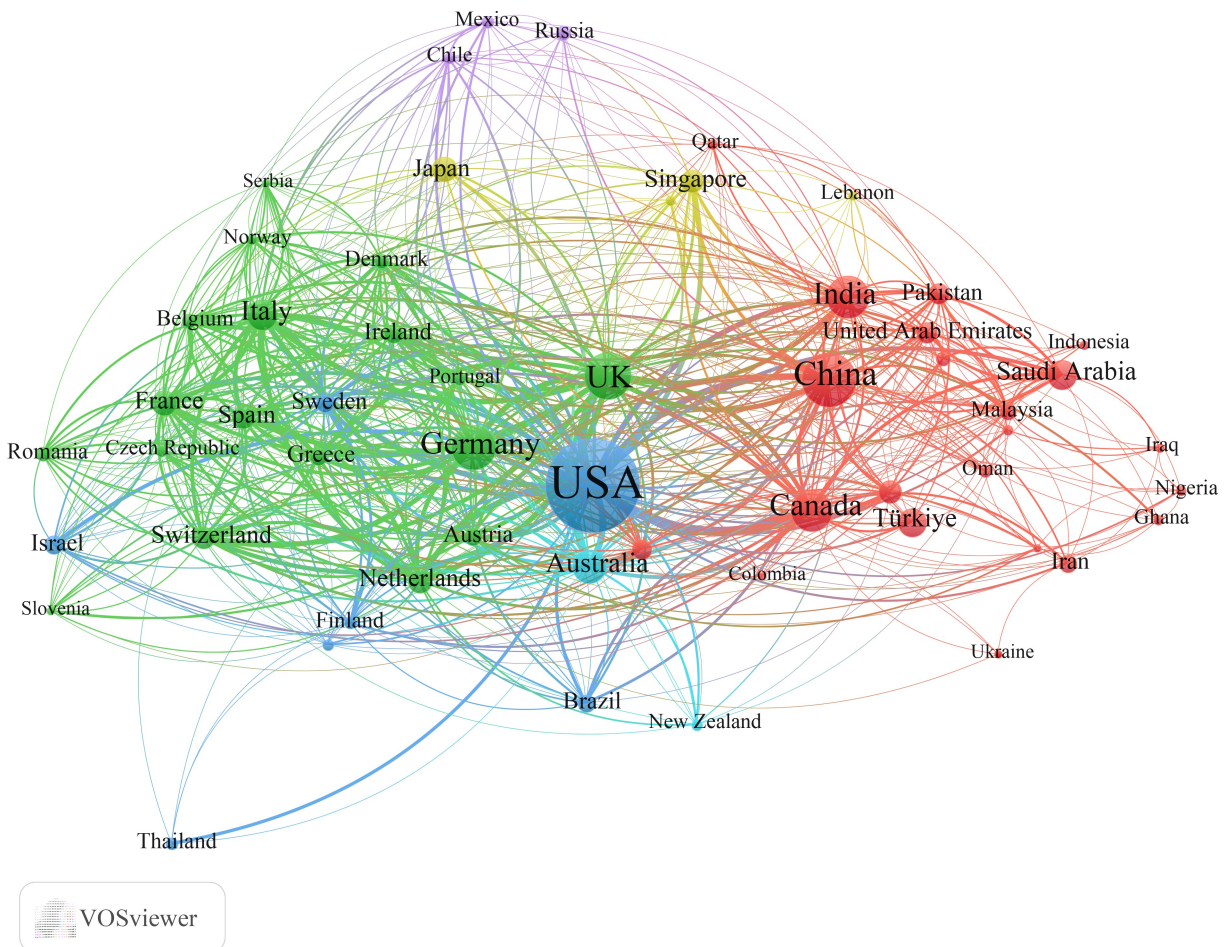
illustrates strong collaborative networks, with Harvard Medical School and Mayo Clinic showing link strengths of 89 and 52, respectively.

3.4 | Analysis by Authors

Over the past decade, 35 researchers have contributed to the field of digital and intelligence education in medicine (Tables 8–10). Figure 4 reveals the absence of any dominant research team or author, implying that this field is still in its early developmental stage.

3.5 | Analysis by Journals

The analysis of journals highlights key contributors to the research field of digital and intelligence education in medicine. According to Tables 11 and 12, *arXiv* (1,376 citations, 24,557 total link strength), *Academic Medicine* (1,337 citations, 26,582 total link strength), and *JMIR Medical Education* (1,193 citations, 25,241 total link strength) emerged as the leading journals, showcasing their significant influence on the dissemination of knowledge. Other prominent journals include *Medical*

**Figure 2** National and regional co-authorship map.

Teacher, *JAMA*, and *PLoS One*, which also demonstrated notable contributions through high citation counts and substantial link strengths. Figure 5 visualizes the citation relationships among these journals.

3.6 | References Analysis

According to Tables 13 and 14, 33 papers serve as the

Table 5 Top 10 publications of institutions

Rank	Document	Institution
1	64	Harvard Medical School
2	61	Mayo Clinic
3	56	Stanford University
4	48	University of Toronto
5	37	University of Michigan
6	35	University of California, Santa Cruz
7	31	University of Pennsylvania
8	29	McGill University
9	26	Emory University
10	26	National University of Singapore

Table 6 Top 10 citations of institutions

Rank	Citation	Institution
1	1,347	King's College London
2	1,307	Nanyang Technological University
3	1,141	University of Toronto
4	838	University of California, San Diego
5	796	University of Arizona
6	795	Harvard Medical School
7	784	Vanderbilt University
8	653	Stanford University
9	609	Charité-Universitätsmedizin Berlin
10	582	McGill University

Table 7 Top 10 centrality of institutions

Rank	Total link strength	Institution
1	89	Harvard Medical School
2	52	Stanford University
3	40	University of Toronto
4	38	University of Pennsylvania
5	38	University of California, Santa Cruz
6	36	University of Michigan
7	34	Massachusetts General Hospital
8	33	Emory University
9	29	Mayo Clinic
10	28	University of California, San Diego

primary references in digital and intelligent medical education research. The most frequently cited paper (Kung et al., 2023), garnered 36 citations and 109 mentions. This study evaluated ChatGPT's performance on the United States Medical Licensing Examination (USMLE). The second most cited reference (Gilson, 2023) ranks second in total link strength. Figure 6 visualizes the citation relationships among these key references.

Table 8 Top 10 publications of authors

Rank	Document	Author
1	11	Friedman, P.
2	11	Noseworthy, P.
3	10	Cheungpasitporn, W.
4	10	Kiyak, Y.
5	9	Seth, I.
6	9	Thongprayoon, C.
7	8	Celi, L.
8	8	Kapa, S.
9	8	Lopez-Jimenez, F.
10	8	Masters, K.

Table 9 Top 10 citations of authors

Rank	Citation	Author
1	282	Winkler-Schwartz, A.
2	282	Yilmaz, R.
3	274	Del Maestro, R.
4	263	Masters, K.
5	194	Celi, L.
6	150	Seth, I.
7	144	Friedman, P.
8	134	Mondal, H.
9	132	Lopez-Jimenez, F.
10	129	Kapa, S.

Table 10 Top 10 centrality of authors

Rank	Total link strength	Author
1	25	Friedman, P.
2	21	Lopez-Jimenez, F.
3	21	Kapa, S.
4	21	Noseworthy, P.
5	21	Cheungpasitporn, W.
6	21	Thongprayoon, C.
7	19	Miao, J.
8	17	Winkler-Schwartz, A.
9	17	Yilmaz, R.
10	17	Del Maestro, R.

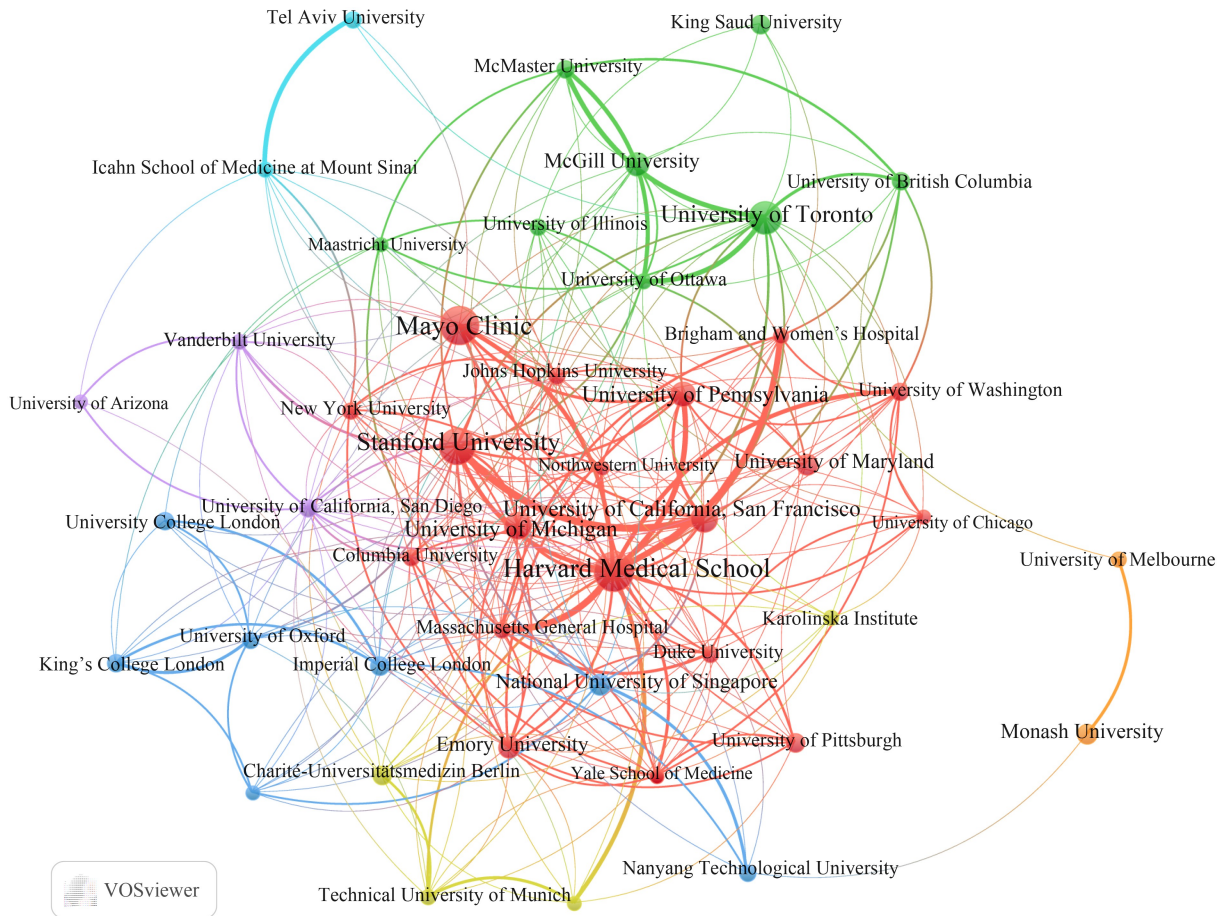


Figure 3 Institutions co-authorship map.

Table 11 Top 10 citations of journals

Rank	Citation	Journal
1	1,376	<i>arXiv</i>
2	1,337	<i>Academic Medicine</i>
3	1,264	<i>Journal of Medical Internet Research</i>
4	1,193	<i>JMIR Medical Education</i>
5	934	<i>Medical Teacher</i>
6	855	<i>JAMA</i>
7	851	<i>Cureus Journal of Medical Science</i>
8	806	<i>BMC Medical Education</i>
9	705	<i>PLoS One</i>
10	674	<i>The New England Journal of Medicine</i>

Table 12 Top 10 centrality of journals

Rank	Total link strength	Journal
1	26,582	<i>Academic Medicine</i>
2	25,241	<i>JMIR Medical Education</i>
3	24,557	<i>arXiv</i>
4	24,463	<i>Journal of Medical Internet Research</i>
5	18,974	<i>Cureus Journal of Medical Science</i>
6	18,596	<i>Medical Teacher</i>
7	15,169	<i>BMC Medical Education</i>
8	15,051	<i>JAMA</i>
9	13,810	<i>npj Digital Medicine</i>
10	12,565	<i>PLoS One</i>

3.7 | Keywords Analysis

Between 2014 and 2025, 27 primary keywords emerged in digital and intelligent medical education research (Tables 15 and 16). Figure 7 highlights artificial intelligence (1,192 mentions), medical education (548 mentions), and ChatGPT (424 mentions) as the most frequent and strongly connected terms.

3.8 | Research Status

Figure 8 summarizes high-impact references and central themes, offering insights into pivotal research clusters.

In cluster 0, patient education highlights the pivotal role of digital tools, such as mobile applications and telehealth platforms, in enhancing patient health

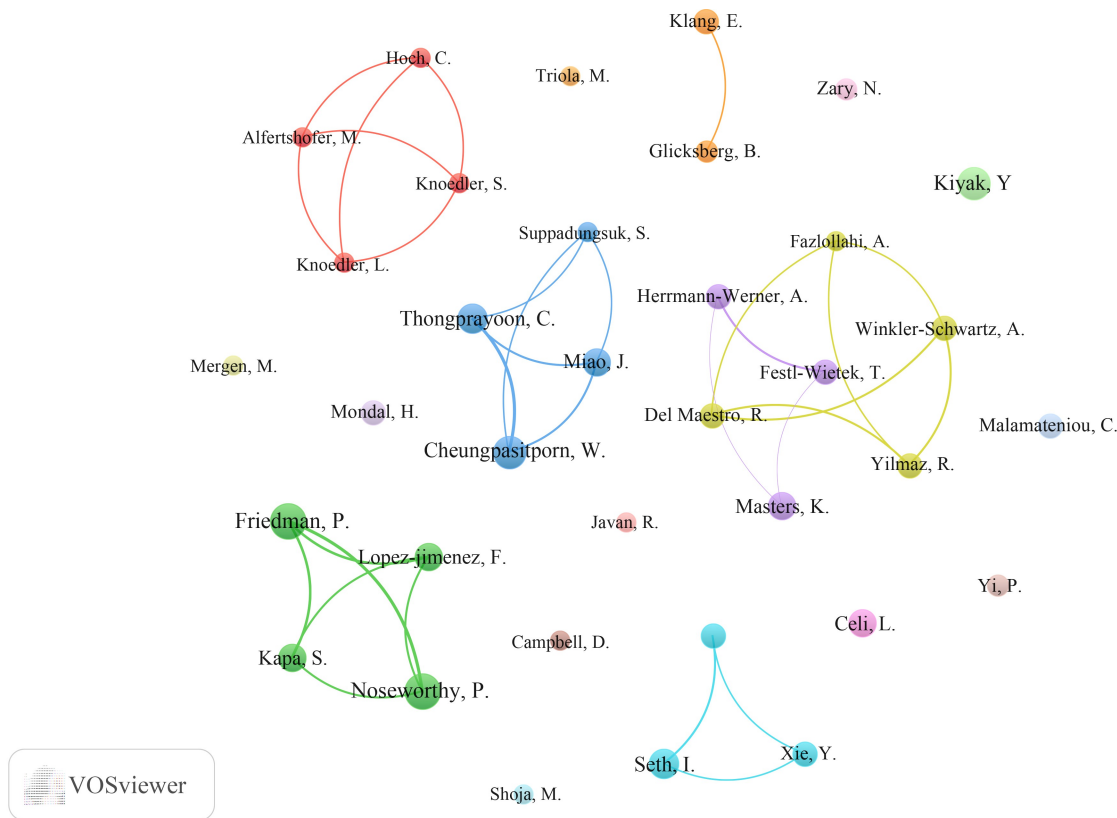


Figure 4 Authors' co-authorship map.

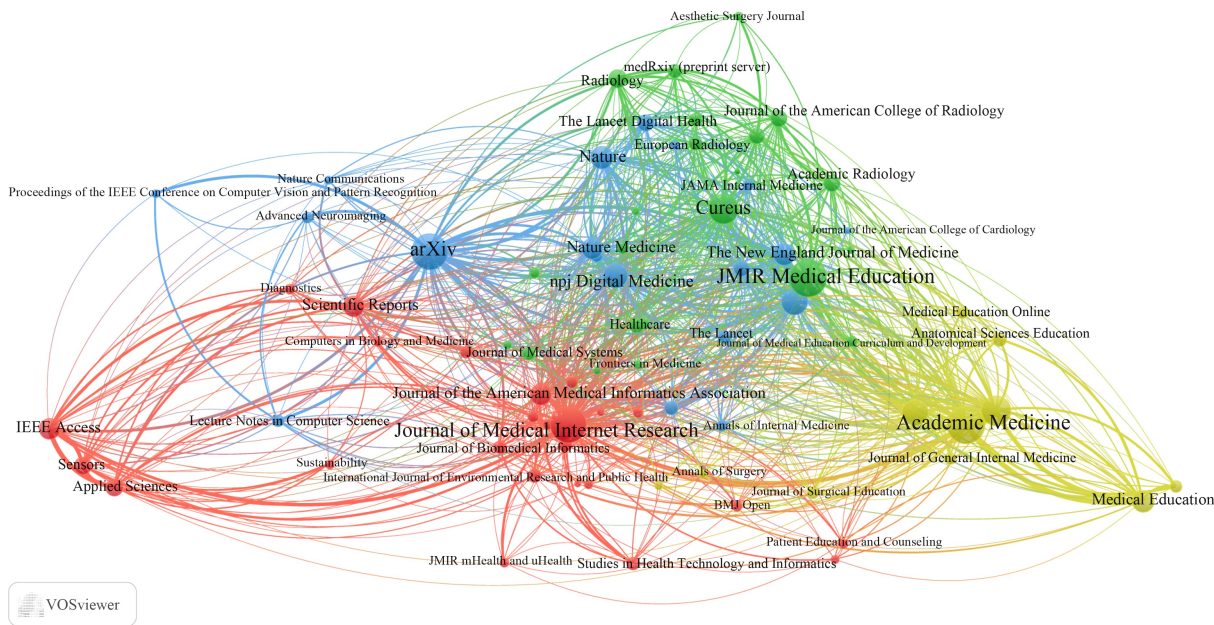


Figure 5 Journals' co-citation map.

literacy and self-management, particularly for chronic disease management (Gupta et al., 2024; Kurniawan et al., 2024). Mobile applications, telehealth platforms, and AI-driven resources are leveraged to improve health literacy and empower patients in managing

chronic conditions like diabetes and hypertension (Van De Vijver et al., 2022). Studies within this cluster focus on designing personalized education programs using AI algorithms that adapt to individual patient needs. Specific research efforts include using natural language

Table 13 Top 10 citations of cited references

Rank	Citation	Cited reference
1	237	Kung et al., 2023
2	208	Gilson et al., 2023
3	155	Sallam, 2023
4	125	Pinto Dos Santos et al., 2019
5	98	Topol, 2019
6	97	Paranjape et al., 2019
7	93	Ayers et al., 2023
8	81	Sit et al., 2020
9	78	Chan et al., 2019
10	78	Lee, 2024

Table 14 Top 10 centrality of cited references

Rank	Total link strength	Cited reference
1	689	Kung et al., 2023
2	655	Gilson et al., 2023
3	436	Sallam, 2023
4	426	Pinto Dos Santos et al., 2019
5	383	Paranjape et al., 2019
6	330	Khan et al., 2023
7	317	Lee, 2024
8	308	Sit et al., 2020
9	302	Wartman & Combs, 2018
10	284	Topol, 2019

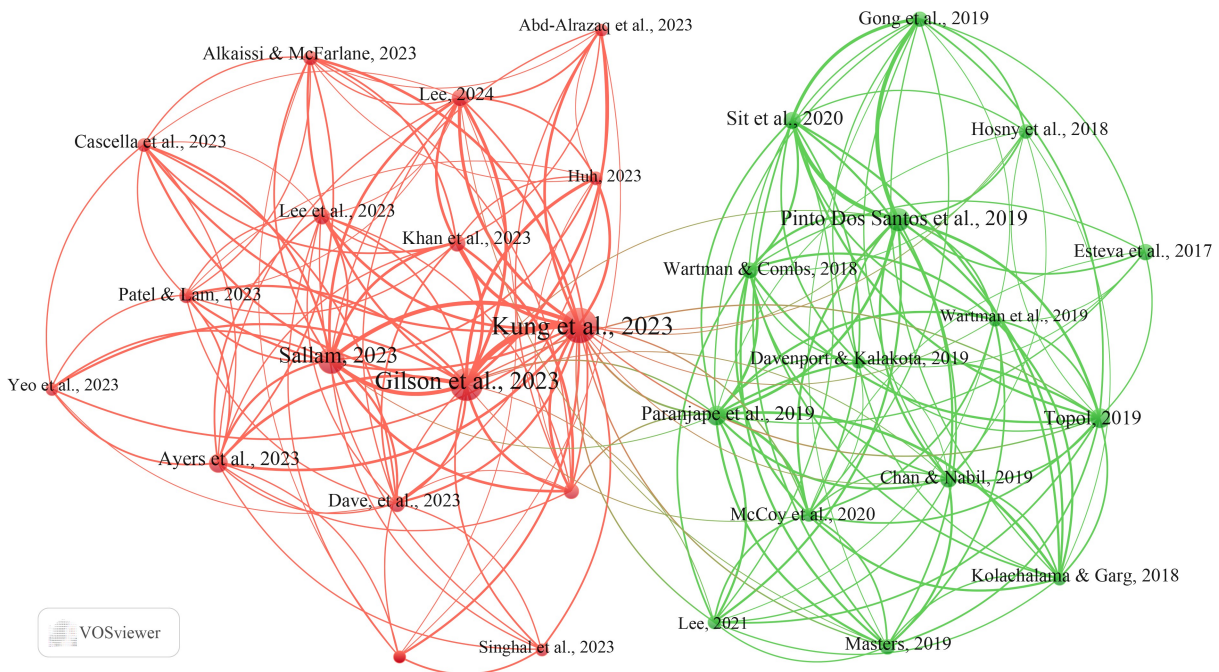


Figure 6 Cited reference co-citation map.

Table 15 Top 10 occurred keywords related to digital and intelligence education in medicine

Rank	Citation	Keyword
1	1,192	Artificial intelligence
2	548	Medical education
3	424	ChatGPT
4	377	Education
5	217	Machine learning
6	171	Large language models
7	137	Big Data
8	135	Healthcare
9	87	Performance
10	84	Virtual reality

Table 16 Top 10 keywords centrality related to digital and intelligence education in medicine

Rank	Total link strength	Keyword
1	2,106	Artificial intelligence
2	1,048	Medical education
3	977	ChatGPT
4	662	Education
5	538	Machine learning
6	485	Large language models
7	274	Healthcare
8	226	Natural language processing
9	222	Performance
10	202	Technology

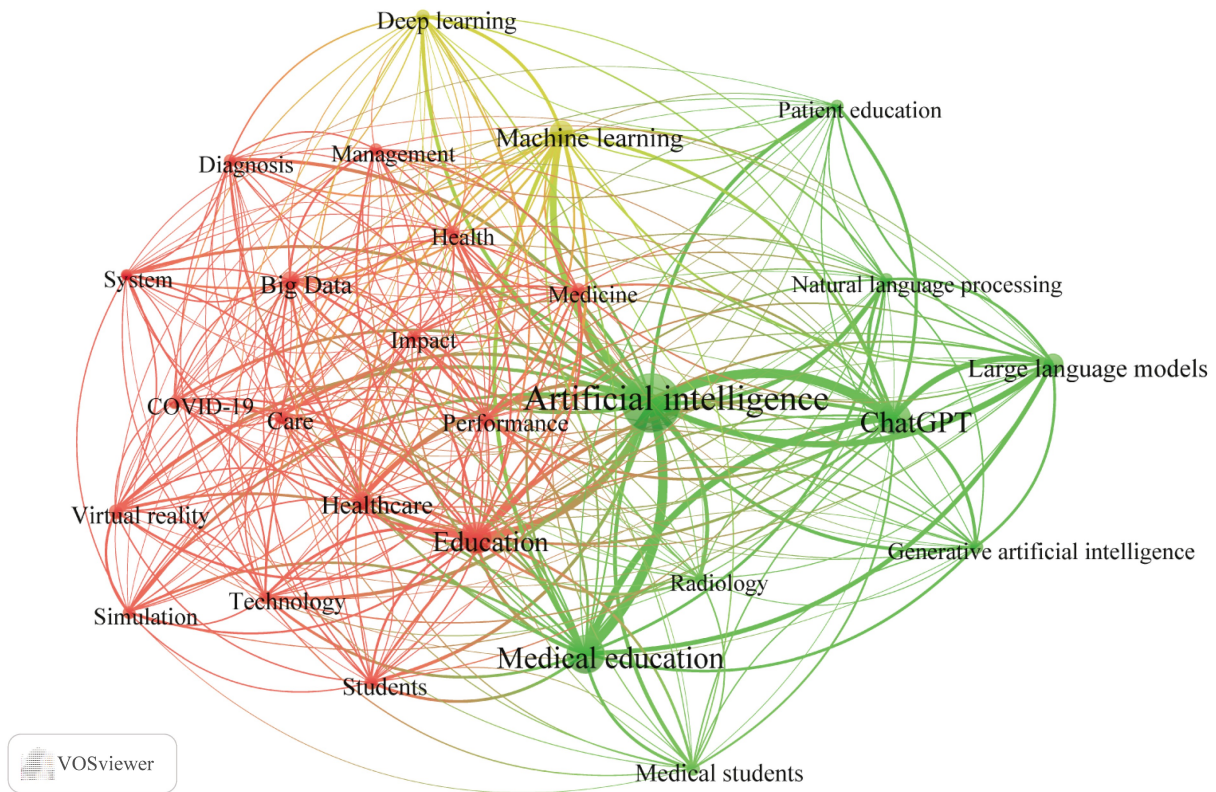


Figure 7 Keywords co-occurrence map.

processing (NLP) to develop conversational agents that provide real-time support and feedback to patients (Schachner et al., 2020). However, challenges such as cultural barriers, language differences, and ensuring content accessibility remain significant (Brands et al., 2022).

In cluster 1, medical education underscores the integration of digital tools in training healthcare professionals to meet modern medical demands. Adaptive learning platforms, supported by Big Data and machine learning, tailor educational content to individual students, addressing their unique learning needs (Menon et al., 2017). Innovations such as virtual dissection labs and 3D simulations are revolutionizing anatomy and clinical teaching (Darras et al., 2019; Neyem et al., 2024). Studies also emphasize the importance of using Internet of Things (IoT) devices to provide real-time performance feedback, improving learning efficiency (Kononowicz et al., 2019). While these advancements hold promise, the cluster identifies gaps in evaluating the long-term impact of these tools on professional competency. Research calls for robust longitudinal studies to measure outcomes and explore how AI can enhance the development of critical thinking and decision-making skills in healthcare professionals (Kyaw et al., 2019).

In cluster 2, virtual reality (VR) showcases its application in medical training, including surgical

simulations, disease diagnosis, and rehabilitation therapies. VR platforms simulate realistic surgical scenarios, enabling students to practice in a safe, controlled environment without the risks associated with real-life operations (Alaraj et al., 2015; Panait et al., 2009). High-fidelity simulations replicate complex procedures, allowing learners to master surgical instruments, understand anatomical relationships, and develop hand-eye coordination (Rangarajan et al., 2020). Moreover, VR applications extend beyond surgery to include diagnostic scenarios, rehabilitation therapies, and patient interaction training (Carpegna et al., 2023; Di Vece et al., 2021). Future research emphasizes integrating VR with AI to create intelligent virtual instructors that provide personalized feedback and adaptive challenges, enhancing the depth and interactivity of training sessions (Boutin et al., 2023). The use of haptic feedback devices to replicate tactile sensations is also identified as a key area for development (Rangarajan et al., 2020).

In cluster 3, AI has emerged as a transformative force in medical education and practice, particularly in diagnostic tools, predictive models, and intelligent tutoring systems. Research focuses on the development of intelligent tutoring systems that guide students through problem-solving processes, personalized learning algorithms that adapt to individual progress, and diagnostic tools that enhance decision-making



Figure 8 Research status map.

accuracy (Furlan et al., 2021; Wu et al., 2020). AI's capacity to analyze large datasets enables educators to identify learning gaps, predict student performance, and optimize teaching strategies (Elanjernan et al., 2024). Additionally, AI-driven predictive models are used in clinical education to simulate patient outcomes and guide treatment planning (Mirchi et al., 2020). However, challenges such as algorithmic transparency, fairness, and bias remain significant barriers to widespread adoption (Nagler, 2024). Future research aims to address these issues by developing interpretable AI systems that enhance trust and usability in medical education.

In cluster 4, deep learning plays a critical role in medical image analysis, speech recognition, and adaptive learning systems. Advanced neural networks have demonstrated exceptional performance in analyzing high-resolution medical images, such as whole slide imaging (WSI) for pathology and radiology. These technologies facilitate automated detection of pathological features, such as cancerous lesions, enabling educators to provide students with highly accurate and annotated datasets for learning (Cui et al., 2023; Li et al., 2023). Beyond imaging, deep learning models are being used to analyze speech patterns in

clinical interactions, providing valuable insights into communication skills (Ravi et al., 2017). Future directions include integrating deep learning with multimodal data—combining imaging, genomics, and electronic health records—to enhance the understanding of complex clinical cases and improve diagnostic training (Huang et al., 2020).

In cluster 5, association emphasizes the synergistic application of various technologies within medical education. For instance, the combination of VR and AI enables real-time simulations with personalized feedback, allowing students to refine their skills in a dynamic environment (Yakkala, 2024). Additionally, research explore the potential of combining AI with Big Data analytics to identify trends and patterns in medical education outcomes. The cluster emphasizes the importance of interdisciplinary collaboration, bringing together expertise from computer science, medicine, and pedagogy to design innovative solutions (Alrashed et al., 2024). Future studies aim to develop integrated platforms that combine various technologies to support diverse educational scenarios, from clinical simulations to theoretical knowledge assessments (Yakkala, 2024).

In cluster 6, language models highlight their role in automating medical documentation and

developing interactive teaching assistants. Applications such as GPT-based models use NLP to process and generate human-like responses, enabling them to serve as virtual teaching assistants. They can answer complex medical questions, provide explanations of diseases and treatments, and facilitate simulated patient interactions for communication training (Benítez et al., 2024; Holderried et al., 2024). Additionally, language models are used to create personalized study plans based on individual learning progress (Xu et al., 2024). Current challenges include ensuring the accuracy and reliability of the information provided and addressing the lack of multilingual capabilities for global accessibility (Takagi et al., 2023). Future efforts should focus on enhancing these tools to support diverse linguistic and cultural contexts in medical education.

In cluster 7, health informatics bridges medicine, information technology, and data science to improve patient care and education. The integration of electronic health records (EHRs) with AI technologies allows educators to teach clinical decision-making using real-world data (Rathore et al., 2025). Research also explores the use of blockchain for secure data sharing and Big Data analytics for identifying trends in healthcare education (Bowles et al., 2021). Challenges such as data privacy, interoperability, and ethical concerns are central to this cluster. Future directions

include developing standardized frameworks for health information management and leveraging Big Data to design more efficient and personalized educational programs (Dave & Patel, 2023).

In summary, the findings highlight the multifaceted impact of digital and intelligent medical education, ranging from personalized learning and immersive training to advanced diagnostics and health informatics. While being transformative, these advancements also present challenges related to equity, ethics, and resource accessibility.

3.9 | Research Frontier

As shown in Figure 9, Big Data (2015–2022) stands out with the most substantial citation burst (27.56), highlighting its foundational role in reshaping healthcare and medical education. Big Data has transformed the field by enabling large-scale integration of heterogeneous data sources, fostering predictive analytics for clinical decision-making, and advancing personalized learning systems (Joy et al., 2024). In medical education, Big Data supports adaptive learning through real-time feedback and outcome analysis, while in healthcare, its application in patient data management and disease surveillance optimizes resource allocation and improves public health

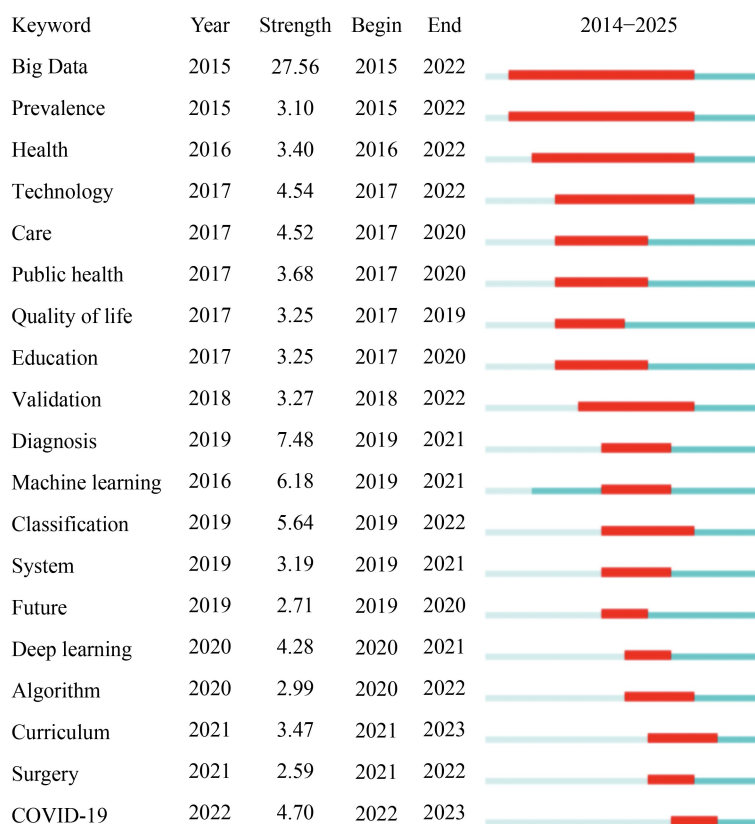


Figure 9 Top 19 keywords with strongest citation bursts.

outcomes (Liu et al., 2022). The significance of Big Data lies not only in its capability to manage vast quantities of information but also in its ability to uncover actionable insights, setting the stage for evidence-based practices.

Machine learning (2016–2021) and deep learning (2020–2021) also display strong citation bursts, underscoring their transformative impact on diagnostic tools, adaptive learning systems, and medical image analysis. Machine learning has become integral to disease classification, risk stratification, and treatment recommendation systems, offering unparalleled accuracy and efficiency (Shukla et al., 2022). Deep learning, on the other hand, has revolutionized areas such as radiology and pathology by automating image recognition with minimal human intervention (Chan et al., 2020). For instance, convolutional neural networks (CNNs) are widely employed in detecting abnormalities in medical imaging, such as tumors and fractures, while NLP models aid in extracting insights from unstructured clinical notes (Hossain et al., 2023; Ou et al., 2021). These technologies have significantly personalized education by creating data-driven, tailored curricula and simulations for healthcare professionals.

Other keywords, including diagnosis (2019–2021), validation (2018–2022), and classification (2019–2022), reveal a strong focus on ensuring the robustness and reliability of digital tools in healthcare. The emphasis on validation reflects a growing awareness of the need to bridge the gap between theoretical models and real-world applications, ensuring that new technologies perform consistently in clinical and educational settings (Qiu et al., 2023). Emerging technologies, such as algorithms (2020–2022) and curriculum (2021–2023), highlight the integration of digital tools into structured educational frameworks. Algorithm development is central to optimizing the performance of machine learning models, while the focus on curriculum signals efforts to embed these technologies into the training of healthcare professionals, ensuring they are equipped with the skills to navigate a technology-driven healthcare landscape (Dolai & Mitra, 2024).

Furthermore, keywords such as public health (2017–2020) and quality of life (2017–2019) extend the focus beyond individual tools to consider broader societal impacts. These bursts indicate a growing recognition of how digital technologies influence healthcare access, equity, and outcomes at a population level. For example, telehealth solutions, which gained prominence during the COVID-19 pandemic, have improved healthcare delivery in remote areas, enhancing overall quality of life (Sadek et al., 2023).

The emergence of COVID-19 (2022–2023) as a significant keyword further underscores the pandemic's role in accelerating the digital transformation of

healthcare systems and medical education. During this period, the adoption of remote learning technologies, virtual simulations, and telemedicine saw unprecedented growth (Fu et al., 2023). The pandemic reshaped research priorities, emphasizing the need for resilient, adaptable, and scalable solutions in response to global crises (Park et al., 2022). These shifts have not only expanded the scope of digital health technologies but have also fostered innovations that prioritize continuity in healthcare delivery and education.

In summary, the keyword analysis highlights the dynamic and interdisciplinary nature of this research field, with Big Data, machine learning, and deep learning leading the way in shaping future innovations. At the same time, emerging areas like curriculum development and pandemic-driven adaptations signal evolving priorities and opportunities for further exploration.

4 Discussion

This study provides a comprehensive bibliometric and visualization analysis of the development and current status of publications on digital and intelligence education in medicine over the past decade, with a focus on integrating digital and intelligent technologies into medical education. The findings provide valuable insights into annual publication trends, leading contributors, research themes, and emerging technologies, while also identifying critical challenges and future directions for digital and intelligent technologies in medical education.

The steady increase in publications, particularly from 2022 to 2024, reflects the rapid growing global interest in applying digital and intelligent technologies to medical education. This surge aligns with the broader integration of AI into various domains, driven by technological advancements and the COVID-19 pandemic, which accelerated the adoption of digital tools in education and healthcare (Dudok et al., 2024). While the publication growth indicates rising recognition, the limited diversity in contributing nations and institutions suggests an uneven distribution of research capacity. China, UK, and the USA have emerged as leaders, but fostering contributions from underrepresented regions is crucial for global advancements. The focus should be on capacity building, international collaboration, and equitable resource distribution to ensure inclusivity (Pupic et al., 2023).

The findings highlight prominent institutions, such as Harvard Medical School and Mayo Clinic, as key contributors to digital and intelligent technologies research in medical education. Their strong collabora-

tive networks, evidenced by high link strengths, emphasize the importance of interdisciplinary partnerships. However, the study also reveals limited global collaboration, possibly due to regional disparities in medical education systems and access to advanced technologies (Sharma et al., 2023). Encouraging international partnerships and standardizing frameworks could address this gap, enabling shared resources and knowledge exchange (Huijser et al., 2024). Collaborative platforms can also facilitate innovation in curriculum design and pedagogical strategies, fostering a unified approach to digital and intelligence education in medicine (Kurahde & Joshi, 2024).

The analysis identifies several key themes that demonstrate the transformative role of digital and intelligence education in medicine. AI-powered personalization, through tools like knowledge graphs and adaptive learning platforms, has emerged as a significant innovation, enabling precise and tailored instruction. These technologies enhance learning efficiency by systematically organizing medical knowledge, fostering critical thinking, and providing personalized feedback based on individual learner needs (Kermany et al., 2018). Similarly, VR has transformed traditional medical training methods, offering immersive and risk-free environments for skill acquisition (Queisner & Eisenträger, 2024). VR technologies, particularly in surgical training and clinical simulations, allow students to practice procedures, receive real-time feedback, and refine their skills without real-world consequences (Mistry et al., 2023). Some studies also explore how VR can be integrated with AI to offer more adaptive learning environments (Viswanathan et al., 2021). The integration of VR with AI holds the potential to further enhance these experiences, providing adaptive challenges and a more personalized approach to training (Mistry et al., 2023). Additionally, deep learning has become a cornerstone in data-intensive applications such as medical imaging and diagnostics. Tools like WSI analysis have demonstrated unparalleled accuracy in identifying pathological features, contributing not only to education but also to clinical decision-making (Deshmukh, 2024). Finally, the rise of language models like ChatGPT highlights the potential for AI to streamline medical education by offering interactive teaching, automating medical documentation, and facilitating patient-doctor communication simulations. These technologies, while transformative, also require careful optimization to ensure they address the diverse linguistic and cultural contexts of medical education globally (Chaddad et al., 2023).

Despite the promise of digital and intelligence education in medicine, its integration presents significant challenges that warrant careful consideration. One notable concern is the potential gap in real world

clinical experience. While virtual simulations, digital learning platforms, and AI systems provide valuable training tools, they cannot entirely replace the experiential learning derived from real-world clinical exposure, which is essential for developing practical skills (Divito et al., 2024). Over-reliance on technology-driven educational tools may inadvertently reduce students' ability to engage in critical thinking, clinical reasoning, and hands-on decision-making, which are fundamental in real-world healthcare settings (Turner et al., 2024). Furthermore, the quality and reliability of digital and intelligence education systems are intrinsically tied to the data they are trained on. Inaccurate, biased, or incomplete datasets can lead to misleading educational content, potentially reinforcing disparities and limiting the broader applicability of intelligent learning solutions (Jeyaraman et al., 2023). Another key challenge is the lack of standardized implementation of digital and intelligent technologies in medical curricula. While some institutions have successfully integrated digital education tools, there remains a lack of consensus on how these technologies should be incorporated into structured educational frameworks (Chan & Zary, 2019). Establishing global standards and best practices for digital and intelligence education in medicine is necessary to ensure consistency, quality, and equitable access to training across different regions (Farooqi et al., 2024).

Ethical considerations also require immediate attention, particularly concerning data privacy, transparency, and fairness in digital and intelligence education. The integration of digital learning tools and intelligent technologies often relies on vast amounts of students' data, raising concerns about data security, informed consent, and potential misuse of personal information (Abd-Alrazaq et al., 2023). Institutions must develop robust policies to safeguard students' and patients' data while ensuring transparency in technology-driven decision-making processes (Parmar, 2024). Bias in digital algorithms and learning systems is another critical issue, as models trained on unrepresentative datasets may lead to skewed educational outcomes, disproportionately affecting students from diverse backgrounds (McLean, 2024). Addressing these ethical concerns requires collaborative efforts among technology developers, educators, and policymakers to establish fair, transparent, and accountable frameworks for digital and intelligence education (Marques et al., 2024).

Additionally, disparities in resource availability pose a significant challenge, as many institutions in resource-limited settings lack the infrastructure to adopt and implement advanced digital and intelligent technologies (Li & Qin, 2023). This inequity risks widening the gap between institutions with abundant resources and those without, further stratifying access

to high-quality medical education (Jeyaraman et al., 2023). Developing accessible and cost-effective digital education solutions, particularly for underfunded medical schools in low- and middle-income countries, is crucial for ensuring equitable access to technology-enhanced education. International collaborations and funding initiatives should prioritize efforts to democratize digital and intelligence education, making these innovations widely available across different educational settings (Farooqi et al., 2024).

5 Conclusions

This study underscores the transformative role of digital and intelligence education in medicine, providing valuable insights into its current status and future potential. While significant progress has been made, addressing existing challenges and fostering collaboration are critical to fully leveraging these technological advancements. By integrating cutting-edge technologies with a humanistic approach, digital and intelligence education can reshape medical training, enhancing the adaptability, efficiency, and inclusivity of learning experiences. This transformation will equip future healthcare professionals with the necessary skills, critical thinking abilities, and empathy to navigate an increasingly complex healthcare landscape.

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