



Application of Artificial Intelligence in Medical Education: A Systematic and Narrative Review of Pedagogical Potential and Ethical Implications

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Abstract: Artificial intelligence (AI) is rapidly transforming medical education through large language models (LLMs), virtual reality (VR), intelligent tutoring systems, and decision-support platforms. These tools enable adaptive instruction, immersive simulation, and real-time feedback, showing strong potential to improve outcomes across health professions training. To explore both opportunities and risks, we conducted a systematic review of PubMed, EMBASE, Web of Science, and Scopus for English-language studies published between January 2015 and May 2025, following the PRISMA framework. Nineteen studies met eligibility criteria. AI modalities identified included LLMs such as ChatGPT, VR-based simulation systems, automated tutoring platforms, and clinical decision-support tools, spanning specialties including radiology, surgery, and psychiatry. Across contexts, AI enhanced examination performance, procedural competence, self-directed learning, engagement, and motivation relative to traditional methods. Students and faculty expressed strong interest and optimism but reported limited formal AI training, favoring interactive practice over didactic lectures. Despite these benefits, concerns consistently emerged regarding algorithmic bias, inaccuracy, data security, and the necessity of human oversight in educational and clinical settings. Ethical issues such as job displacement, the erosion of humanistic care, and the impact on the patient-physician relationship were also highlighted. Limited formal AI training, uneven institutional readiness, and gaps in faculty expertise were common challenges across regions. To harness its transformative potential responsibly, investment is required in faculty development, structured curricula addressing both technical and ethical competencies, and governance frameworks that ensure equitable, transparent, and accountable use. Properly integrated, AI can not only personalize learning and expand access but also support a more inclusive and ethically grounded vision for the future of medical education.

Keywords: artificial intelligence, medical education, simulation-based learning, student perceptions, curriculum integration

Introduction

The rapid integration of artificial intelligence (AI) into clinical practice is driving profound changes in medical education.¹ AI technologies, particularly large language models (LLMs) such as ChatGPT² and domain-specific platforms, are increasingly being explored for use in medical teaching, clinical simulation, and decision support.³ Current applications encompass automated generation of case vignettes, anatomy instruction, radiographic interpretation, and facilitation of ethical reasoning through natural language interaction.⁴ Immersive modalities such as virtual patient simulations, adaptive learning platforms, and AI-assisted decision systems offer scalable solutions to faculty shortages, infrastructural limitations, and resource disparities, thereby enhancing both educational quality and accessibility, especially in underserved regions.^{5,6}

However, the adoption of AI in medical education extends far beyond technological innovation.³ It necessitates rethinking core paradigms, including student-teacher interaction, cultivation of critical thinking amid generative content, and ethical use of AI outputs. Concerns over data privacy, algorithmic bias, authorship, and accountability pose complex



challenges for curriculum design and governance. Educators must not only teach about AI but also prepare students to collaborate with it ethically and clinically.

While many studies describe specific AI applications, such as simulation-based learning or diagnostic tutorials, most are fragmented by specialty, stage, or geography, and few link pedagogical benefits with ethical considerations. This review addresses this gap by synthesizing evidence on: (1) current AI use cases in preclinical and clinical education; (2) learners' and educators' perceptions, literacy, and readiness; (3) core ethical concerns, including fairness, accountability, privacy, and transparency; and (4) proposed curricular and governance strategies for responsible integration. The aim is to inform educators, leaders, and policymakers on leveraging AI's potential while preserving professional values and clinical integrity.

Methods

Study Design

This systematic review was conducted by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The objective was to identify, synthesize, and critically appraise peer-reviewed literature addressing both the pedagogical applications of artificial intelligence (AI) in medical education and the ethical issues arising from its implementation.

Data Sources and Search Strategy

A comprehensive literature search was performed in PubMed, EMBASE, Web of Science, and Scopus for studies published between January 2015 and May 2025, a period selected to capture the rapid evolution of generative AI technologies such as ChatGPT. The search strategy combined population terms (eg, "medical education," "health professional education," "clinical training," "medical students," "residents") with intervention terms (eg, "artificial intelligence," "large language models," "ChatGPT," "generative AI," "machine learning," "educational technology"), application terms (eg, "AI-assisted learning," "AI-based education," "simulation-based learning," "virtual reality training," "problem-based learning"), and ethical terms (eg, "ethics," "bias," "privacy," "accountability," "trust," "autonomy," "AI governance").

Inclusion and Exclusion Criteria

Eligible studies included peer-reviewed articles published in English that reported original research (quantitative, qualitative, or mixed-methods), systematic or narrative reviews, or theoretical discussions explicitly focusing on AI applications in medical or health professional education and incorporating an ethical dimension. Studies involving undergraduate medical students, postgraduate trainees, or medical educators were considered. Exclusion criteria comprised non-English publications, conference abstracts, editorials, letters, or opinion pieces without primary data; studies addressing AI solely in clinical practice without educational relevance; and papers on AI technical development lacking pedagogical or ethical focus.

Study Selection

All identified records were imported into a reference manager (eg, Rayyan), and duplicates were removed. Two independent reviewers screened titles and abstracts. Full texts were retrieved for all potentially eligible studies. Disagreements were resolved by discussion or consultation with a third reviewer.

A PRISMA flow diagram was used to depict the study selection process.

Data Extraction and Synthesis

A standardized extraction form was used to collect bibliographic details, study design, participant characteristics, AI application type and role (eg, simulation, diagnostics, assessment, chatbot-based learning), target educational level, reported outcomes (eg, learning effectiveness, attitudes, engagement, literacy), and ethical considerations (eg, privacy, bias, explainability, responsibility, emotional impact). A thematic synthesis approach was employed: descriptive coding

was first applied to classify AI application contexts and ethical themes, followed by the generation of analytical themes grouped under four overarching domains, applications in medical education, AI literacy and student perception, ethical challenges, and curriculum and governance implications.

Results

Study Selection

The initial database search yielded 1488 records. After removing 688 duplicates, 800 titles and abstracts were screened. A total of 41 full-text articles were assessed for eligibility, and 19 studies met the inclusion criteria.

A PRISMA flow diagram summarizing the selection process is shown in [Figure 1](#)

Study Characteristics

The target populations across the studies varied widely. A total of 12 studies involved undergraduate and postgraduate medical students. Three studies focused on interns, trainees, and residents, while one study included endoscopists with varying levels of experience. Additionally, two studies targeted healthcare professionals, including nurses and trainees. One study incorporated multi-stakeholder perspectives, involving both students and educators. Studies originated from 13 countries, predominantly USA, UK, China, Japan, Pakistan, Germany, Austria, Switzerland, Saudi Arabia, Jordan, Canada, Spain and India.

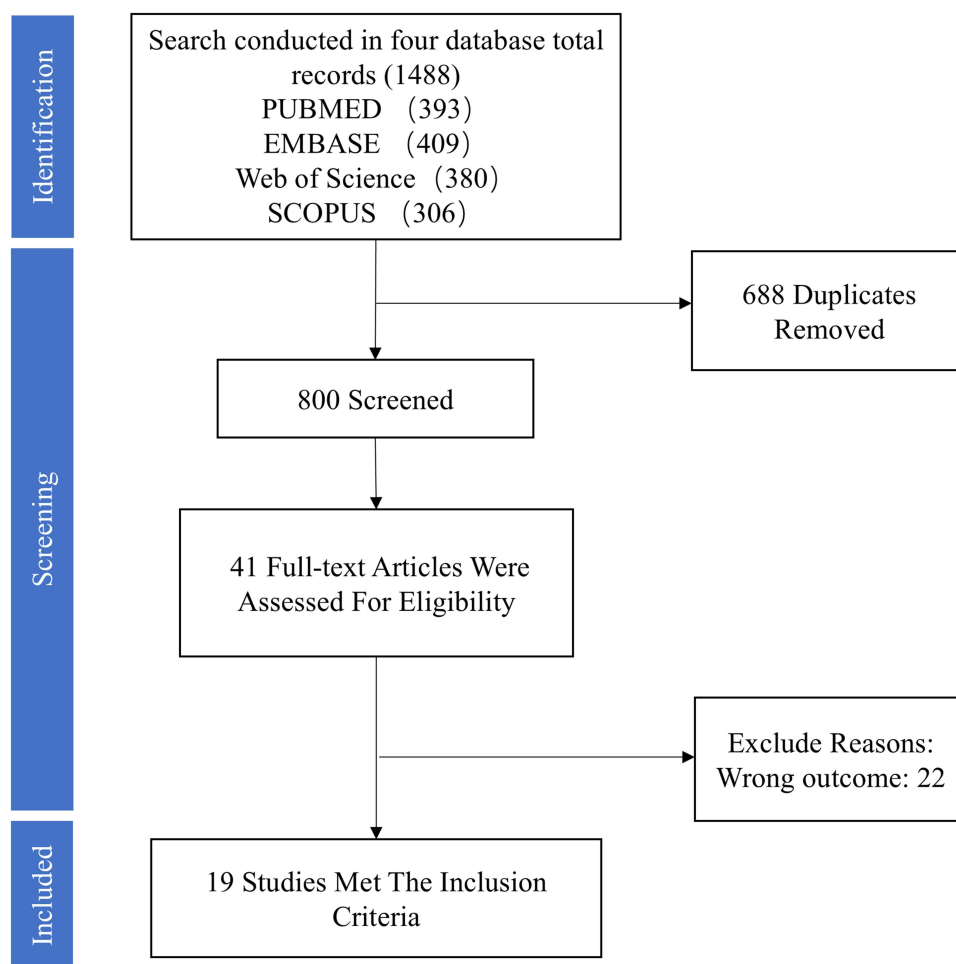


Figure 1 A PRISMA flow diagram.

For the study on AI applications in medical education, the AI tools used varied across the research. Specifically, 3 studies utilized ChatGPT, 2 studies employed Virtual Reality (VR), 1 study applied AI-based teaching tools such as Watson for Oncology, and 2 studies incorporated Simulation-based Education (SBE).

Themes Identified

Effectiveness of AI-Based Tools

Eight studies evaluated the impact of AI-based tools on medical education outcomes, involving interventions such as ChatGPT ($n = 3$), Watson for Oncology ($n = 1$), simulation-based education ($n = 1$), and virtual reality (VR) systems ($n = 2$) with sample sizes ranging from 22 to 317 participants across undergraduate, intern, and resident cohorts. Outcomes clustered into three domains: academic performance, clinical/practical skills, and learning-related psychological measures (Table 1).

Six studies assessed academic performance through standardized or course-specific examinations. Compared to traditional teaching, AI-based interventions were associated with significantly higher academic scores.

Three studies evaluated clinical and procedural skills in contexts such as OSCEs, communication training, and surgical/endoscopic instruction. AI-enhanced simulation-based education provided personalized, real-time feedback and adaptive pathways, yielding marked improvements in practical skills, communication, imaging interpretation, and teamwork. In VR-based endoscopy training, AI integration significantly increased GAGES and FES scores, improved practice efficiency, and elevated post-training pass rates. Similarly, AI models have demonstrated substantial potential in diagnostic and prognostic applications. The RAINMAN deep learning-based semiautomated workflow improved diagnostic performance for nasopharyngeal carcinoma, enhancing both sensitivity and specificity, while reducing radiologist workload.¹⁴ AI-based models for nasopharyngeal imaging in NKTCL also outperformed resident radiologists, with AUCs ranging from 0.905 to 0.960, and improved prognostic accuracy for survival prediction.¹⁵ Moreover, the MODERN deep learning model for detecting recurrent nasopharyngeal carcinoma achieved accuracy comparable to expert radiologists, and when combined with radiologists, further boosted diagnostic accuracy ($P < 0.001$).¹⁶ These examples highlight AI's potential to optimize clinical skills, diagnostic accuracy, and therapeutic decisions.

Four studies evaluated engagement,^{7–10} motivation, or cognitive outcomes of AI-assisted education. Across these studies, AI interventions consistently led to significantly higher levels of independent learning, self-directed learning, learning motivation, participation, and satisfaction compared with traditional approaches. Notably, AI-supported groups also demonstrated enhanced self-efficacy, critical thinking skills, and reduced cognitive load. These findings suggest that AI-based tools such as ChatGPT and Watson for Oncology may promote deeper learning and more positive learner experiences. Students reported high satisfaction with ChatGPT-based learning, citing its interactive and personalized features as key motivators. However, some noted limitations, including occasional misunderstanding of prompts and difficulty handling surgical terminology. An observed AI error rate of approximately 15% highlighted the need for instructor oversight to ensure accuracy.⁹

Medical Students' AI Literacy and Attitudes

Most students held positive views about digital health, especially technologies like big data, telemedicine, and wearables, though fewer recognized the value of decision support systems (Table 2). Practical, hands-on training was preferred over traditional lectures, and interest in the ethical and legal aspects of digital health remained relatively limited.¹⁷

Review studies reveal that medical students and trainees generally hold a positive attitude toward the application of artificial intelligence (AI) in healthcare. Across studies from Europe, the Middle East, South Asia, East Asia, and North America, students widely recognized AI's potential in radiology, diagnostics, and education but reported minimal exposure and limited formal training—often electives, workshops, or online modules rather than core curriculum. Over 80% in several studies had no structured AI education, and confidence in AI tool use was generally low among both students and faculty.

However, a significant gap exists between general interest and actual competence. Many students and educators expressed a lack of confidence in effectively using AI tools. For example, in Pakistan, fewer than half of both students

Table 1 AI Tools in Medical Education: Comparison of Study Findings and Outcomes

Author (Year)	Population	AI Tool	Comparator	Key Comparative Findings	Statistical Significance
Zhao et al (2023) ⁷	72 medical undergraduates (n = 36 per group)	Watson for Oncology (WFO)	Traditional teaching	AI group significantly outperformed control in independent learning, knowledge mastery, and course satisfaction	P < 0.05
Wang et al (2025) ⁸	103 medical undergraduates and postgraduates	ChatGPT	Traditional teaching	ChatGPT group superior in Self-Directed Learning, Critical Thinking, and Global Flow.	P = 0.01 to < 0.001
Zeng et al (2025) ⁹	42 urology medical interns	ChatGPT+ PBL	Traditional teaching	Higher exam scores in ChatGPT + PBL group.	P < 0.01
Yu et al (2025) ¹⁰	317 second-year medical students	Simulation-based education (SBE)	Traditional OSCE	All domains improved significantly: knowledge, skills, teamwork.	P < 0.001
Huang et al (2025) ¹⁰	187 undergraduate dental students	ChatGPT	Traditional teaching	Significant improvement in scores and reduced cognitive load with ChatGPT.	P < 0.001
Cassidy et al (2022) ¹¹	22 residents	Virtual reality (VR)	Proficiency vs repetition group	Improved skills in VR group, no difference between proficiency vs repetition groups.	P = 0.013
Hashimoto et al (2018) ¹²	Experienced (>100) Inexperienced endoscopists (<50)	Virtual reality (VR)	Repetition group	Inexperienced group improved significantly in scores and pass rates.	P < 0.01
Majeed et al (2024) ¹³	40 postgraduate radiology residents	AI-based teaching	Traditional teaching	Higher post-test scores in AI-based teaching group.	P < 0.05

Table 2 Summary of Studies on Awareness, AI Training, and Ethical Concerns

No.	Author(s) & Year	Country	Dataset	Awareness/Needs	AI Training	Concerns in Ethics
1	Weidener et al 2024 ¹⁸	Germany, Austria, Switzerland	487 Medical Students	71.7% anticipated a positive impact of AI on medicine. 72.1% believed that AI could find practical applications in medicine	26 (5.3%) had previously received AI education	4.9% agreed that the current instruction on AI ethics in medical education is adequate
2	Rjooop et al, 2025 ¹⁹	Jordan	394 (328 medical students and 66 pathology residents)	54.1% thought AI could diagnose diseases automatically.	14% were aware of AI through medical schools. 66.2% disagreed that their medical schools had educated them about AI	Attitudes toward AI's role in automated diagnosis.
3	Ahmed Hafez et al, 2024 ²⁰	9 Arab Countries	Medical Students (Radiology)	84.9% believed AI would revolutionize medicine and radiology.	92.4% had no formal AI training; 87.1% had low AI knowledge.	Concerns about AI replacing radiologists and its future role.
4	Sit et al, 2022 ²¹	UK	484 Medical Students	99% believed AI will play a major role in healthcare. 49% less likely to consider radiology as a career due to AI.	Only 45 students received any AI training; none as part of their compulsory curriculum.	Need for formal AI training in medical education.
5	Naseer et al ²²	Pakistan	236 Medical Students	84.3% of faculty and 74.5% of students agreed AI could enhance teaching and learning in medical education.	Only 45.7% of faculty and 45.1% of students were confident using AI tools.	Lack of confidence in using AI in teaching and learning.
6	Fernanda et al ²³	Canada	57 Oncology Trainees	73% were interested in learning more about AI; 63% wanted formal AI education during residency.	79% preferred learning through workshops.	Lack of formalized AI education in residency.
7	Wang et al ²⁴	China	1243 Nursing Students, Nurses, Healthcare Professionals	>50% showed positive attitudes toward AI in nursing.	57% had limited AI knowledge; 95.7% supported strengthening medical ethics with AI in nursing.	Need for AI ethics training in nursing education.
8	Salih et al ²⁵	Saudi Arabia	11 faculty members, 34 Medical students	91.11% believed AI systems would positively impact medical education, especially in research, knowledge gain, assessment, and simulation	80% Faculty and students felt a need for training on AI use	Threats to academic integrity, plagiarism, privacy/confidentiality issues

9	Jackson et al ²⁶	India	325 medical students	More than half of the participants (173/325) agreed that they would become better physicians with the widespread use of AI applications.	91.4% had not received any training on AI in their medical curriculum	Over half of respondents either totally or mostly agreed that AI may reduce the humanistic aspect of medicine (225/325, 69.2%) and negatively affect the patient–physician relationship (177/325, 54.5%). Concerns were also raised about potential violations of professional confidentiality (174/335, 51.9%) and damage to trust (172/325, 52.9%). While fewer students strongly believed that AI devalues the medical profession, a substantial number remained uncertain, highlighting the need for better education around the ethical implications of AI integration in clinical practice
10	Gualda-Gea et al ²⁷	Barcelona	61 students	66% expressed a strong interest in the practical applications of AI in medicine	79% responses had limited knowledge of specific AI applications in medicine	48% participants concerns about the moral and deontological implications of integrating these tools into medical practice, 59% concern about the existence of biases, suggesting that students are aware of the risk of partiality in the recommendations or information provided by AI tools.
11	Sanad ²⁸	Saudi	349 Newly Graduated Interns	41.8% identified as familiar with AI applications in healthcare. 14.3% claimed to be very familiar with AI,	45.8% having received some form of training related to AI, 54.2% had not received any training.	Job displacement: 31.5%; Ethical implications, 25.8%; Overreliance on technology, 15.7%; Data privacy and security, 40.1%; Disparities in access, 22.4%

and educators felt comfortable applying AI in teaching or learning. In Jordan and other Arab countries, while students had high expectations of AI's diagnostic potential, they lacked hands-on experience and structured training.

Perceptions of institutional readiness varied by region. In Saudi Arabia, most educators believed their institutions had the resources to integrate AI, yet students cited issues such as outdated software, poor infrastructure, and insufficient expert support. Educators often indicated that they required more training and support, while students were seen as more adaptable to emerging technologies.²⁵ Despite these gaps, both faculty and students generally agreed that AI could be integrated into current curricula with moderate adjustments and appropriate oversight.

In terms of AI usage in medical education, more than half of the students (54.1%) recognize AI's potential for automating disease diagnosis, with 80.7% agreeing that AI could assist in recommending appropriate investigations. However, training on AI applications, particularly in fields such as radiology and diagnostics, remains insufficient. For example, 92.4% of students in an Arab countries study had not received formal AI training, and 87.1% had low levels of AI knowledge. This lack of training is echoed by the findings in Pakistan, where 45.7% of faculty and 45.1% of students expressed a lack of confidence in using AI-based tools for teaching and learning.

Ethical Challenges in the Use of AI for Teaching

Ethical concerns were prominent across all regions, especially regarding job displacement, data privacy, algorithmic bias, and the erosion of humanistic care (Table 2). In the UK, 49% of medical students said AI made them hesitant to pursue radiology as a career. In India and Canada, over half of the participants worried that AI might damage the patient-physician relationship. Many students also expressed uncertainty about AI's legal and moral accountability, and in some studies, fewer than 5% felt their current ethics training was adequate. To address these concerns, some educators have begun integrating ethical training into AI-related teaching, including using tools like ChatGPT to simulate clinical dilemmas and promote critical reflection.²⁹ Further, viewpoints from educational literature advocate for an embedded ethics approach, systematically integrating AI ethics content into existing bioethics or medical ethics curricula. Such frameworks help students grasp not only ethical principles but also practical implications of AI in healthcare.³⁰ Complementing this, case-based and scenario-driven teaching strategies are commonly used to enhance students' ethical sensitivity and humanistic awareness.³¹

Discussion

Summary of Key Findings

This review highlights the expanding applications of AI across various levels of medical education, including undergraduate, postgraduate, and continuing education. Participants reported AI being used in diverse instructional formats, such as virtual and augmented reality, intelligent tutoring systems, and machine learning-driven simulations. These tools have been adopted across multiple clinical disciplines, such as radiology, cardiology, psychiatry, surgery, as well as related fields like nursing, anesthesia, and public health.³² Some institutions were reported to have introduced AI-focused curricula covering topics such as programming, algorithms, and computer science. Learners described VR-based instruction as engaging and helpful in building confidence, providing a safe environment for problem-solving and experiential learning. AI and telemedicine were generally viewed as key enablers for improving healthcare access, particularly in underserved settings.³³

Compared with lecture-based, standardized, and uniform curricula, AI enables adaptive, interactive, and data-driven instruction, offering personalized feedback, complex clinical simulations, and continuous performance analytics. When combined with traditional teaching, AI has been shown to improve examination performance, procedural competence, and decision-making. However, mentorship, empathy, and ethical reasoning, core strengths of conventional education remain irreplaceable, positioning AI as a complement rather than a substitute. Although students generally view AI positively, most lack formal training on its responsible use. Despite strong enthusiasm, current medical curricula often do not include structured AI education. Therefore, institutions must prioritize the development of policy frameworks, pedagogical strategies, and oversight mechanisms to ensure that AI is integrated responsibly into traditional medical education models.

Comparison with Existing Literature

It is our view that AI functions best as a complement to, rather than a substitute for, traditional medical education, a stance supported by prior studies. Systematic reviews in anatomy confirm that AI-powered tools, such as virtual dissection simulations and machine learning–enhanced feedback systems, can improve knowledge retention and application-level reasoning while preserving human judgment.^{34–36} Similarly, radiology education literature suggests that AI enables “precision education”, allowing customized feedback and adaptive learning tailored to trainee progress.³⁷ Although these domain-specific studies highlight AI’s value, few reviews integrate educational applications and ethical dimensions cohesively. Our review addresses this gap by mapping AI tools to both pedagogical benefits and ethical considerations across undergraduate and postgraduate education.

Although these domain-specific studies highlight AI’s value, few reviews integrate educational applications and ethical dimensions cohesively. Our review addresses this gap by mapping AI tools to both pedagogical benefits and ethical considerations across undergraduate and postgraduate education.³⁸ Broader analyses identify domains such as fairness, consent, data privacy, and patient-centered care, emphasizing the need for multidisciplinary oversight.³⁹ Narrative reviews also note risks of bias, academic integrity issues, and content misuse, calling for curricula that foster critical evaluation alongside technical competence.⁴⁰

Furthermore, effective implementation of generative AI tools like ChatGPT requires mindful consideration of usability, credibility, fairness, cost, and ethical transparency, elements that must be embedded into faculty training and curriculum design.⁴¹ A recent transparency index framework underscores the essential role of embedding accountability, interpretability, and stakeholder-informed design into AI systems for education.⁴²

Educational Implications

To effectively integrate artificial intelligence (AI) into medical education, a tiered curriculum aligned with the competency-based medical education (CBME) framework has been widely recommended. At the foundational level, students should be introduced to core concepts such as algorithmic logic, data science fundamentals, and digital ethics, to build basic literacy and foster awareness of issues like bias, privacy, and accountability.⁴³ At the intermediate level, case-based learning approaches can facilitate critical appraisal of AI-assisted clinical tools, enabling students to contextualize and apply these technologies in real-world decision-making.⁴⁴ The advanced level may include electives or research projects focused on algorithm development, AI fairness, or human-machine collaboration, which promote deeper technical insight and reflective professionalism.^{1,45} Empirical examples further support this structure: Ngiam and Khor⁴⁶ emphasized the integration of AI literacy and ethical reasoning to enhance students’ preparedness for AI-enabled healthcare, while institutions have begun embedding AI content within interdisciplinary modules across medicine, engineering, and data science.⁴⁷ Such multi-level designs not only improve students’ conceptual understanding but also foster a sense of professional responsibility and critical engagement with emerging technologies in healthcare.

Ethical and Regulatory Considerations

Incorporating ethical principles into AI education is essential to ensure responsible use in clinical practice. Badal et al⁴⁸ identified eight guiding principles, such as promoting equity, ensuring clinical relevance, and integrating social determinants, that highlight the need for fairness, transparency, and patient-centered care. Embedding these values into curricula can foster students’ ethical reasoning and contextual awareness. As AI reshapes healthcare and education, robust governance frameworks and faculty training are critical to balance innovation with accountability and ensure responsible implementation.⁴⁹

AI systems should be consciously designed to mitigate rather than exacerbate health disparities, especially by ensuring access, inclusivity, and adaptability in low-resource settings. This includes designing tools that can operate with locally available data, favoring transparency and cost-effectiveness over black-box sophistication.^{38,50} Second, clinical relevance must be defined from the outset, ensuring that AI outcomes correspond with meaningful patient benefit and align with real-world clinical goals.^{3,51} Third, the reduction of overdiagnosis and overtreatment must be a target in AI development, especially in areas like cancer care, where AI tools may risk amplifying detection without improving survival.^{52,53}

Furthermore, AI tools must demonstrate medical value; that is, they should improve health outcomes or reduce costs compared to existing standards.⁵⁴ To achieve this, the early involvement of key stakeholders, such as clinicians and health economists, is essential.^{55,56} In addition, AI models must integrate the social and biological determinants of health, including socioeconomic status, environmental exposures, and chronic stress, to more accurately reflect the complex drivers of disease.^{57,58} These tools should be adaptable to local populations, prioritizing transferability and modular design over one-size-fits-all solutions.⁵⁹

Beyond technical and clinical considerations, ethical AI education should also address academic integrity, privacy, and humanistic practice. Students' use of AI in learning or assessments raises concerns about plagiarism and over-reliance, emphasizing the need for clear guidelines on responsible use and proper attribution. Data security and privacy must be highlighted, particularly when AI interacts with patient or student data, ensuring anonymization, informed consent, and secure handling. AI should augment rather than replace human judgment, maintaining patient-centered care and professional empathy, which can be reinforced through ethics discussions and communication training. Transparency and explainability of AI outputs are essential for fostering critical thinking and understanding system limitations. Moreover, AI applications must comply with legal and regulatory frameworks to clarify accountability and liability. Finally, ethical education should be adapted to diverse global contexts, promoting equitable access, culturally sensitive instruction, and scalable, low-cost training resources to bridge disparities in AI readiness.

Governance and Curriculum Frameworks for Responsible AI Integration

International consensus increasingly underscores the need for ethical guidelines and regulatory structures for AI integration in medical education. The FUTURE AI guideline, developed via a modified Delphi process with global experts, outlines six principles for trustworthy AI: fairness, universality, traceability, usability, robustness, and explainability, spanning technical, legal, clinical, and ethical dimensions across the AI lifecycle.^{60,61} Similarly, Delphi-based consensus in surgical training has produced frameworks addressing data protection, transparency, bias, and accountability in AI-driven tools.⁶²

To operationalize these principles, educators propose curriculum strategies such as modular AI courses integrating AI literacy and ethics into existing bioethics programs. The Embedded AI Ethics Education Framework builds on established ethics curricula to target risks like misuse or bias, offering a practical roadmap for medical schools.³⁰

Model frameworks aligned with governance principles include Trustworthy AI, Human-in-the-loop designs, and AI-augmented feedback systems. For instance, AI-based formative feedback in clinical skills training, such as MedSimAI simulations has improved performance assessment while maintaining educator oversight.⁶³ Augmented feedback models, validated through expert consensus, further validate the pedagogical value of real-time data-driven guidance balanced with human judgement.⁶⁴

Limitations and Future Directions

This review is limited by its English-only scope, potential bias from self-reported data, and the absence of longitudinal or interventional studies, which restricts our understanding of AI's long-term impact on learners. A key limitation is the lack of more comparative studies, which reflects the early stage of research in this field. The heterogeneity in study designs and populations prevented the use of quantitative meta-analysis, and thus, a narrative synthesis approach was employed to summarize the findings across studies. Rapid advances in generative AI may also render some findings outdated. Future priorities include developing standardized AI-literacy frameworks, conducting long-term evaluations, and fostering interdisciplinary co-creation to ensure relevance and ethical soundness.⁶⁵ Recognizing the significant regional disparities in healthcare resources and infrastructure, future efforts should tailor AI implementation strategies to local contexts. For example, resource-rich settings could focus on advanced AI models and multi-centre validation studies, while resource-limited regions may benefit from lightweight, scalable AI solutions and shared data platforms.⁵⁴ Achieving global consensus on core AI competencies will be critical; however, these competencies should remain adaptable to diverse local capabilities to ensure both feasibility and practical impact. Moreover, the recent FUTURE-AI international consensus guideline emphasizes fairness, universality, traceability, usability, robustness, and explainability as key guiding principles for trustworthy healthcare AI systems.⁶¹ Incorporating such internationally endorsed guidelines

into region-sensitive adoption pathways can help bridge the gap between high-resource and low-resource settings, enhancing both scalability and equity of AI deployment.

Conclusion

AI offers unprecedented opportunities to enhance medical education, but its value lies in complementing, not replacing human teaching. Embedding AI literacy, ethical reasoning, and critical appraisal into curricula is essential to address fairness, accountability, privacy, and transparency. With collaborative governance, institutions can harness AI's potential while safeguarding professional values and patient-centered care.

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