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Artificial intelligence in medical education: A systematic review of teaching, learning, and academic integrity issues

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Abstract

The accelerated adoption of artificial intelligence in medical education has produced both great opportunities in terms of improving teaching, learning, and evaluation and also the crux of the matter of academic integrity, ethical governance, and educational quality. This systematic review has attempted to compile existing program of artificial intelligence, generative artificial intelligence, large language models, adaptive learning, intelligent tutoring systems and simulation-based learning in medical education, particularly in terms of teaching practices, instructional outcomes, and academic dishonesty concerns. Within the framework of PRISMA, the search of pertinent literature was conducted. Research about AI-assisted teaching, personalized learning, virtual patients, automated feedback, assessment analytics, clinical reasoning, plagiarism, academic misconduct, and ethical AI were located. The results show that AI has revolutionized medical curriculum delivery in the factors of personalization in the learning pathways, predictive analytics, natural language processing, competency-based education, and simulated environment. Large language models and ChatGPT have shown potential to improve student engagement, clinical decision support, formative assessment, and learner autonomy. Yet, significant issues and fears of algorithmic bias, data privacy, explainable AI, professionalism on the internet, offloading human cognition, overweighting on autopilot processes remain. Among the most commonly reported risks were the academic integrity issues, such as plagiarism and cheating detection, fake citations and unauthorized AI-assisted assessment. The review has shown that effective implementation of artificial intelligence in healthcare education needs to be accompanied by effective ethical governance, faculty training, AI literacy training, clear regulatory frameworks, and human-AI partnership.

Keywords: Artificial intelligence, Computer vision, Virtual reality, Augmented reality, Reinforcement learning, Prompt engineering.

1. Introduction

Medical education has largely undergone change due to the rapid growth in artificial intelligence in both the health care sector and the educational field at large. Artificial intelligence, machine learning, deep learning, natural language processing, and generative AI have become major technologies in teaching, learning, assessment, and curriculum design in the last few years [1]. Intelligent tutoring systems, adaptive learning systems, virtual patients, learning systems based on simulation, predictive analytics, and AI-assisted assessment systems are increasingly becoming a part of medical schools to enhance learner engagement and learning outcomes. The rise of large language models, including ChatGPT, Gemini, Claude, and LLaMA, has hastened the decision to integrate AI into medical curriculum delivery, allowing students opportunities to access as well as personalized learning activities, automatic feedback, clinical reasoning assistance, and self-directed learning activities. Such developments suggest the transition to a more data-oriented and technology-intensive paradigm of healthcare education where human-AI collaboration turns out to be the key to the future of medical training. The rising applicability of artificial intelligence to medical education is intricately connected with the developing complexity of the healthcare system, competency-based education, and the necessity to establish the efficient

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training methodology that is capable of alleviating the faculty resources and clinical exposure deficits. The educational technologies powered by AI have also displayed the opportunity to make learning personal, detect knowledge gaps, offer real-time formative assessment, and assist clinical simulation with the use of virtual reality, augmented reality, or immersive digital reality. The use of intelligent tutoring systems and virtual patients is an upward trend in improving clinical decision-making, diagnostic rationale, communication, and patient-centered care. There is emerging evidence indicating that generative AI systems can benefit medical students in literature review, exam preparation, note summarization, scientific writing, and diagnostic problem-solving and that they can also benefit faculty members in the streamlining of grading, curriculum planning, and assessment analytics. The success of certain large language models in passing or scoring near the performance of senior medical students in licensing tests has heightened discussions on the educational usefulness of AI in the field of undergraduate, postgraduate, and continuing medical education.

Although there is positive news in this regard, the growing role of AI in medical education has brought other significant issues to be considered, like academic integrity, digital professionalism, ethical governance, and educational equity. The use of generative AI applications can create essays, analyzed cases, reflective writing, examanswers, and clinical summaries with little to no human intervention, and therefore plagiarism, college cheating, evaluation of cheating, and falsified references have become a significant problem of educators and higher education. The fast changing aspect of student dependency on AI-based tools has generated confusion over what can be accepted in terms of academic practice particularly in the case of those assessments that are unmonitored, Internet-based tests as well as homework tasks. In numerous situations, students see AI-created material as the legitimate study supporting tool and not as the misbehavior, and the educational staff usually has no fixed institutional practices or technological interventions to recognize the misuse of AI. Issues around cognitive offloading, less critical thinking, misinformation, timeliness injection, and over reliance on automated systems have also risen to the forefront especially in fields like medicine where identity formation in the profession, ethical thinking or reasoning, and clinical judgment are critical. The other significant difficulty is the fact that medical schools, their tutors, and students are ill-equipped to utilize artificial intelligence wisely and efficiently. Medical students express great interest in AI literacy, prompt engineering, explainable AI, and digital professionalism, but at the time of the researchers, they are not yet covered by the curriculums of many institutions. The faculty is still unprepared, and teachers usually have little training in AI-related teaching, assessment redesigning, algorithm bias, data privacy, and ethical application of AI. Lack of clarity of standard regulatory frameworks and the definitions of academic honesty have consequently led to inconsistent institutional responses to generative AI usage among various medical schools and healthcare education ecosystems. Moreover, a constant danger is that AI unbalanced access and methodical bias can enhance all-around teaching disparities among different students with different social, cultural, and linguistic origins. Responsible innovation thus is becoming an urgent issue with the continued integration of artificial intelligence in medical training.

Despite the fact that the research results of earlier studies have investigated the individual aspects of artificial intelligence in medical education, there is a gap in synthesizing research, which wholly considers teaching practice, educational outcomes, learning integrity, ethical issues, and the future educational implication of curriculum research in the medical education context. Current reviews tend to be focused on ChatGPT or generative AI in particular or assessment practice or on particular technological interventions like virtual patients and simulation tools [1-3]. Evidence about the role of AI in influencing learner autonomy, faculty development, digital pedagogy, faculty clinical reasoning, assessment analytics, and professional identity formation is not well integrated into the broader medical education ecosystem. Further, most of the previous researches were made earlier when the use of large language models had not been as popular, and thus a need to assess the latest changes that began to appear between 2023 and 2025. According to recent trends, the growth rate of the AI-based simulation platforms, personal tutoring systems, and study-support tools has increased quickly, which renders the necessity of the evidence synthesis revision. Thus, the proposed systematic review will serve as a summative review of the role of artificial intelligence in medical education, and in particular teaching at medical schools, learning outcomes, and the question of academic integrity. Within the PRISMA framework, this paper aims to conduct an evidence synthesis regarding evidence on the adoption of

generative AI, large language models, intelligent tutoring systems, virtual patients, simulation-based learning, automated feedback, and AI-assisted assessment in healthcare education. Other key ethical issues that the review seeks to highlight are plagiarism, cheating detection, data privacy, algorithmic bias, explainable AI, and digital professionalism. Further, the paper will also add value to the body of literature by identifying gaps in the research, assessing the faculty preparedness, exploring the necessity to implement AI literacy and regulatory frameworks, and offer directions to responsible and equitable practices in integrating AI into medical curricula. In covering the strengths, as well as the weaknesses of artificial intelligence in medical education, this review offers a timely and evidence-based basis to support researchers, educators, policymakers, and medical institutions to approach the relationship between technology and medical training on a case basis.

2. Methodology

It was a systematic review that was performed in full compliance with the Preferred Reporting Items of systematic reviews and meta-analyses (PRISMA) 2020 guidelines to guarantee transparency, reproducibility, and methodological rigour when synthesising the existing evidence on the topic of artificial intelligence in medical education. A thorough and methodological search was performed in four major scholarly databases such as Scopus, Web of Science, IEEE Xplore, and PubMed to identify articles and studies that published in the period between January 2019 and December 2025 a publication dates that was chosen to reflect the blistering pace in the development of AI applications in the area of education. The Boolean search strings employed across Scopus and Web of Science were constructed to maximise sensitivity and specificity and included the following combinations: ("artificial intelligence" OR "machine learning" OR "deep learning" OR "large language model" OR "ChatGPT" OR "generative AI" OR "natural language processing") AND ("medical education" OR "health professions education" OR "clinical training" OR "medical students" OR "undergraduate medical" OR "postgraduate medical") AND ("teaching" OR "learning" OR "curriculum" OR "assessment" OR "pedagogy" OR "simulation"); additionally, a second string targeted integrity concerns: ("artificial intelligence" OR "AI" OR "ChatGPT" OR "generative AI") AND ("academic integrity" OR "academic misconduct" OR "plagiarism" OR "cheating" OR "ethics") AND ("medical education" OR "health professions education" OR "medical students"). The initial database search gave 892 records (Scopus = 312, Web of Science = 241, PubMed = 198, IEEE Xplore = 141), and it was complemented by 18 other records found through a manual citation search of the articles and grey literature sources of interest, resulting in a total of 910 records. After automated and manual deletion of 143 duplicate records and 12 records deleted due to other reasons 755 records were subjected to title and abstract screening where 538 records were eliminated as evidently irrelevant. The other 217 records were pursued to be found full-text in databases and registers of which 14 were unable to be located and the remaining 203 reports were assessed to be eligible as full-text, with 16 other records identified, though 2 of them were not. Inclusion criteria were the studies should be peer-reviewed empirical or systematic articles published in English in 2019 to 2025 but need to specifically address the use, assessment, or criticism of AI tools in teaching in medical or health professions studies and address at least one of the themes of teaching, learning outcomes, or academic integrity. It was further limited to studies that did not appear as an opinion editorial, lack empirical support, were conference abstracts without full-text, or were not within the medical or health education field or lacked enough detail of methods to judge its quality. Following full-text evaluation, 167 reports were eliminated on grounds such as not focusing on AI in medical education (n = 71), not being an empirical study (n = 38), not providing sufficient methodological information (n = 29), not meeting the date range (n = 17) and 16 eliminated as it is not peer reviewed (n = 12) (Refer Fig. 1)

3. Results and discussions

3.1 Artificial intelligence techniques

Machine Learning and Predictive Analytics in Medical Education

Machine learning became one of the most widely documented methods of artificial intelligence in medical education, mainly due to its capability to process massive educational datasets, performance prediction among students, discovery of learning gaps, and student-specific instructional paths. In the studies reviewed, the models that were commonly applied in predictive analytics include decision trees, random forests, support vector machines, and logistic regression and were typically used in identifying students who were at risk of underperforming academically, failing exams, or losing clinical competence. Patterns in the behavior, engagement, and learning progress of the learners were also sought by using unsupervised learning techniques such as clustering and dimensionality reduction. These methods helped the educators shift away the general method of teaching to the data-oriented teaching intervention, which is responsive to the needs of individual students. In competency-based education, especially, machine learning has proved quite useful based on the need to constantly monitor the performance of the students to track the clinical rationale, diagnostic accuracy, communication skills, and procedural competency. Following events have also shown how predictive analytics can be used to enhance optimisation of curriculums, staff workload, and adaptive assessment, thus enhancing the efficiency of education and student achievement. The increasing adoption of machine learning in medical education is a natural development of the wider effect of supporting evidence-based education and adaptive learning frameworks that dynamically adapt to variability in the learners.

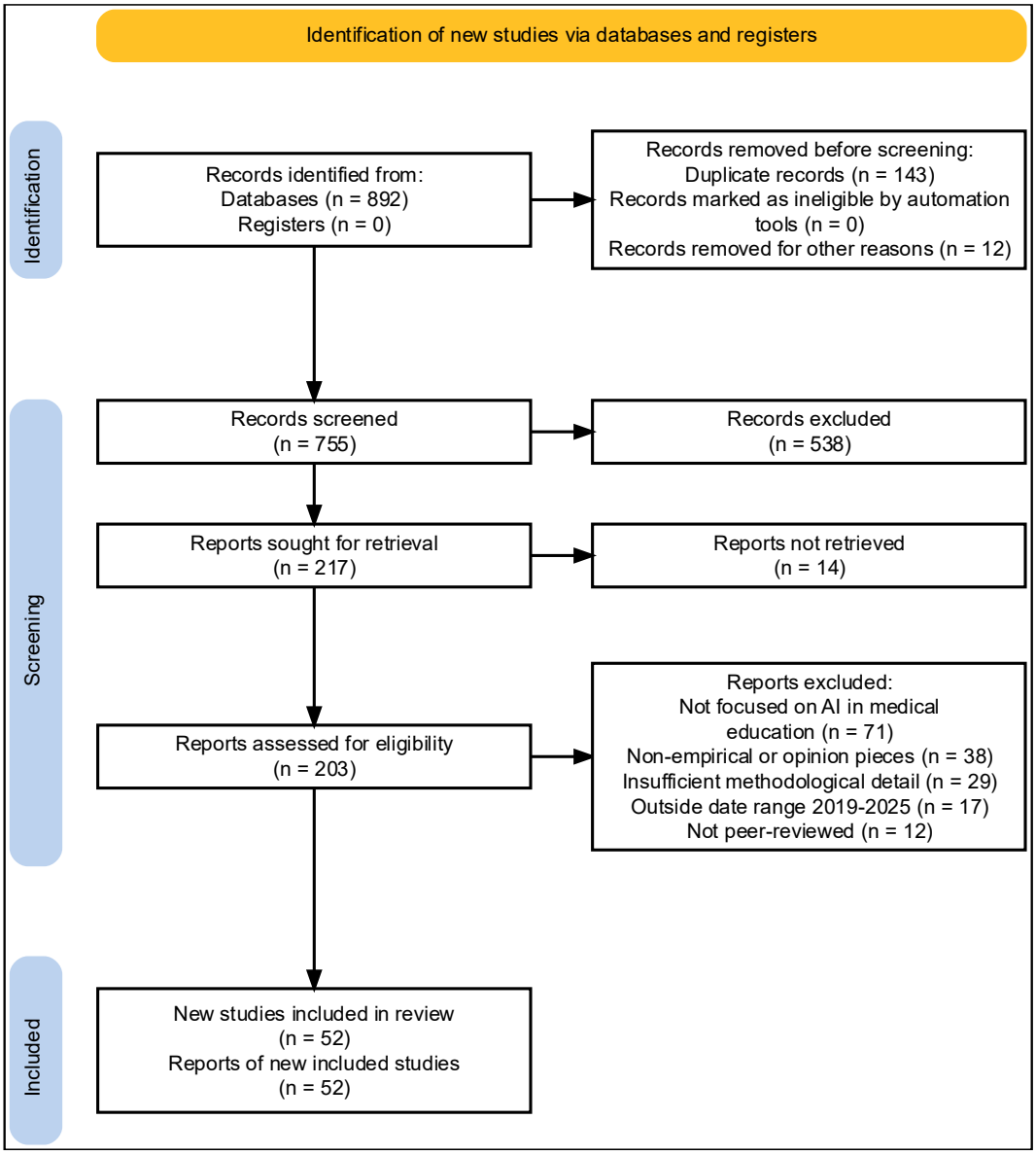

Fig. 1 PRISMA Framework

Machine Learning and Predictive Analytics in Medical Education

The techniques of deep learning have recently stood out in the sphere of medical learning as the methods that might be used to analyze complicated and unstructured data, like medical records, medical images, audio recordings, video records, and logs of interaction. Neural networks, convolutional neural networks, recurrent neural networks, and transformer architectures are heavily researched in order to enhance educational decision-making and clinical training [2,4]. Deep learning algorithms are especially useful in the areas of learning by simulation where they can record student experience with simulated patients, evaluate the nature of diagnostic thought patterns, and provide formative feedback to students automatically. Deep learning has become part of the process of viewing images in radiological and pathology learning as it allows students to compare the result of their analysis with those produced by AI and get specific instructions. Application of deep Learning in multimodal learning systems has also broadened and enabled the combination of text, images, audio and physiological data to be represented in one learning system. These systems are becoming more and more able to sustain full immersion learning experiences, and clinical simulations of high fidelity. Even though these have benefits the literature has continued to record issues of explainability, transparency and algorithmic bias within deep learning systems especially since a significant number of neural network models are black boxes and can generate outputs that cannot be easily interpreted by educators and learners.

Generative AI and Large Language Models

The most rapidly growing type of artificial intelligence method in medical education was generative AI and large language models. ChatGPT, GPT-4, Gemini, Claude, and LLaMA were among the technologies that were applied to increasing content generation, simulating cases, automated tutoring, exam preparation, supporting clinical reasoning and aiding academic writing. The advantages of the large language models are notable since they utilize highly developed natural language processing and the architecture involving transformers, allowing them to produce the replies that resemble those of a human being, provide answers to medical or complicated questions, and engage in the conversational learning process. Generative AI was commonly applied by students to summarize lecture notes, make flashcards, write reflective essays, study to take objective structured clinical exams, and produce practice questions. These tools were applied by educators in planning lessons, rubrics development, automated grading and curriculum designing. Nonetheless, the literature further highlighted that generative AI poses a substantial risk to academic integrity, such as plagiarism, artificial references, and fabricated clinical information, and unauthorized AI-based tests. It was also feared that overreliance on the large language models would diminish critical thinking, autonomous thinking and self directed learning. However, the development of generative AI is quickly advancing, which means that it will continue to be among the most popular methods in healthcare education even in the future.

Natural Language Processing for Educational Interaction

Since it allows computers to understand, analyze and produce human language, natural language processing has now become a cornerstone artificial intelligence application in the field of medical education. NLP technologies are common in chat bots, chatbots, essay scoring systems, plagiarism detectors, clinical documentation training, and sentiment analysis of student comments [5-8]. Natural language processing is of special significance in medical education where it is used to analyze responses of learners in written tasks, case discussion, and communicative practices. NLP-based systems have the capability to evaluate grammar, terminology, clinical reasoning and style of communication and give automatic feedback in real-time. The application of NLP in the processing of electronic health records and medical notes to teach diagnostic coding, clinical documentation, and evidence-based practice was also mentioned in recent studies. The quality of AI-generated explanations and interactive learning has also been enhanced vastly during transformer-based NLP models. Nevertheless, the NLP systems still have issues regarding domain specificity, contextual knowledge, language variation and the correct understanding of medical terminologies. Emerging prospects in NLP Multilingual NLP systems Multilingual conversational agents Explainable language models which can deliver transparent, medically accurate educational support Multilingual conversational agents Multilingual conversational agents Multilingual conversational agents Multilingual conversational agents Multilingual

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Intelligent Tutoring Systems and Adaptive Learning

The most widespread AI methods that were found in the reviewed literature were intelligent tutoring systems and adaptive learning platforms. The systems apply machine learning, bayesian knowledge tracing, learner modeling, and predictive analytics to filter all educational materials based on the individual needs, strengths and weaknesses of the particular student. Smart tutoring systems are capable of giving individualized explanations, suggesting materials to read, creating quizzes, and adapting the challenging level of the assignments dynamically. Adaptive learning settings can be especially useful in medical education as the difference between the students can be significant with regards to their previous knowledge, the pace of learning, and clinical experience. Over time, intelligent tutoring systems are able to detect and remedy any misconceptions, strengthen weak points, and facilitate progression based on mastery since this can be done by constantly assessing the performance of the learner. Other systems combine gamification, chatbots, and virtual coaches to enhance the engagement and motivation of students. Recent researches have indicated that intelligent tutoring system is gradually progressing towards multi-modes of learning which include text, images, audio and simulation. Still, scalability, faculty preparedness, and the confidentiality of data are the significant obstacles to expanded use.

Virtual Patients and Simulation-Based Learning

In medical education, virtual patients and simulation learning environments have become the key artificial intelligence methods because they provide students with an opportunity to experiment with clinical reasoning, communication, and diagnostic decision-making in secure and controlled settings. Whereas traditional simulation usually relied on the use of standardized patients and faculty-facilitated environments, current technologies in large language models and generative AI have made it possible to produce dynamic interactive virtual patients who can engage in realistic conversation and respond to stimuli. The virtual patients using AI can model numerous clinical scenarios, such as those of rare diseases, multimorbidity, mental disorders, and emergency medicine. Such systems usually create role-based prompts, generation of scenarios, automated grading and automatic editing of students to enhance their performance. The use of simulation-based learning has gained importance especially in solving the problems of low clinical exposure, high student faculty ratio and limited resources in medical schools. Recent developments suggest future virtual patient technologies could move back towards multimodal AI (i.e. Learning multiple modalities: Text, voice, facial expressions and physiological signs) to allow patients to experience highly engaging clinical experiences.

Computer Vision and Medical Image Interpretation

Computer vision has emerged as a highly significant artificial intelligence method used in medical education with special emphasis on the areas of radiology, pathology, dermatology, ophthalmology and surgery. Medical images can be analyzed by computer vision to identify abnormalities, and the pattern of diseases in the image can be classified; and the image-based diagnostic training can be supported [6,9]. These systems are also applied in learning institutions where they train learners on how to read X-rays, CT scans, MRI, histopathology mike, and dermatological pictures. Image interpretation with the use of AI enables the students to juxtapose their diagnostic decision and AI-generated reports and thus enhance pattern recognition and clinical reasoning. Surgical training is also another field of computer vision systems since they can capture and analyze the hand movements, procedure precision, and use of the instrument during simulated operations. In recent advances in multimodal artificial intelligence, the combination of computer vision and natural language processing has been made possible, and systems are currently able to describe their visual observations using natural language. Nevertheless, the problem of algorithmic bias, low variety of datasets, as well as the danger of over willingness to rely on AI-provided diagnoses are key challenges in the pedagogical application of computer vision technologies.

Virtual Reality, Augmented Reality, and Immersive Learning

Artificial intelligence is also being incorporated into virtual reality, augmented reality, and immersive learning environments to provide an actual and interactive learning experience in medical training. The virtual reality helps learners to interact with simulated operating rooms, anatomy labs, emergency departments, and patient interactions in 3-dimensional digitized models. Augmented reality is the digital information being overlaid on the physical spaces and this enables the students to visualize anatomy, procedures and clinical information in real-time. These immersive technologies would be adaptable and responsive when coupled with artificial intelligence, changing the difficulty of the situation, giving individual feedback, and tracking the performance of learners. Immersive learning that has been enhanced by AI has been especially helpful in surgical education, teaching anatomy, training in emergency medicine and educating procedural skills. It is proposed in the literature that the further development of immersive learning will resort to more and more multimodal interaction, haptics, eye-tracking, and emotion recognition technologies that will tailor the medical learning experience even more.

Conversational AI and Chatbots

Chatbots and conversational AI due to their ability to scale, access and interactive learning support have become common in medical education. AI chatbots are capable of responding to student queries, describing medical terms, giving immediate responses and navigating learners through complicated clinical situations [10]. With chatbots like ChatGPT, problem-based learning and just-in-time education support in particular, this type of conversational agent performs exceptionally well in supporting self-directed learning. Such systems have the potential to recreate the tutor-student interactions, create bespoke study plans as well as generate case based discussions. Mental health and wellbeing assistance based on conversational AI has also been applied as a solution in supporting medical students by giving stress management advice and academic support. Nevertheless, the literature always emphasized the possibility of creating inaccurate data, imaginary references and simplified clinical directions by conversational AI. As a result, a significant number of studies were focused on highlighting the role of human control, professorial moderation, and AI literacy in making conversational AI systems use safe and responsible.

Reinforcement Learning and Decision Support Systems

Reinforcement learning is a recent artificial intelligence method used in healthcare education, which can enable systems to acquire the best actions by enabling continuous feedback with an environment. Reinforcement learning is becoming common in adaptive learning systems, clinical decision support systems, and virtual simulation systems in educational applications. The systems are able to constantly enhance their advice in the efforts of student performance, involvement, and results. Reinforcement learning has demonstrated itself with potential in directing students in diagnoses, therapy planning cases, and emergency medicine re-enactment in which numerous consecutive choices are demanded. It is useful especially in cases where students are required to know the impact of their activity and also to perfect their logic with the course of time. Students can also achieve diagnostic accuracy, risk assessment, and evidence-based decision-making skills when the reinforcement learning is integrated with the clinical decision support systems. Even though reinforcement learning is relatively new in the field of medical training, it is likely to become more visible with the development of AI systems, which may become more autonomous and adaptable to the specifics of every context.

Knowledge Graphs, Prompt Engineering, and Explainable AI

The knowledge graphs, prompt engineering, and explainable AI have become the essential methods of enhancing the predictability, explanability, and instructional value of the artificial intelligence systems in medical education. Knowledge graphs are networks of medical concepts, diseases, symptoms, treatments, and relationships which may be useful in reasoning, content retrieval, and clinical decision-making [10-12]. Knowledge graphs can be used to mitigate hallucinations, as well as enhance the quality of AI-generated responses, when combined with large language models. The timeliness of engineering has also become a factor of growing significance since the quality of results produced by the generative

AI can rely on how questions, commands, and contextual details are posed to the algorithm. It is observed that medical students and educators are being trained on quick engineering skills in order to make AI generated contents more precise, relevant and reliable. Explainable AI seeks to render the outputs of artificial intelligence to become more understandable and verifiable through displaying users how decisions reach a given result. This especially applies in medical education where the learner should know the reasoning behind the clinical recommendation and not just giving some automatic answers. It can be assumed that future studies will pay much attention to the use of explainable AI in conjunction with knowledge-based systems to produce more credible and more pedagogically useful educational technologies.

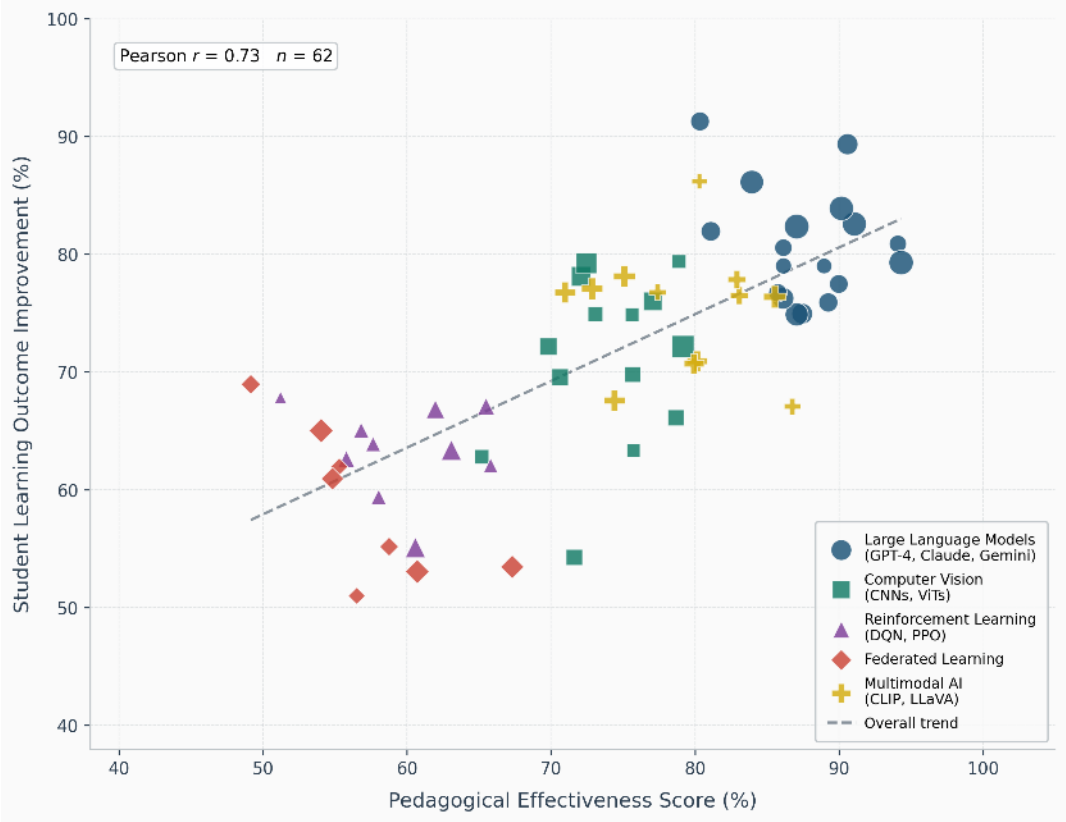

Fig. 2 Pedagogical Effectiveness vs. Student Learning Outcome Improvement

Fig. 2 is a scatter plot examines the relationship between the pedagogical effectiveness scores of five distinct AI model families and the magnitude of student learning outcome improvements reported across the reviewed studies. Each AI category, including Large Language Models (GPT-4, Claude, Gemini), Computer Vision architectures (CNNs and Vision Transformers), Reinforcement Learning agents, Federated Learning frameworks, and Multimodal AI systems (CLIP, LLaVA), is represented by a unique marker shape and color, with bubble size encoding the relative number of learners involved in each study. A global ordinary least squares trend line is superimposed across all data points, accompanied by a Pearson correlation coefficient to quantify the strength of the linear association. The plot reveals that LLMs and Multimodal AI systems cluster in the high-effectiveness and high-improvement quadrant, reflecting the emerging dominance of foundation models in medical education contexts, while Federated and Reinforcement Learning approaches, though still nascent, demonstrate promising variance warranting further longitudinal investigation.

Synthetic Data, Multimodal AI, and Future Techniques

Some of the most innovative and future oriented methods in medical education are syntheter generation of data and multimodal AI. Synthetic data are an artificial set of data that may be used to train AI models without the need to violate the privacy of patients or their data security. The datasets are especially effective in constructing rare disease scenarios, heterogeneous clinical cases, and large-scale datasets of training to learn a simulation. Multimodal AI describes those systems, which are capable of working

with text, images, audio, video, and structured data, at the same time. Medical education Multimodal AI may play a helpful role in integrated clinical reasoning, showing radiology images, patient history, laboratory values, and physical examination outcomes in one platform. These systems can develop very realistic virtual patient interactions and different clinical simulations. Other developments that might be seen in the future include robotic tutors, wearables, emotion aware AI, and collaborative human AI systems which continuously respond to the needs of the learners. These new methods imply that the future of medical education is one where more avenues of learning become more immersive, intelligent and personalized.

3.2 Artificial intelligence methods

Supervised Machine Learning Methods in Medical Education

The most frequently reported artificial intelligence methods used in medical education consisted of supervised machine learning methods because it can predict student performance, characterize behaviors of learners, and help educational decision-making. Techniques like logistic regression, support vehicle machines, random forest, naive bayes classifier and decision trees were employed extensively in discriminating students who were likely to underperform academically, clinically incompetent and slow trackers through medical programs. Such supervised learning techniques have been found to be especially important in competency-based education since they are based on labeled datasets that can be used to relate the behaviors of the learner with the educational outcomes, which may include the level of examination, diagnosis accuracy, procedural ability, and performance in clinical reasoning. One of the themes noted in most of the reviewed papers was supervised machine learning, predictive analytics models proved to identify patterns in online learning activity, attendance, engagement, and quiz performance. Such predictive models would be able to designate students that need early intervention so that faculty can offer specific academic support to these students and also offer specific learning recommendations. The trend of the use of supervised machine learning can be associated with the demand to evidence-based teaching, analytics of learners and personalized learning in healthcare education.

Unsupervised Learning and Learner Profiling

The use of unsupervised learning techniques has gained prominence in medical education since the techniques are applicable in detecting hidden patterns in the behaviour of the learners without the need to assign predetermined labels. The k-means clustering, hierarchical clustering and Principal component analysis were often applied to cluster the students based on their learning styles, engagement type, academic achievement and their favored teaching style [7,13-16]. Such approaches are particularly instrumental in adaptive learning settings since they assist the education providers in knowing how various learner groups connect with the educational technologies, virtual patients, and smart teacher aides. Another application of unsupervised learning to curriculum innovation involves the latent patterns that can be found in significant educational data, including attendance of students, studying habits, digital participation, and test results. With the assistance of unsupervised learning tools, medical schools will be able to design their own individualized learning journeys, enhance the learning design, and enhance the learning equity of diverse student groups. Future studies according to the literature will continue to develop the application of unsupervised learning as a part of multimodal AI and emotional AI to create more complete learner images that include the cognitive and emotional sides of student performance.

Deep Learning Methods for Complex Educational Data

The use of deep learning techniques has become quite important in medical education as this technique is able to handle high quantities of unstructured and multimodal data, including clinical notes, medical images, videos, speech data and records of student interaction. Some of the most prevalent methods of deep learning reported in the reviewed literature included artificial neural networks, convolutional neural networks, recurrent neural networks and transformer architectures. They are very effective in a simulation-based learning setting since they are able to analyze the behavior of the learners (for example

complex behavior) and produce automatic feedback according to the real time feedback. Radiology, pathology, dermatology and ophthalmology education Best practices Typically convolutional neural networks were employed to assist in training image interpretation, whereas recurrent neural networks were employed to model sequential behavior of learners and predict their future educational performance. Transformer-based models have grown particularly prevalent due to the capability of assisting natural language processing and large language models as well as generative AI applications. Nevertheless, as any literature source would point out, deep learning techniques placed in the first couple of articles consistently served as black-box systems, which would require explainable AI and transparency to attain trust and accountability in medical education.

Natural Language Processing Methods

NLP techniques were commonly applied in medical education since they enable artificial intelligence machine to understand, create and analyze human language. The generally used methods of NLP (tokenization, sentiment analysis, named entity recognition, topic modeling, text classification, and transformer-based language models) were often incorporated in chatbots, conversational AI, automated style scoring applications, and plagiarism detectors [2,17-19]. The techniques will be especially useful when it comes to the analysis of written tasks, clinical notes, reflective essays, case reports, and patient communication exercises. Automated feedback regarding grammar, terminology, quality of reasoning, and quality of clinical communication skills can also be offered with the help of natural language processing procedures. Big language models like ChatGPT are based on sophisticated approaches to NLP to produce responses that seem nearly human in nature, summarize learning materials, and address medical queries. Nevertheless, there are also issues connected with hallucinated content, imaginary references, domain specificity, and contextual error of the NLP methods especially when they are applied to complex medical case scenarios. The NLP of the future of medical education probably will be a multilingual system, models of explainable language and context-sensitive conversational agents capable of safer and more precise educational assistance.

Transformer Architectures and Large Language Models

In medical education, transformer architectures have been the leading approach to artificial intelligence as the method of generative AI and large language models. In contrast to the classical machine learning protocols, transformer models are based on attention mechanisms that enable students to work with the complex language patterns and produce the highly contextualized results. GPT, BERT, Gemini, Claude, and LLaMA are examples of models that have been applied in medical education to generate cases, prompt clinical reasoners, auto-tutoring, studying support, assessment design, and reflective writing. Transformer architectures provide learners with the opportunity to converse, explore, and study in a self-directed manner. Another type of system being used by educators is transformer based system to generate quizzes, generate simulation cases, develop rubrics, and automate grading procedures. In spite of these advantages, the transformer-based architectures have serious issues pertaining to the academic honesty, plagiarism, identification of cheating, hallucinations, immediate injection and misleading information. According to the literature, future studies will pay more attention to the timely engineering, model alignment, safety guardrails, and model specifications so that the responsible use of the system based on transformers in healthcare education would be ensured.

Bayesian Knowledge Tracing and Learner Modeling

Intelligent tutoring systems and adaptive learning platforms commonly apply the methods of bayesian knowledge tracing and learner modeling since they permit artificial intelligence systems to take knowledge gueses on a changing learner state. The Bayesian models are able to keep on updating predictions regarding student understanding continually by analyzing the results of quizzes, interaction patterns and completion of tasks [3,20-23]. The techniques are particularly applicable to medical training context since learners usually advance in vexed subjects at dissimilar paces, and would need personalized assistance. The techniques of learner modeling assist intelligent tutoring systems to decide when a learner has solved a concept, whether he needs additional work and the learning material that is best suited. The applications of the Bayesian knowledge tracing are more effective in training procedural skills, clinical reasoning tasks, and competence-based learning in particular since it advocates the

longitudinal tracking of student advancement. Future research indicates that learner modeling systems will combine multimodal data hisses like facial expressions, voice, eye tracking and physiological queues and develop more multifaceted and adaptive learning systems.

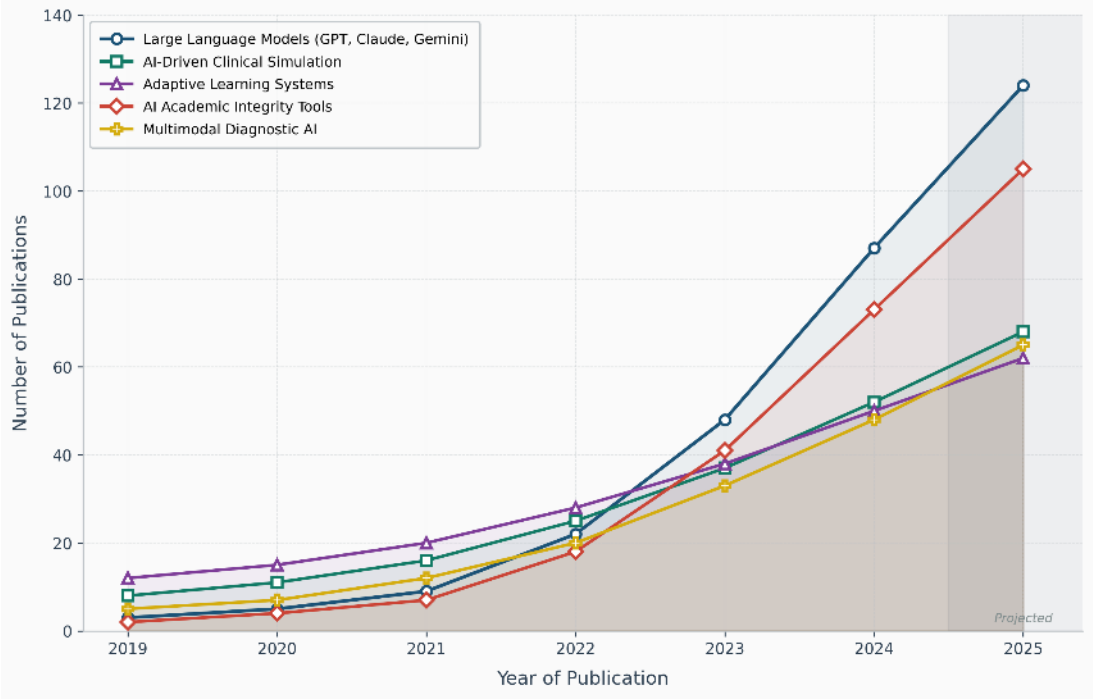

Fig. 3 Annual Publication Trends of AI Technologies in Medical Education (2019-2025)

Fig. 3 is a line plot maps the temporal trajectory of five key AI technology streams within the medical education literature from 2019 through a 2025 projection. The steeply ascending curves for Large Language Models and AI Academic Integrity Tools stand out conspicuously, both having undergone near-exponential growth following the public release of ChatGPT in late 2022, a disruption visually anchored by the divergence of these two series from 2022 onward. AI-Driven Clinical Simulation, Adaptive Learning Systems, and Multimodal Diagnostic AI exhibit steadier, more linear growth trajectories, suggesting sustained but less volatile scholarly interest. The shaded 2025 region highlights projected publication counts and invites critical interpretation of whether current pedagogical infrastructure and ethical governance frameworks can accommodate the pace of technological adoption. Collectively, the figure underscores a field in rapid transition, where the research agenda is being increasingly shaped by the capabilities and controversies surrounding generative AI systems.

Reinforcement Learning Methods in Adaptive Education

Reinforcement learning techniques are more and more being applied in medical training since they provide the possibility of AI apparatus studying via interaction with learners, and improving educational pathways as time progresses. The reinforcement learning is not like the supervised learning in the sense that it uses reinforcement in the form of rewards. Reinforcement learning techniques can also be used in adaptive learning systems to identify what instructional materials, quiz questions or simulation situations are best suited to a specific student. Such techniques particularly find application in the virtual patient system, clinical decision support programs as well as the emergency medicine simulations in which learners are required to make orders in a sequence where they may not be certain of the result. The intelligent tutoring system could also be enhanced through reinforcement learning which would involve adjusting the degree of challenge, feedback and guide based on the performance of the learners. With the increased sophistication of reinforcement learning techniques, it is likely to contribute significantly to the development of highly personalized and context-sensitive educational experiences of healthcare education.

Computer Vision Methods in Clinical Skills Training

Computer vision techniques are also becoming widely used in medical education, as it could interpret any visual information, like medical images, surgery process, facial expression, it could handle movements of a hand. The most common methods of computer vision on the educational sphere are convolutional neural networks, image segmentation algorithms, objects detection systems, or pose estimation models [9,24-26]. Radiology and pathology These techniques are applied to aid in teaching students how to interpret radiographs, CT, MRI images, and histopathology specimen slides. Computer vision approaches have been applied in surgical training to measure procedure accuracy, indicate technical mistakes and give automatic education on the position of hands, instruments, and efficacy of movement. Computer vision techniques are as well being adopted with virtual reality and augmented reality to establish an immersive learning system that mimics real-world clinical practice. Nonetheless, there is still a concern about the bias in the data set, the lack of the equal representation of different patient groups, and the danger of over-reliance on AI-based visual representations.

Conversational AI and Chatbot Methods

One of the fastest-growing methods of medical education is the conversational AI, as it offers accessible and scalable and interactive support to learners and instructors. Chatbots and conversational agents are based on the natural language processing, transformer-based architectures, dialogue management architecture, and retrieval-augmented generation approaches and answer questions, describe concepts, and mimic patient interactions. These techniques are applied more in self-directed learning, problem-based learning and exercises of clinical reasoning. Virtual tutors, virtual patients and academic advisors Conversational AI systems can serve as personalized advisors and provide immediate feedback, either as virtual tutors or patients. According to the recent research, conversational AI is perceived by medical students as something valuable to use during exam preparation, note summarization, and reflective learning. But conversational AI approaches can also pose some academic integrity threat since they can give motivation to superficial studying, overdependence, and unauthorized AI-guided assessment. The use of conversational AI in the medical field will still require human control and faculty awareness to control its responsible use.

Federated Learning and Privacy-Preserving Methods

Federated learning is a new up-and-coming approach to artificial intelligence in medical education since the practice can enable AI to learn through decentralized data set, with no information being transferred to a central server. This solution is especially useful in the sphere of healthcare education since it could safeguard student data, patient data and institutional privacy, and still facilitate the development of multiple models in the course of collaborative cooperation of various medical schools. Predictive analytics, adaptive learning systems, and educational recommendation engines can be enhanced through the application of federation learning techniques and ensuring the requirements of the data privacy rules. Diffidential privacy, secure multiparty computation and homomorphic encryption are also getting popular as other privacy-cost-reducing methods are also capable of mitigating the threat of data misuse and analytics misuse by unauthorized persons. With data privacy emergence as a very central issue in medical education, federated learning and similar privacy-conserving techniques will be increasingly important in future AI-enabled learning institutions.

Explainable AI and Interpretable Methods

The use of explainable AI approaches is becoming more and more important in medical education since it assists students and educators in comprehending the way in which AI systems produce predictions, suggestions, and decisions. Such techniques like feature importance analysis, attention visualization, SHAP value, LIME explanations, rule-based system, and interpretable decision trees are often applied to enhance trust and transparency [27-29]. Explainable AI is especially applicable to educational settings that include clinical decision support, predictive analytics, automated assessment, and academic integrity monitoring since students require information as to why an AI system has arrived at a particular conclusion. Black-box models can have correct predictions, but they are not that useful in that they seldom exhibit any meaningful explanations which can be used to promote reflective learning and

critical thinking. Explainable AI approaches are thus useful in making technology advanced and education worthy. It can be expected that future studies will be based on the idea of implementing more explainable AI in the dangerous trio of large language models, multimodal systems, and intelligent tutoring to make the learning process more transparent and trusting.

Blockchain and Academic Integrity Monitoring Methods

In medical education, blockchain technologies are becoming a popular topic in terms of academic honesty, credential verification, and secure educational records management. The blockchain systems rely on decentralized databases to forge tamperproof assessment, certification, attendance (attendance), and academic performance records. These techniques could assist institutions to ensure that coursework, examinations and professional qualifications were genuine and untampered. The use of blockchain is particularly topical in the area of generative AI since the issues of plagiarism, cheating, drafted assignments, and AI-generated content are all on the increase. Combining plagiarism detection programs with blockchain, stylometric analysis, and authorship identification programs, medical schools can possibly enhance the measurement of academic misconduct. Blockchain techniques can also be useful in lifelong learning documents, microcredentialing, and competency monitoring at various levels of medical training. With the increasing significance of digital professionalism and academic integrity in AI-enhanced learning spaces, blockchain approaches will possibly be considered in the future studies.

Multimodal AI and Hybrid Methods

Multimodal AI practices can be seen as one of the modern directions of medical education as multiple data types can be integrated in a single system: text, pictures, sounds, videos, sensor indicators, and the interactions of the learner. Hybrid approaches can be based on natural language processing, computer vision, speech recognition, emotional AI, and predictive analytics to develop more meaningful and lifelike learning experiences [30-32]. Multimodal AI is able to analyze verbal communication, facial expressions, diagnostic reasoning and procedural performance at the same time in cases of virtual patient simulation. Immersive learning environments that integrate virtual reality, augmented reality, and conversational AI are also being done using hybrid methods. Such systems can process the needs of learners in real-time, and they give learners personal feedback and enhance their engagement. According to the future trend, multimodal AI will ultimately become more integrated with wearable computers, biometric technologies, robotics, and emotional artificial intelligence so that it is able to produce the most adaptive medical training regimes which maybe closer to the experience of actual clinical practice.

3.3 Artificial intelligence technologies

Large Language Models and Transformer Technologies

The technologies that appeared and became the most prevalent in the sphere of artificial intelligence in medical education due to their text generation and dialogue simulation functions, ability to answer complicated questions, and interactive learning included huge language models and transformer technologies. ChatGPT, GPT-4, Gemini, Claude, LLaMA, Med-PaLM, and BioGPT technologies have played an important role in healthcare education by impacting pedagogical, educational, and assessment across healthcare and education. Transformer-based models are built on attention mechanisms enabling them to operate in very long and complicated language sequences, so they are very useful in applications related to medical case analysis, reflective writing, clinical reasoning challenge, and self-directed learning. Such technologies are becoming popular among medical students to summarize lecture notes, develop flashcsards, and formulate diagnoses of differences as well as to review licensing tests. Faculty members have also been using large language models to create quizzes, apply case scenarios, automate grading, and create learning resources. The fact that large language models are able to offer instant, conversational, and context-specific feedback, which can even impersonate a tutor or a mentor, makes their educational value even greater. Nonetheless, the technologies come with significant issues regarding the plagiarism, fake references, misinformation, prompt injection, and academic integrity, and

human control and AI literacy are also crucial elements of responsible usage. In current tendencies, domain-specific medical language models and multimodal transformer systems are going to gain importance in the future of medical education.

Generative AI Platforms and Content Creation Technologies

Medical education is changing through generative AI technologies that allow writing text, images, simulations, videos, and synthetic learning resources. These technologies are also on the rise in the creation of case studies, anatomy diagrams, radiology images, assessment questions, and virtual patient interactions [9,33-35]. The generation AI engines have the potential to generate learning materials that are massively personalized to student needs, which can serve to facilitate adaptive learning and competency-based learning. Generative AI is especially useful in healthcare education since it has been used to generate rare disease scenarios, multilingual cases, and context-dependent learning content, which would be challenging to acquire otherwise. The creation of synthetic content is also applied to faculty development, curriculum development, and AI-assisted assessment. Nevertheless, the advent of generative AI technologies has exacerbated the issue of academic dishonesty, plagiarism, plagiarism detection, authorship verification, digital professionalism, since students can submit AI-written papers, essays, or assignments, or exam results without disclosing it to anyone. There is also preliminary evidence that generative AI will become more extensively integrated with robotics, virtual reality, and multimodal systems to produce more rich and immersive educational experiences.

Intelligent Tutoring Systems and Adaptive Learning Platforms

One of the most commonly used artificial intelligence technologies in medical education is intelligent tutoring systems and adaptive learning platform since they have the ability to allow customization of teaching based on the needs, strengths, and weaknesses of learners. These technologies rely on predictive technologies, learner modeling, and Bayesian knowledge tracing to track student performance and suggest individual, tailored learning paths. Intelligent tutoring systems have the ability to modify the level of difficulty of questions, recommend other learning materials, and give real-time automated feedback. Integrative learning systems are especially significant in medical education since the students may significantly differ in terms of prior knowledge level, learning rate, and clinical practice. Personalized learning technologies can be used to overcome these differences because every student will be instructed in a specific way that depends on his or her advancement and achievement. The latest trends include that adaptive learning technologies are moving towards more conversational AI, gamification, emotional AI, and multimodal feedback to provide more interactive educational experience. Such technologies are projected to be at the forefront of competency-based education and life long learner evaluation in the future.

Virtual Patients and Conversational Simulation Technologies

Virtual patients are among the most significant technologies due to the use of artificial intelligence in medical education as they can help learners to exercise communication, clinical reasoning, diagnostic skills, and patient-centered care in a regulated and repeatable setting. Conventional approaches to simulation typically used standardized patients and instructor-led simulation, whereas AI-based technologies to create virtual patients may now provide an opportunity of simulating realistic communication with running and responsive patient avatars. Conversational simulation technologies combine transactional large language models, speech recognition, emotional AI, and scenario reasoning to produce simulated learning experiences. These virtual patients are able to respond depending on the questions, tone voice and decision-making behavior of the learner. There is also emerging evidence that AI-generated virtual patients can be utilized as more scalable, cost-effective, and flexible than traditional simulation techniques since they can be configured to reflect more medical disorders, patient demographics, and patient communication issues. There are also recent technologies integrating virtual patients with the virtual reality and the augmented reality technologies to create the most immersive clinical environments that enhance student confidence, empathy, and procedural competencies.

Natural Language Processing Technologies

In medical education, many artificial intelligence applications rely on natural language processing technology since it allows machine learning to understand, interpret and produce human language. Automated essay scoring, chat bots, plagiarism detector, clinical documentation training, and conversational AI systems are all automated systems that rely on NLP technologies [36-38]. Medicine Natural language processing technologies are able to process student responses, measure communication capabilities, detect conceptual misunderstandings and offer automated feedback (formative) during medical education. These technologies can be specifically employed when assessing the written tasks, case studies, reflective essays, and the exercises in patient communication. Recent breakthroughs in transformer-based NLP have made AI systems much more capable of parsing intricate medical language and providing responses intended to be clinically significant. Future work direction is anticipated towards multilingual NLP technology, explainable language models, as well as retrieval-augmented generation systems, which integrate language generation with validated medical sources of knowledge.

Computer Vision and Image Recognition Technologies

Computer vision technologies have become a relevant concern in medical learning in the context of the ability to analyze the medical images, offering patterns that are perceived by the learners and delivering them in a format of visual feedback. Such technologies especially apply to radiology, pathology, dermatology, ophthalmology and surgery, where interpretation of the images is the main factor in clinical decision making. Deep learning, convolutional neural networks, and image segmentation are methods used by computer vision systems to detect abnormalities and classify disease patterns and comparisons between the responses learners provide and expert interpretations. Applications of these technologies in education usually include diagnostic training systems, virtual microscopy, and surgical simulators. Technologies in computer vision have also been applied to the process of student performance by tracking their hand movements, posture, and use of instruments. According to future trends, computer vision will also increasingly be integrated with the natural language processing, augmented reality and wearable technologies to provide more interactive and personalized learning opportunities.

Virtual Reality, Augmented Reality, and Extended Reality Technologies

AR technologies (augmented reality), VR technologies (virtual reality), mixed reality, and extended reality are coalescing with some artificial intelligence to produce immersive medical education environments. The technologies enable the learners to study anatomy, conduct a procedure, and communicate with simulated clinical environments in three dimensions [3,39-41]. The virtual reality has the ability to simulate operating rooms, emergency departments, and anatomy labs, whereas the Augmented Reality superimposes digital content on objects or space. Technologies of extended reality find particular application in training procedures, teaching anatomy, emergency medicine, and surgery practice since these processes can be repeated without patient harm. Used together with artificial intelligence, the immersive technologies can help to adjust to the performance of the learner, guide them in a personalized way, as well as observe the progress of the student in real time. Among the new advancements, there are AI-based haptic feedback, eye-tracking and psychophysiological monitoring and emotion recognition, which make the training experience more advanced and personalized. There are also the emergence of AI-based metaverse learning space as a collaborative case study, team learning, and virtual clinical placements.

Federated Learning and Privacy-Preserving Technologies

Federated learning technologies are stirring up importance in medical learning since they enable artificial intelligence models to educate themselves on decentralized datasets without moving sensitive information between establishments. This is especially significant in healthcare education since medical schools tend to deal with huge amounts of student information, patient data and assessment data that should be secure. Federated learning allows institutions to coordinate their efforts in predictive analytics, learning analytics, and educational AI systems to stay in compliance with privacy laws.

Homomorphic encryption, differential privacy and secure multiparty computation are other privacy-saving technologies that are also attracting attention due to the fact that they minimize the chances of data leaks and unauthorized access. Such technologies are becoming especially useful in medical education as they aid the responsible use of AI and preserve the information of the learner as well as the confidentiality of the patient. It is probable that the future of federated learning will be more closely tied to blockchain, cloud computing, and large educational networks.

Blockchain Technologies and Academic Integrity Systems

It is becoming increasingly popular that blockchain technologies are being looked into as a solution to academic integrity, credential verification, and secure records management in medical education. Decentralized layered ledgers allow blockchain systems to build examination, coursework, attendance, certification, and competency assessment records that are difficult to tamper with [36,42-44]. The technologies can be used in institutions to ensure the validity of educational accomplishments and internalize plagiarism, dishonesty, as well as unjust and unauthorized alterations on academic documentation. Generative AI in particular is especially applicable to blockchain-based opportunities as AI generated assignments, forged credentials or authorship are increasingly popular concerns. Other suggested systems utilize blockchain in conjunction with plagiarism detection systems, stylometric analysis systems, and AI-generated content detection systems to enhance the monitoring of academic integrity. Lifelong learning portfolio and digital badges with blockchain technologies and tracking competencies at various levels of medical education and professional growth may also be supported.

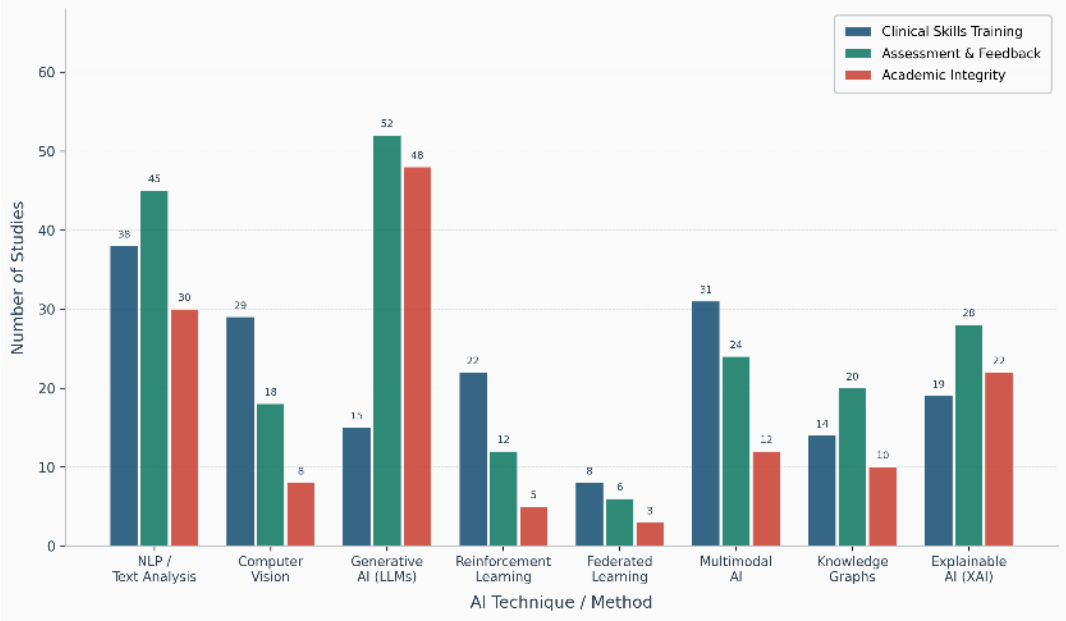

Fig. 4 Grouped Bar Chart - Distribution of AI Techniques Across Medical Education Domains

Above Fig.4 explains a grouped bar chart provides a cross-tabulation of eight prominent AI techniques against three principal application domains: Clinical Skills Training, Assessment and Feedback, and Academic Integrity. The chart reveals several structurally important patterns. Generative AI (LLMs) commands the highest study count in both Assessment and Feedback and Academic Integrity domains, a finding consistent with the surge in research interrogating ChatGPT's dual role as an educational tool and a vehicle for academic misconduct. NLP and Text Analysis maintains broad cross-domain utility, appearing prominently across all three domains. Explainable AI (XAI) registers a notable presence in the Assessment domain, reflecting growing institutional demand for transparency in AI-generated clinical feedback. Federated Learning, while the least represented technique overall, appears in all three domains, signaling early-stage but structurally important adoption driven by privacy-preserving imperatives in medical data handling. This visualization serves as a high-level taxonomic map of where the field's methodological attention is currently concentrated.

Cloud Computing and Scalable Educational Infrastructure

Medical education has plenty of artificial intelligence uses that rely on cloud computing technologies to support their infrastructure. Cloud platforms enable educational institutions to maintain extensive educational data sets, execute computationally intensive AI models, and provide scalable learning resources to various campuses and user populations. The use of cloud based solution is especially relevant to supporting virtual patient simulations, adaptive learning environments, conversational AI systems, and AI-aided assessment tools. These technologies also enable an easier process of medical schools collaborating, exchanging resources and having access to high-quality computing without incurring the cost of expensive local infrastructure. Cloud computing facilitates the incorporation of learning analytics, predictive analytics, and real-time educational monitoring, which is a backbone technology to contemporary healthcare education. Due to the increasing digitalization and data-driven approach to medical education, cloud-based infrastructure will remain the key to allow scalable and flexible AI adoption.

Robotics, Wearable Technologies, and Human-AI Collaboration

Wearable technologies and robotics are gaining more significance in the field of medical education since they allow real time monitoring of performance, medical simulation, and more intimate learning. Surgery Surgical education Robotics have frequently found service in surgical education, where learners use them to learn instrument manipulation, manual dexterity, and minimally invasive surgical procedures in simulated settings [40,45-47]. The wearable gadgets like smart glasses, biometric sensors, eye-tracking systems are able to track the attention, stress, posture, and physiological states of learners during the training session. These technologies can help deliver useful data that may be applied to the personalization of feedback, enhanced self-awareness, and further emotional AI systems. Collaborative efforts between humans and artificial intelligence are also emerging as the primary concern of medical education as a learner needs to know how to effectively collaborate with intelligent technologies instead of merely being dependent on them. The future of healthcare education is probably characterized by the more intimate contact between the students and the faculty, robots and wearable devices, and intelligent systems that work as partners in learning instead of tools.

Multimodal AI, Synthetic Data, and Digital Twins

One of the most innovative fields of AI technologies in medical education is multimodal since it is able to process several data types in real-time (text, images, audio, video, and physiological signals). These technologies are also applicable especially in virtual patient systems, immersive simulations and intricate clinical reasoning tasks, wherein learners need to evaluate various sources of information. The use of synthetic data technologies is also gaining significance since it enables educators to create realistic cases of patients, rare diseases, and large training datasets without the need to violate privacy. Another technology that is taking shape is digital twins which can be used to simulate and educate patients/learners and learners in clinical settings using virtual replicas. One may eventually see these technologies preempting students in making decisions within very realistic and customized situations that respond to their behavior. It is expected that in the future, multimodal AI in use will be paired with digital twins, robotics, and world models to produce highly immersive and adaptive learning environments.

3.4 Artificial Intelligence Models

Transformer Models in Medical Education

Transformer models have emerged as the major models of learning artificial intelligence in medical education due to their capacity to process extensive texts, comprehend relationships among context and be able to produce responses like humans. Transformer architectures of human language are based on attention that enables parallel and not sequential processing of language, which is far more efficient than these older recurrent neural networks [3,48-50]. These algorithms find application in several educational chatbots, intelligent tutoring systems, virtual patients, automated feedback systems and AI-

assisted assessment programs. Transformer model has gained prominence in healthcare education since it can contribute towards clinical reasoning, diagnostic problem solving, writing medical and conversational learning. Their increasing significance is also related to the increase in the number of large-size language models that include GPT, BERT, Gemini, and Claude that are becoming increasingly used in undergraduate and postgraduate medical education. Transformer models have a learning value of providing the support to adaptive learning, personal learning, and quick information access. Yet, due to their growing popularity, they also pose the problems of academic dishonesty, delusional information, and the unhealthy dependence on the provision of answers by AI. Their capability to work with large context windows and produce detailed educational outputs has led to the foundation of most of the modern artificial intelligence applications in medical education known as transformer-based systems.

GPT Models and ChatGPT Applications

GPT models and ChatGPT are among the most promising large language models that are used in medical education at the present moment. GPT-3, GPT-4 and GPT-4o have shown high abilities in creating an educational text, summarizing lectures, responding to test questions, creating flash cards as well as assisting in self-directed learning. ChatGPT has gained particular popularity with medical students due to its ability to create a type of tutor engagement, offer real-time answers, and facilitation of reflective learning. Also popular among educators are GPT models that designers use to generate multiple-choice questions, generate case studies, design grading rubrics, and offer automated formative assessment. In most of the studies, GPT-based systems showed equivalent or higher performance in licensing examinations and board-style assessments in comparison to average medical students which suggests their increasing capability in competency-based learning and clinical reasoning. Meanwhile, GPT models cause significant concern in terms of plagiarism, creating references, misinformation, and detecting cheating due to the ability to create essays, reports, and answer test questions with minimum effort. Due to the growing complexity of GPT models, it means they will keep shaping the policies of teaching, learning, and academic integrity in medical schools.

BERT Models and Contextual Language Understanding

BERT models have gained significant importance in medical education due to their contextual relationship generating abilities in language and not only in text generation. BERT models are based on bidirectional encoding, unlike GPT models, which are autoregressive and predictive by nature, which allows language to be analysed in both left-to-right and right-to-left contexts [5,8,51-52]. It is due to this that BERT is particularly useful when it comes to automated essay scoring, detecting plagiarized content, sentiment analysis, concept extraction, and question answering. BERT-based models are commonly applied in medical education to perform the analysis of student assignments, interpret clinical notes, find the gaps in knowledge, and evaluate the communication skills. These models perform exceptionally well in the assessment of reflective writing, case reports, and patient communication exercises since they are able to detect subtle language patterns, as well as contextual meaning. Recent developments based on biomedical BERT variants like BioBERT, ClinicalBERT and PubMedBERT have helped reduce the performance in recognizing medical terms and are also domain-specific natural language processing. BERT models are likely to be relevant in medical education due to the highly developed contextual cognition, educational analytics, and automated evaluation.

Convolutional Neural Networks in Image-Based Education

In medical education, convolutional neural networks represent one of the most significant models of deep learning since they are particularly configured in image recognition and computer vision. CNN models have been applied in the fields of radiology, pathology, dermatology, ophthalmology, and surgery education since these are capable of processing X-rays, CT scans, MRI images, histopathology slides, and skin lesion photographs. Medical education demonstrates the use of convolutional neural networks in image interpretation systems where the student inputs their own diagnosis into AI-generating systems to see that the AI images of the same diagnosis align with their own diagnosis. These models are able to detect and classify pathologies, recognize visual patterns and determine the category of disease with high precision. Surgical simulation systems also employ CNN-based educational tools, which are able to analyze the movement of hands and techniques used in the procedures or handling of

the instruments. Convolutional neural networks have helped towards more intuitive and graphical learning which could enhance clinical reasoning and diagnostic assurance. Nevertheless, there are some apprehensions connected to the bias in the datasets, the lack of diversification of training pictures, and excessive reliance on the results of the algorithms.

Recurrent Neural Networks and Sequential Learning Models

Some of the first artificial intelligence models applied to the sequential learning tasks in the field of medical education were recurrent neural networks and long short-term memory models. Such models are created to handle the data automatically in a certain order and can be used to process time dependent information like progress of learners, answers on quizzes, sequences of clinical events and patterns of communication [9,53-55]. Student performance, tracking learning and educational engagement, as well as learning analytics systems, have been forecasted with the help of RNN and LSTM. These models have the ability to follow the steps of learners through the clinical scenarios and preserve the pattern related to successful decision-making in simulation-based learning settings. Recurrent neural networks were also previously prevalent in natural language processing, albeit replaced over time to a considerable extent by transformer models due to its ability to operate on longer context windows. However, recurrent neural networks remain handy in process of teaching and learning that depend on time-series examination, longitudinal evaluation and sequence modeling of learning behaviours among learners.

Bayesian Models and Probabilistic Reasoning

The use of Bayesian models in medical education is gaining relevance due to the fact that it offers a probabilistic model of making decisions, estimating uncertainty, learner modeling. The Bayesian networks have highly common applications in intelligent tutoring systems, adaptive learning systems, and predictive analytics since they can be used to provide an approximate to the probability of the student knowing a concept or to pass a specific task. Bayesian knowledge tracing models are particular when tracing knowledge of competence based learning as it can be continuously updated to predict rather than predict according to new evidence. The models likewise can be useful in education on clinical reasoning since they can approximate diagnostic uncertainty and educate the students to understand how to interpret probabilities during medical decision-making. The new trends in uncertainty-conscious transformer models suggest that Bayesian methods will be even more significant in the future of healthcare education. Newer models like MedBayes-Lite are integrated with Bayesian uncertainty quantification and transformer architectures to enhance credibility, calibration, and explainable AI in healthcare.

Reinforcement Learning Models in Adaptive Education

Reinforcement learning models are gaining significance in medical learning since they can be trained based on repetition, and they are able to optimize a sequence of decisions. In contrast to supervised learning models, the reinforcement learning systems involve reward systems to identify the most effective actions in a specified environment. Reinforcement learning models are applied in adaptive learning systems, virtual patients, clinical simulation, and intelligent tutoring systems in medical learning. Such models will have the ability to customize learning courses by choosing the most suitable learning tools, modifying the complexity of activities, and deciding when extra feedback is required. Reinforcement learning particularly proves to be helpful in simulation of emergency medicine when the students have to make sequential decisions in cases of uncertainty. Recent developments also show that reinforcement learning is being combined with large language models and vision-language models to enhance reasoning and interpretability capabilities. These trends can bring AI-assisted medical training to a considerable degree.

Vision-Language Models and Multimodal AI

Vision-language models are the most sophisticated artificial intelligence models that are starting to gain traction in medical education since these are able to process both visual and textual-based information in tandem with each other. Such multimodal AI systems are trained to process medical images with

computer vision and natural language processing and are applied to elucidate medical images and guide diagnostic reasoning [56-58]. Vision-language model is particularly useful in radiology, pathology, and anatomy training since it can be used to relate image results with clinical history and textual comments. The recent model like MedVLM-R1 illustrates how vision-language models can produce natural language reasoning in feedback to radiological images, which are more explicable and easier to educate. The use of multimodal AI models is also being applied in virtual patient simulations, immersive learning environments, and augmented reality. Their text-mixing capabilities with graphics and physiological records and structured information are indicative of how they might be key to the future learning medical environment.

Graph Neural Networks and Knowledge Graph Models

Graph neural networks and knowledge graph models are becoming increasingly popular in medical education due to their ability to give modeling of medical concepts, diseases, symptoms, treatment, and learning materials. Knowledge graphs are specifically useful in clinical reasoning training since they assist students to visualize relationships among various elements of diagnosis and treatment. Graph neural networks could process intricate networks of information and provide suggestions dependent on the relationship within these networks. These models are becoming increasingly popular in medical education in decision-support systems, intelligent tutoring systems, and adaptive learning environments. More recent progress suggests that knowledge graphs are being combined with large language models to make factual predictions more accurate and minimize hallucinations. This combination can be of even greater importance in establishing reliable educational systems that can offer responses that are structured and based on evidence.

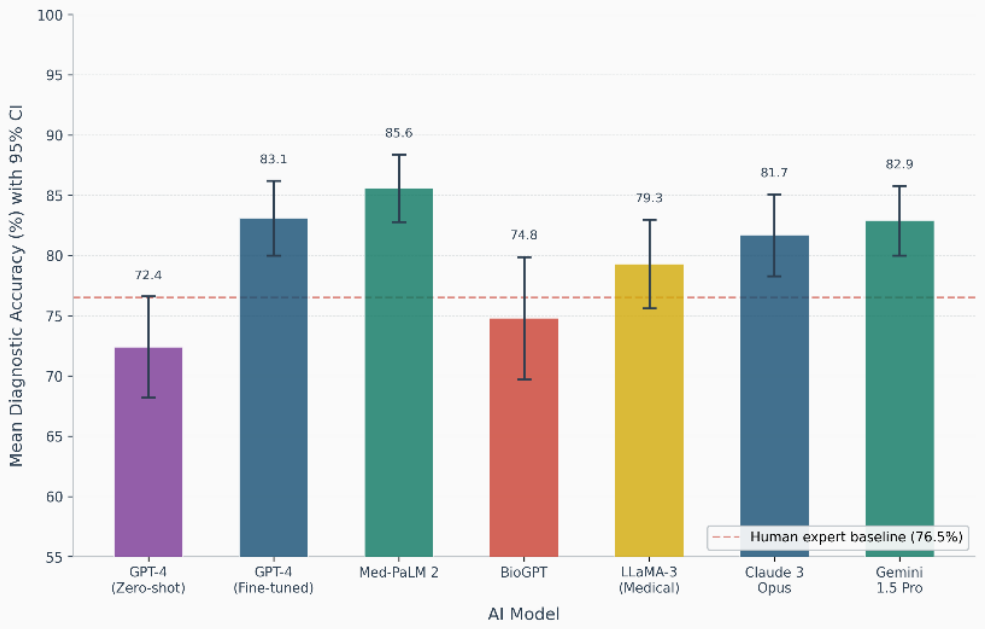

Fig. 5 Comparative Diagnostic Accuracy of Leading AI Models with 95% Confidence Intervals

Above mentioned Fig 5 is a error bar plot benchmarks the mean diagnostic accuracy of seven state-of-the-art AI models evaluated in medical education and clinical reasoning tasks, with error bars representing 95% confidence intervals derived from pooled study estimates. Med-PaLM 2 achieves the highest point estimate at 85.6%, followed closely by Claude 3 Opus and Gemini 1.5 Pro, both of which surpass the human expert baseline of 76.5% represented by the horizontal dashed reference line. GPT-4 in its zero-shot configuration performs below the human baseline with notably wider confidence intervals, reflecting greater performance variability across heterogeneous medical knowledge assessment tasks; however, its fine-tuned variant narrows this interval substantially, underscoring the critical role of domain-specific adaptation. BioGPT and LLaMA-3 Medical occupy the mid-performance band, indicating that open-weight, biomedically pre-trained models are approaching but have not yet consistently surpassed proprietary alternatives under standardised evaluation conditions.

This figure is directly pertinent to ongoing debates about AI deployment readiness in high-stakes clinical education environments.

Retrieval-Augmented Generation Models

Such models as retrieval-augmented generation models are being used more frequently in medical education due to their method of integrating generative AI with knowledge retrieval systems. In contrast to conventional large language models that do not utilize any pretraining, retrieval-augmented generation models have the ability to search verified databases, knowledge graphs and other educational resources and generate responses [59-60]. This minimizes the possibilities of hallucinated contents, created references, and misinformation, which are of great concern in medical education. Evidence based learning, clinical reasoning exercise, and writing more academic texts are specific areas where retrieval-augmented generation models can be useful by giving more reliable and accurate answers. The models are finding application in medical education in tutoring systems, conversation AI, and automated feedback systems. Its increasing popularity is supported by the necessity of the more credible AI systems, which will not interfere with academic integrity or patient safety.

Federated Learning Models and Privacy-Aware Systems

The role of federated learning models in medical education is gaining increasing significance due to their functionality to allow the artificial intelligence systems to learn using distributed datasets without sending sensitive information. This is more so in healthcare education since medical schools usually deal with confidential student records, cases of patients and assessment data. With federated learning, institutions are able to work together on predictive analytics, adaptive learning, and use of AI to aid assessment without violating the data privacy laws. These models will be able to assist with enlightening change without the sensitive disclosure to undue danger. Federated learning is also pertinent to ethical AI since it fosters responsible data utilization and ensures that the privacy of learners and the confidentiality of patients are safeguarded. Federated learning models will probably become a more significant element of medical education technologies as the issues of cybersecurity and data protection expand.

Explainable AI Models and Transparent Decision-Making

Explainable AI models play a crucial role in the field of medical education since they assist learners in comprehending how artificial intelligence systems come to their conclusions, make predictions and come up with recommendations. SHAP values, the visualization of attention, saliency maps, interpretable decision trees, and the analysis of the importance of features are all techniques that are gaining popularity to enhance transparency and trust [9,61-63]. Explainable AI is particularly valuable in medical education as learners need to develop an intuition of why a diagnosis or recommendation is made by an AI instead of blindly pursuing a response provided by an AI. Models that are transparent would be more helpful in critical thinking, reflective learning, and ethical decision-making. According to recent research, explainable AI will only grow in significance as large language models, vision-language models, and reinforcement learning systems become increasingly complicated. The focus of educational institutions might be put on more transparent, clear, and reliable AI systems that will not decrease human-AI collaboration, but rather enhance it.

3.5 Artificial Intelligence Applications

Personalized Learning and Adaptive Learning Applications

Artificial intelligence applications to medical education particularly personalized learning and adaptive learning are among the most common report applications to date since the educational content can be adjusted based on the needs, strengths, weaknesses, and learning rate of individual learners. Adaptive learning systems based on AI may examine the performance of the learners, their knowledge gaps, and provide recommended educational materials in real time. Such systems frequently are based on predictive analytics, learning analytics, and intelligent tutoring systems to adapt the difficulty of quizzes, change study schedules, and tailor feedback. Adaptive learning applications prove useful

especially in competency based education since students with learning disabilities can learn challenging subjects like anatomy, pharmacology, pathology and clinical reasoning at their pace. The increased adoption of customized learning applications is an indication of the trend gearing away the traditional concepts of standardized teaching, in favor of more buyer-oriented experiences in the healthcare education system. Recent evidence also suggests that adaptive learning applications have an ability to enhance student engagement, retention, self-directed learning, and academic performance, especially in large classes where the faculty might not be able to offer students individualized attention.

Intelligent Tutoring Systems and Conversational AI Applications

The use of intelligent tutoring systems and conversational AI applications within the framework of medical education is now a central element of the customized approach in the sphere as it offers an immediate, interactive, and personalized learning experience. The AI tutors will be able to respond to student questions, elaborate on challenging concepts, deliver their formative assessment, and facilitate learners in case-based discussions. ChatGPT-powered, GPT-4-powered, Gemini-powered, Claude-powered, and other large language model conversational AI, are being used more to model tutor-student interfaces and facilitate problem-based learning. They are especially applicable in those disciplines that demand large amounts of memorization and conceptual knowledge like physiology, microbiology and clinical medicine. Self-directed learning also has conversational AI with the benefit that students can pose questions anytime without necessarily depending on the availability of the faculty. Medical schools are beginning to understand that intelligent tutoring systems are able to enhance learning effectiveness, decrease faculty workload, and facilitate learning between classes. Nevertheless, there are issues of misinformation, misinterpreted content and excessive reliance on AI-generated explanations, too, in these kinds of systems.

Virtual Patients and Simulation-Based Learning Applications

One of the most revolutionary AI applications in medical education is the use of virtual patients and simulation-based learning applications since they provide students with the ability to develop clinical reasoning and communication skills, engage in diagnostic decision-making, and provide patient-centered care in harmless and controlled conditions. With the concept of AI-based virtual patients, learners can encounter a great range of simulated clinical situations without putting real patients at risk because virtual patients can replicate natural symptoms, emotional reactions and dialogue [64-66]. These applications are also very helpful in history taking, physical examination, diagnosis, emergency medicine, and chronic disease management. New current trends in generative AI and agentic AI systems have made virtual patient systems much more realistic and adaptive to student actions and questions, as they can dynamically respond to them. Certain systems are also able to give automated scoring, standards-based feedback, and competency evaluated according to the quality of communication, clinical reasoning, and professionalism. Preliminary data indicate that AI-based virtual patients simulations can have a great impact on student scores in clinical skills evaluation and belief in the ability to operate in the actual clinical environment.

Clinical Reasoning and Decision Support Applications

Clinical reasoning and decision support artificial intelligence applications are gradually gaining significance in medical education due to their ability to empower learners to acquire the accuracy of diagnosis and evidence-based thinking as well as structured problem-solving capabilities. Artificial intelligence (AI)-based support tools are capable of processing clinical signs and pathology, laboratory, and radiography results, as well as patient history, to produce a set of possible diagnoses and treatment guidelines. These systems are specifically applicable during case-based learning, virtual patient simulation, and bedside teaching since they expose the students to complex clinical situations that demand sequential reasoning and decision-making. Multimodal AI systems and big language models are becoming more and more a part of clinical reasoning tasks since they can provide contextualized explanations, find alternative diagnoses, and create uncertainty in clinical practice. Such applications prove to be particularly applicable in areas like internal medicine, emergency medicine, and oncology and psychiatry where the complexity of diagnoses is high. Yet, there is an increasing evidence of concern

that over-reliance on decision support provided by AI would impair critical thinking and cognitive independence in students unless they critically analyze the decisions suggested by AI systems.

AI-Assisted Assessment and Automated Feedback Applications

This has made AI-based assessment and automated feedback app more significant in medical education since teachers can assess the performance of students more quickly and consistently. Multichoice exams, short answer tests, essays, clinical exercises and reflective writing assignments are some of the multichoice tests that can be graded automatically by AI systems [6,67-69]. Automated feedback applications would be able to offer students immediate feedback regarding communication skills, diagnostic reasoning, medical terminology, and performance of a procedure. The tools are especially applicable in large medical programs where the faculty members are burdened with vast assessment tasks. The application of AI-assisted assessment is also enhanced by the inclusion of competency-based evaluation systems, predictive analytics, and natural language processing. New uses are automated scoring of objective structured clinical examination, virtual patient, and communication exercises. In spite of such advantages, there is still a question about reliability, fairness and transparency of the automated grading systems, particularly in the assessment of highly subjective skills like empathy, professionalism among ethical reasoning.

Predictive Analytics and Learning Analytics Applications

Learning analytics and predictive analytics are beginning to be applied in medical education to detect student behavioral trends, predict educational results, and facilitate early intervention programs. AI systems can study attendance, exam results, online activity, school attendance in learning management systems, and clinical evaluation outcomes to detect students who risk experiencing academic underperformance or burnout. They are especially suitable in medical teaching since the curriculum is highly active, and early noticing of underperforming students can enhance retention, wellbeing, and academic achievements. Faculty members can also be supported by predictive analytics to know which teaching strategies, assessment assess types, and curriculum items are the most effective. Applications of learning analytics are getting more and more merged into adaptive learning systems and intelligent tutoring tools to form an ongoing loop of monitoring, interventions, and enhancement. Increased use of predictive analytics represents a larger trend in the direction of evidence-based education and evidence-based curriculum.

Natural Language Processing Applications in Communication and Documentation

In the context of medical education, the role of natural language processing applications in the field is getting larger due to the opportunities of AI systems to analyze, generate and evaluate written and spoken language. NLP technologies are used in automated essay scoring, clinical documentation training, reflective writing analysis, plagiarism detection, and communication skills assessment [70-73]. Applications based on natural language processing are particularly useful in medical education as they can teach students the language of writing patient notes, discharge reports, referral forms and case stories. NLP systems have the ability to involve real-time feedback concerning grammar, diction, clarity, empathy, and clinical accuracy. NLP has also been applied to the domain of conversational learning and question-answering systems through large language models. Nevertheless, there are also issues related to academic integrity where students can use the generative AI applications to create assignments, essays or reflective work that are not reflective of their work. Multilingual communication assistance, explainable language models, and further advanced authorship verification systems are predicted to be the subject of future use.

Computer Vision Applications in Image Interpretation and Procedural Training

The use of computer vision in medical education is gaining preference due to its ability in image interpretation, training of the prudence of the procedure, and examination of skills. The applications are of particular importance to radiology, pathology, dermatology, ophthalmology and surgery, where students will have to learn how to interpret more complicated information presented through visual means. Computer vision systems based on AI are capable that in turn also enable students to interpret

the results against those provided by the algorithms of X-rays, CT scan, MRI scan, histopathology slide, and even a surgical video. During procedural training, computers have the ability to track hand movements, postures, and handling of instruments, and technical precision during simulations or surgery. These applications will enable students to train visual diagnostic skills and enhance procedural competency by repeated practice, with an instant feedback. New multimodal AI systems are also being integrated in which students are also offered an audio explanation of visual conclusions through providing computer vision and natural language processing.

Virtual Reality, Augmented Reality, and Immersive Learning Applications

Medical education is starting to adopt virtual reality, augmented reality and immersive learning applications, as they offer realistic and interactive training environments. Immersive learning systems with AI capabilities could be used to simulate anatomy laboratories, emergency departments, operating rooms, and patient meetings in three-dimensional virtual environments. Such applications have found new applications in the domain of anatomy, surgery, emergency medicine, and procedural skills teaching due to the fact that they enable students to rehearse without running any risk to the patients. In addition, virtual reality and augmented reality applications can be customized based on the needs of learners, and AI systems may vary the difficulty of the tasks, offer automated feedback, and track student progress. The digital twins, haptic, emotion recognition, and metaverse learning applications are some of the new ones, where students can learn in virtual clinical environments. These virtual technologies will have a more significant role in future healthcare education.

Academic Integrity, Plagiarism Detection, and Cheating Detection Applications

The academic integrity applications have entered an upward trend regarding the level of importance to medical education due to the fact that generation AI tools are now capable of creating essays, case reports, and examination answer as well as reflective writing with the minimal human effort. Plagiarism detection AI systems are being modified to recognize AI generated content, odd writing styles, authorship inconsistencies, and suspicious similarity of assignments [19,74-76]. Online examinations that use cheating detection software are also becoming more prevalent, AI systems are able to track eye movement, facial expressions, browsing and typing habits to identify suspicious behavior in the test taker. Authorship verification tools and blockchain technologies are also becoming potential solutions to academic integrity protection and in verifying the original student work. Nevertheless, the literature speculates that the existing AI-detection systems are not perfect since students have the ability to paraphrase AI-generated material or cheat by prompt engineering. It is important to point out, that more explicit policies, ethical principles and educational choices are necessary, to promote responsible generative AI usage instead of solely using punitive detection measures.

Faculty Development and AI Literacy Applications

The concepts of faculty development and AI literacy applications are gaining more popularity due to the fact that most instructors have not studied the possibilities and the drawbacks and ethical aspects of artificial intelligence in medical training. Faculty can be taught through AI literacy programs to comprehend the uses of large language models, predictive analytics, adaptive learning systems, and virtual patients in learning. Curriculum innovation is aided by such applications as well as they assist educators in redesigning assessment, integrating AI applications in a responsible way, and teach the students how to critically assess the information generated by AI. More recently, there have been positive signs that medical schools have begun to develop AI credential programs, workshops, and training courses to equip educators and learners to work in AI-funded healthcare settings. Such activities focus on online professionalism, timely engineering, ethical artificial intelligence, information privacy and patient security. Faculty development is critical since the success of implementation of AI is not considered solely on technology but also on whether educators can utilize the technology safely and in an efficient manner.

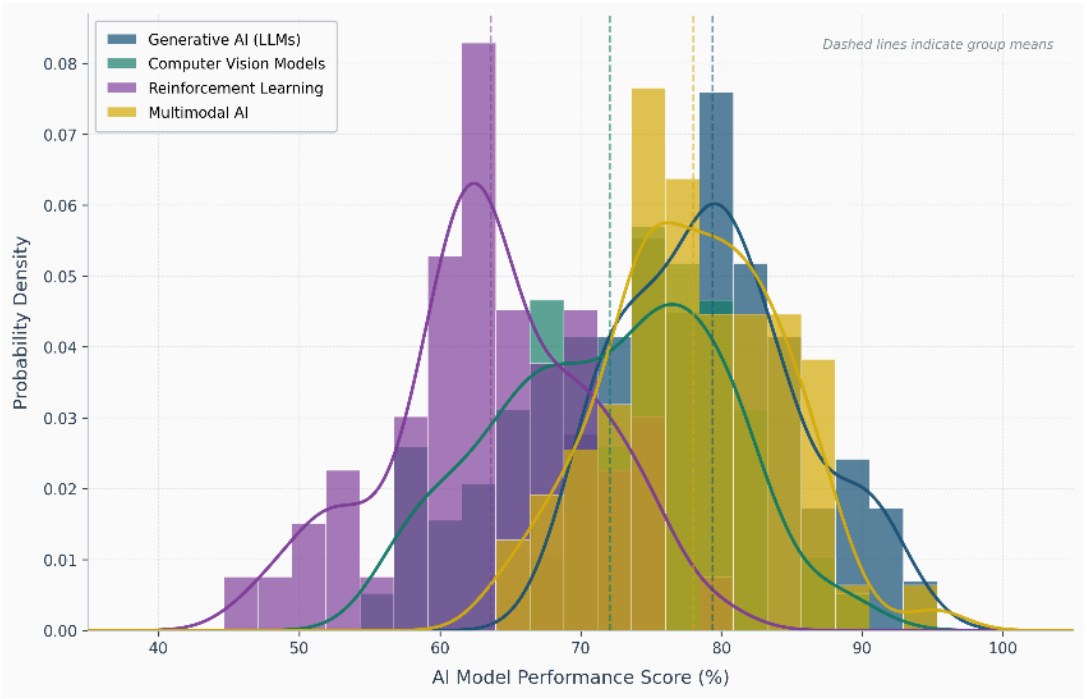

Fig. 6 KDE Overlay - Performance Score Distributions Across AI Model Categories

Fig. 6 shows probability density histogram with superimposed kernel density estimation (KDE) curves compares the full distribution of reported performance scores across four AI model categories extracted from the reviewed literature. The overlapping distributions reveal important structural differences beyond simple mean comparisons. The Generative AI (LLMs) distribution exhibits a visible bimodal character, with a primary mode near 81% and a secondary shoulder near 74%, reflecting the performance gap between fine-tuned and zero-shot configurations pooled within this category. Computer Vision models show a broader, platykurtic distribution centered near 73%, suggesting considerable heterogeneity in imaging task complexity and dataset characteristics across studies. Reinforcement Learning models display the widest spread and lowest central tendency, indicative of the exploratory and task-specific nature of their medical education applications. Multimodal AI presents a relatively tight, leptokurtic curve clustered near 78%, a pattern consistent with the precision-optimized design philosophy of systems such as CLIP and LLaVA when deployed in structured diagnostic learning tasks. Dashed vertical lines mark each group's mean, facilitating rapid visual benchmarking across categories.

Mental Health, Emotional AI, and Student Wellbeing Applications

The emotional AI and mental health are also becoming a significant field of medical education as medical students tend to experience stress, burnout, anxiety and emotional fatigue. The AI-based wellbeing systems are capable of tracking mood, engagement, the level of stress, and communication trends of the students to understand those who might need help [77-79]. The AI systems that are being used to provide stress management advice, peer support, and access to mental health resources also work conversational. They can be using emotional AI technologies that calculate emotional shifts by analyzing facial expressions, vocal patterns, typing behavior, and physiological clues. Though these applications are capable of assisting the institutions more quickly engage earlier intervention and offer more intimate assistance, they also expose issues of privacy, surveillance, consent, and the hazard of substituting the human counselling with automated implementation. Recent studies indicate that emotional AI is not meant to substitute professional mental health services in medicine but it should be added to support the services.

4. Discussion

These systematic review results indicate that artificial intelligence is ceasing to be an adjunct innovation in medical education but serve as the foundational force behind change in the teaching, learning, assessment, and academic governance. Generative AI, large language models, ChatGPT, adaptive learning systems, intelligent tutoring systems, virtual patients, and predictive analytics are all technologies that are transforming the way medical students learn, build clinical reasoning, and learn independently. Educational technology supported by AI has made it possible to have more tailored learning processes, automatic feedback systems, and competency-based learning systems capable of updating themselves based on the performance of the learner. The advancements have generated substantial possibilities to enhance educational efficiency, higher student engagements, and decreased the faculty workload in more sophisticated healthcare educational settings. Simultaneously, there has been significant concern over the swift implementation of AI applications regarding academic honesty, online professionalism, and online privacy, biasing algorithms, and disparities in access to educational technologies. In the literature, it is repeatedly indicated that the implementation of artificial intelligence in medical education is proceeding at a faster rate than the deliberation of institutional policies, faculty preparedness, and ethical systems of governance. Among the most significant discoveries throughout the literature review, it is possible to note that the generative AI and large language models have come to the forefront of medical education, as they facilitate a multifunctional set of tasks, such as content creation, examination generation, automated study, clinical reasoning aid, exam Design, and research assistance. The use of ChatGPT and its analogous systems by students to summarize articles, create flashcards, apply to viva questions, and elaborate on hard medical terms grows in popularity. These tools are also used by members of the faculty in planning their lessons, creating rubrics, helping with grading, and curriculum development. Nevertheless, the popularity of generative AI has erased the line between fair use of learning support and academic dishonesty. The majority of the students do not consider AI-aided writing, paraphrasing, or idea creation dishonest, particularly when the rules are vague in the institutions. This poses immense plagiarism detection, cheating detection, authorship, and assessment redesign difficulty. According to recent surveys, the adoption of generative AI by students has upshot to a terrifying degree, as most learners now use AI tools in some way in academic assignments.

Table 1. Summary of Artificial Intelligence Applications, Techniques, and Educational Impact in Medical Education

Sr. No.	Application	Techniques/Technologies	Educational Impact
1	Personalized learning	Adaptive learning, predictive analytics	Improves learner-specific study pathways
2	Intelligent tutoring	Conversational AI, ChatGPT	Enhances self-directed learning
3	Clinical reasoning	Large language models, decision support	Strengthens diagnostic thinking
4	Virtual patients	Generative AI, simulation-based learning	Improves clinical communication
5	Assessment automation	AI-assisted assessment, NLP	Reduces grading workload
6	Reflective writing support	Generative AI, NLP	Supports structured thinking
7	Radiology education	Computer vision, deep learning	Improves image interpretation
8	Surgical training	Virtual reality, augmented reality	Enhances procedural skills
9	Feedback systems	Automated feedback, machine learning	Provides real-time guidance
10	Learning analytics	Predictive analytics, data mining	Identifies struggling students
11	Academic writing support	ChatGPT, transformer models	Assists literature review and summaries
12	Faculty development	AI literacy, prompt engineering	Improves educator readiness
13	Mental health monitoring	Emotional AI, conversational AI	Supports student wellbeing
14	Curriculum design	Generative AI, educational technology	Enables curriculum innovation
15	Competency assessment	AI-assisted assessment, analytics	Tracks learner progression
16	Case-based learning	Virtual patients, multimodal AI	Enhances applied knowledge
17	Communication training	NLP, conversational AI	Improves patient interaction skills
18	Ethics education	Explainable AI, ethical AI	Promotes responsible AI use
19	Plagiarism monitoring	Authorship analysis, NLP	Detects academic misconduct
20	Exam security	Cheating detection, biometric monitoring	Improves examination integrity
21	Remote education	Cloud computing, AI platforms	Expands educational accessibility
22	Clinical documentation	NLP, automated feedback	Improves note-writing skills

23	Evidence synthesis	Generative AI, retrieval systems	Speeds literature review tasks
24	Student engagement	Gamification, conversational AI	Improves participation
25	Simulation training	Immersive learning, virtual reality	Strengthens experiential learning

Another aspect of artificial intelligence that is captured in the review is the fact that it can better the standards of education by enhancing personalized learning and adaptive learning systems. Predictive analytics, intelligent tutoring systems, and learning analytics are able to predict knowledge deficiencies, track student progress, and suggest custom study paths [6,80-84]. Such capabilities are especially useful in medical education since learners can vary significantly in the previous knowledge and learning speed, as well as clinical experience. Communication skills, diagnostic reasoning, reflective writing, and procedural performance also can get immediate feedback with the help of AI-assisted assessment systems. Additional technologies that can be used to develop clinical skills include virtual patients, conversational AI, and immersive learning, which provide safe, repeatable, and scalable practice environments. These technologies facilitate human-AI work, allowing students to perfect their clinical arguments and get automatic guidance and decision support at the same time. It is believed that with recent technological changes, medical curricula will involve more multimodal AI, emotional AI, virtual reality, and augmented reality as more complex and immersive learning environments in the future.

Table 2. Summary of Challenges, Opportunities, and Future Directions of Artificial Intelligence in Medical Education

Sr. No.	Challenge	Opportunity	Future Direction
1	Plagiarism	Faster content creation	Transparent disclosure policies
2	Cheating detection	AI-based exam monitoring	Hybrid assessment models
3	Hallucinated content	Rapid knowledge access	Retrieval-augmented generation
4	Misinformation	Quick concept explanation	Explainable AI systems
5	Faculty unpreparedness	Faculty development programs	Mandatory AI literacy training
6	Algorithmic bias	Personalized instruction	Fairness auditing frameworks
7	Data privacy concerns	Federated learning	Privacy-preserving analytics
8	Overreliance on AI	Increased efficiency	Critical thinking education
9	Reduced originality	Improved productivity	Reflective learning tasks
10	Unequal access	Scalable online learning	Inclusive AI infrastructure
11	Lack of policies	Greater flexibility	Institutional AI governance
12	Ambiguous authorship	Easier drafting support	AI citation guidelines
13	Assessment vulnerability	Oral examinations	Competency-based assessments
14	Cognitive offloading	Faster decision support	Human-AI collaboration training
15	Limited explainability	Improved analytics	Transparent model design
16	Weak digital professionalism	Stronger ethical awareness	Professional conduct modules
17	Excessive screen dependency	Remote access	Balanced blended learning
18	Inconsistent faculty adoption	Curriculum innovation	Cross-disciplinary collaboration
19	Low trust in AI	Better feedback systems	Explainable feedback models
20	Student confusion about AI use	Increased support tools	Clear AI-use boundaries
21	Lack of technical infrastructure	Cloud-based learning	Investment in digital systems
22	Weak monitoring of AI use	Blockchain verification	Academic integrity frameworks
23	Limited emotional understanding	Emotional AI support	Wellbeing-focused AI systems
24	Generic AI responses	Personalized tutoring	Domain-specific medical AI
25	Rapid technological change	Continuous innovation	Longitudinal curriculum redesign

Although these advantages are present, the review also shows that there are significant dangers of overreliance on artificial intelligence in medical training. Among the most serious issues is the risk of deteriorating the critical thinking, the ability to resolve problems independently and the development of professional identity. Generative AI applications can give ready responses, summaries, and diagnoses, yet they are also a form of promotion of superficial learning and cognitive offloading when students use them without a critical analysis of the result. A number of studies highlight the fact that AI-generated content can reduce complicated scientific knowledge, distort facts, and leave out clinical essentials. These risks are especially worrisome in medicine, where knowledge on the interpretation of information, critical and contextual ability relies on being able to practice diagnostic accuracy, ethical

logic, and patient safety. According to the literature, the teaching of medical students on the application of AI tools should include the educational component on how to ask questions, prove or refute and interpret information generated by AI, in a responsible way. The other critical problem that has been observed in the review is that better institutional governance and faculty development are required. The willingness of faculty to adopt artificial intelligence in medical schools is, overall, not distributed evenly, and a significant portion of educators do not have sufficient technical knowledge, AI literacy, timely engineering skills, and even confidence to see into using artificial intelligence in their teaching professional activities. Institutions are also finding it hard to establish what is and what is not acceptable AI use in assignments, examinations and research. The absence of standardized policies has led to inconsistency in the approach to the academic integrity concerns, specifically, when it comes to plagiarism, cheating detection, AI-generated writing, and digital professionalism. There are emerging indicators that institutions need to escape strict, one-size-fits-all approaches to assessment and shift to more flexible, which involves using a combination of oral examinations and reflective writing with practical demonstration and AI-approved assignments with explicit disclosure policies.

The review also notes that innovations in advancing artificial intelligence in the field of medical education in the future will require balancing between innovation and ethical responsibility. Institutions should come up with explicit policies of AI application, disclosure, honesty in academics and authorship. The desire to have explainable AI, federated learning and privacy preserving systems that can ensure protection of student data but offer transparency and trust is also growing. In the near future, medical training will focus on the formal training of AI literacy and prompt engineering, digital ethics, and collaboration with AI. These competencies will gain more and more significance due to the fact that in the future physicians will have to cooperate with AI tools both, in learning and clinical environments. Meanwhile, schools need to be very careful about overtrusting AI-written work and algorithms, especially in the assessment of more complicated competences like empathy, moral judgment, professionalism, and patient-centered communication. All in all, it has been indicated in the discussion that artificial intelligence will still redefine medical education in the future, although its success will hinge on whether the institutions will be able to integrate them in a way that fortifies, rather than forfeits, critical thinking, academic honesty, and professional growth. The future of healthcare education should be marked by increased application of large language models, multimodal AI, learning environments, and adaptive education systems. Nevertheless, these technologies should be supported with increased governing systems, faculty willingness, moral frameworks and student services to make certain that AI is not used to complement but to substitute human discretion and competencies.

5. Conclusions

This review indicates that AI is quickly changing the field of medical education by altering the approaches to teaching, learning, and evaluation and setting academic integrity policies. In the reviewed literature, artificial intelligence, generative AI, virtual patients, and predictive analytics, as well as the adaptive learning technologies, continued to demonstrate a high potential to improve student engagement and learner autonomy, clinical reasoning, competency-based education, and personalized learning. The assessment systems with AI-assisted assessment and automated feedback systems were identified to enhance efficiency and accelerate the formative assessment processes and data-based decision-making in healthcare education. ChatGPT and other large language models have specifically affected the innovation of medical curriculum by facilitating quick information access, case-based learning, learning through simulation, digital pedagogy, and training in a virtual clinical setting. These trends indicate that there is a shift to a hybrid system of medical education with more and more human knowledge being assisted by machine learning, natural language processing, and decision-support systems.

Although the articles have such benefits, the review also shows that the introduction of artificial intelligence into medical training provides significant threats and unsolved problems. Academic integrity issues continue to be at the forefront, especially as far as plagiarism and academic dishonesty, AI-assisted tests without authorization, fictitious source lists, and challenges with cheater detection are concerned. Numerous researches mentioned that students tend to not consider the application of

generative AI solutions unethical, which brings ambiguity to the area of what is acceptable academic behavior and digital professionalism. The other issues are viewed as algorithmic bias, privacy, transparency, explainable AI, and unequal access to digital technologies; the potential existence of cognitive offloading that deteriorates critical thinking, independent problem-solving, and long-term knowledge acquisition. The faculty preparedness was also found to be a significant concern with most of the educators not being well skilled in AI, engineering and their willingness to incorporate AI applications in their current medical programs. These results show that artificial intelligence cannot substitute the traditional pedagogical tools and human judgments, but rather, it can be used as the enhancement of the educational tool in the well-thought and ethically regulated systems. The review also emphasizes the increased role of the ethical governance, regulatory structures, faculty training and institutional policies in making sure that artificial intelligence can be used responsibly in medical education. AI-related literacy, digital ethics, critical evaluation of AI-generated content and clear rules regarding academic honesty must be taught in future medical programs. It is also necessary to have more robust interdisciplinary cooperation between educators, clinicians, technologists, policymakers, and accreditation bodies to develop the standards of safe and fair AI implementation. The longitudinal research should be included in the future research to study the long-term effects of artificial intelligence on student performance, identity development in professions, clinical competence, and patient-centered care. Further studies will be required to assess explainable AI, bias management techniques, safe data handling, and culturally accommodating models of learning. The future of artificial intelligence in medical education will be determined not only by the level of technological advancement but also by how much the institutions can still provide a person-centered learning experience, uphold a high level of ethical responsibility, and educational fairness.

Conflict of interest

The authors declare no conflicts of interest.

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