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Artificial intelligence in undergraduate medical education: an updated scoping review

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Abstract

Background The irrevocable alteration of medical education due to widespread access to large language models (LLMs) in 2022, and the concomitant surge in AI-related literature, has prompted us to update the evolving impact of AI on undergraduate medical education (UGME).

Methods The scoping review adhered to the framework of Arksey and O'Malley. A literature search was conducted in April 2024 on PubMed, Scopus, Web of Science Core Collection, ERIC, and Google Scholar using the terms "UGME", "medical students", "AI", "NLP", "ML", "ChatGPT", and "LLM", and included publications that appeared from January 2020 to April 2024. The inclusion criteria were UGME and AI-related topics. The exclusion criteria were postgraduate education, continuing medical education, and non-AI technologies.

Results After screening 3,238 identified publications, 310 were ultimately included in the review. One hundred sixty-one publications (52%) related to AI use solely in UGME appeared in eight months between the time the last general medical education scoping review on AI took place and the current study. The use of AI is rapidly increasing in UGME, both in basic and clinical courses, with applications ranging from autonomous tutoring, self-assessment, and simulation-based learning to assessment generation and grading, clinical assessment, procedural skills evaluation, and predictive analytics, among others. No publications assessed AI's impact on critical thinking or clinical reasoning in medical students. While students strongly demand the acquisition of AI literacy during UGME, and some institutions have begun integrating AI into their curricula, there is neither a standardized approach for doing so nor a consensus on AI competencies or ethical frameworks in UGME.

Conclusions This review highlights the dramatic increase in the use of AI in UGME, presenting both benefits and challenges. While AI can enhance learning experiences, the best evidence for its implementation is unclear and requires, as key priorities, the definition of AI competencies, pedagogical methods, and ethical guidelines. Further research is needed to assess the impact of AI on ethics, empathy, critical thinking, and clinical reasoning. Faculty development in AI is vital, as is the need for collaborative and international endeavors.

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Keywords Artificial intelligence (AI), Undergraduate medical education (UGME), Large language models (LLMs), AI competencies, Scoping review

Background

With the rise of artificial intelligence (AI), its use in healthcare, covering diagnostics, decision support, administration, and population health, has steadily expanded [1]. Moreover, the importance of equipping future doctors with key AI skills has increased, leading to efforts to incorporate AI literacy into undergraduate medical education (UGME) [2–4].

To address this issue, Lee et al. carried out a scoping review of the literature from 2000 to July 2020, identifying 22 studies on AI in UGME [5]. This review summarized key themes regarding AI training in UGME and identified priorities to advance curricular development.

Since then, a significant breakthrough occurred in November 2022 with the public release of large language models (LLMs) driven by generative AI, signifying a qualitative shift in both capability and accessibility [6]. The utilization of AI-based chatbots among medical students worldwide varies from sporadic to widespread application across numerous domains [7]. Concurrently, the scholarly literature concerning its application in medical education has expanded substantially, thereby fueling the demand for its integration into medical curricula [8, 9].

The extensive proliferation of scientific literature in various domains prompted Gordon et al. to investigate AI comprehensively across undergraduates, graduates, and continuing medical education, including publications up to August 2023 [8]. However, their comprehensive scoping review considered UGME as one of many other disciplines within healthcare education. As part of our extensive effort to incorporate AI into our UGME curriculum, we recognized the need to conduct a new scoping review focused exclusively on UGME. This sector has unique educational goals, assessment methods, governance structures, and learner needs [10]. Indeed, in the eight months following Gordon et al.'s review, there was a twofold increase in the number of publications related to AI and UGME compared with those included in their study. Finally, our work was specifically motivated by the significant increase in publications that occurred after the release of Lee et al.'s scoping review of AI in UGME [11] in 2021.

The goal of this work was to analyze the changing landscape of literature on the use of AI in UGME after the global availability of LLMs in 2022 and thus provide a foundation for curriculum design, faculty development, and policy.

Methods

Study design

Given our research goal, a scoping review was deemed the best approach [12, 13]. We followed the framework proposed by Arksey and O'Malley [14] and modified by Levac et al., in line with the six stages of the scoping review framework [15]. Additionally, we adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) reporting standards [16]. Supplement A contains the PRISMA-ScR checklist.

Stage 1: identifying the research question

The three UGME-centric research questions that informed the overall study aim were:

1. How has the literature on AI evolved since the introduction of LLM-based tools, particularly with respect to geographic distribution, scope, and areas of application?
2. What are the perceptions and ethical considerations of students and faculty regarding the use of AI, and how does AI impact students' critical thinking skills?
3. What competencies are recommended, and what educational methods and practices are employed or explored to teach AI effectively?

Stage 2: identifying relevant studies

Inclusion criteria

The inclusion criteria were articles related to UGME and the use of AI technologies and approaches (e.g., machine learning (ML), natural language processing (NLP), LLM), AI-driven teaching tools, AI in the curriculum, and ethical and professional considerations associated with AI use in UGME. We included publications that mentioned other levels of training, such as post-graduate training (residents) and continuing education, physicians in practice, or other health profession students, provided that they also included medical students and UGME. We included peer-reviewed articles, empirical studies, different types of reviews, opinion papers, and letters to the editor.

Exclusion criteria

Publications that did not include medical students or UGME were excluded, as were articles that focused exclusively on non-AI technologies, such as virtual reality (VR) and augmented reality (AR). Abstracts-only, study protocols, and books were also excluded.

Search strategy

A literature search strategy was collaboratively created by the research team. Supplement B provides a detailed search strategy including MeSH terms and keywords. The main key search terms were “UGME”, “medical students”, “AI”, “NLP”, “ML”, “ChatGPT”, and “LLM”. Four databases (PubMed, Web of Science Core Collection, Scopus, and ERIC) and two additional engines (Google Scholar, Unika) were used to identify publications in English or Spanish that appeared between 1 January 2020 and 17 April 2024.

Stage 3: study selection

Following the search outlined above, citations were imported into the Covidence web-based platform to facilitate collaboration and analysis (Veritas Health Innovation, Melbourne, Australia available at www.covidence.org).

The screening was performed collaboratively. An initial screening of 20 publications was conducted with the entire research team to ensure standardization and consensus. Then, we individually screened the articles in batches of 20, and the entire team convened periodically to ensure consistency. The screening continued until all publications were processed. Articles were reviewed by pairs of authors who independently examined the titles and abstracts first, and then the full texts (JS, JP, MR, JU, DE, OH, LL, AM, PS, AV). The lead author (JS) resolved conflicts at each step through discussion and consensus with the entire team or with the medical librarian (MR). Supplement C summarizes the PRISMA process.

Stage 4: charting the data

The lead researchers (JS, JP) developed an extraction form within Covidence, which was informed by an initial pilot literature search and previous scoping reviews. The form was first tested on a batch of 10 articles using an iterative process that involved five researchers (MR, PS, AM, JS, JP). The team convened to reach a consensus on the final form.

The final Covidence data extraction form included information related to basic publication details (year of publication, title, journal, author, countries of authors); type of publication (study, perspective, intervention, guideline or overview); areas or fields discussed (basic sciences, clinical skills, clinical sciences, ethics/professionalism, empathy/compassion, AI in general, other); and additional contextual information (curricular development, competencies, learning methods, course, learning tool, personalized learning, simulation, assessment, clinical reasoning, and LLM performance). Studies were further categorized according to study methods (survey, literature review, randomized/case-control, qualitative, Delphi, and other). Assessment-related publications were further categorized by type of assessment (generating tests, narrative text analysis, clinical procedure skills, or self-assessment).

Stage 5: collating, summarizing, and reporting the results

The extracted data were analyzed by three principal researchers (JS, JP, DS) using a mixed-methods approach that incorporated descriptive statistics and thematic analysis [17]. Descriptive statistics were utilized to describe types of articles, study designs, authors' geographic origins, and the number of publications on various themes [15, 18]. Thematic analysis was conducted to identify and explore underlying themes and patterns within and across the selected articles [19] by several principal researchers (JS, JP, DS).

The data were tabulated by category and theme [18]. To understand the nature of global collaboration, we utilized network analysis techniques [20] using the Cosmograph application [21] to visualize the results. Regionalization of the world was performed according to the United Nations (UN) report on AI Governance [22].

Stage 6: undertaking consultation

Our team intentionally included an AI expert (DS) and medical education experts (JP, EM) to provide these perspectives.

Ethical approval

The University of Navarra Research Ethics Committee reviewed and approved the study protocol (2024.084 mod1).

Results

Three thousand two hundred thirty-eight publications were identified, 820 duplicates were removed, and 2,414 studies were screened based on their titles and abstracts, resulting in 400 full-text articles assessed for eligibility. Ultimately, 310 publications were included in the final analysis and synthesis. Supplement D contains the complete list of references.

Publication characteristics

Out of the 310 publications, 179 were categorized as *Studies* (58%), 73 as *Perspectives* (24%), 29 as *Interventions* (9%), 17 as *Guidelines* (5%), and 12 as *Overviews* (4%). Among those categorized as *Studies*, 60 corresponded to *Surveys* (34%), 23 to *Literature Reviews* (13%), 15 to *Randomized/Case-Controls* (8%), 14 to *Mixed Methods* (8%), 7 to *Qualitative* (4%), 2 to *Delphi* (1%), and 58 to *Other* (32%).

The number of articles published per year was charted for comparison among the four complete years analyzed (from 1 January 2020 to 31 December 2023; see Fig. 1). Studies published within the first four months of 2024 (*n*

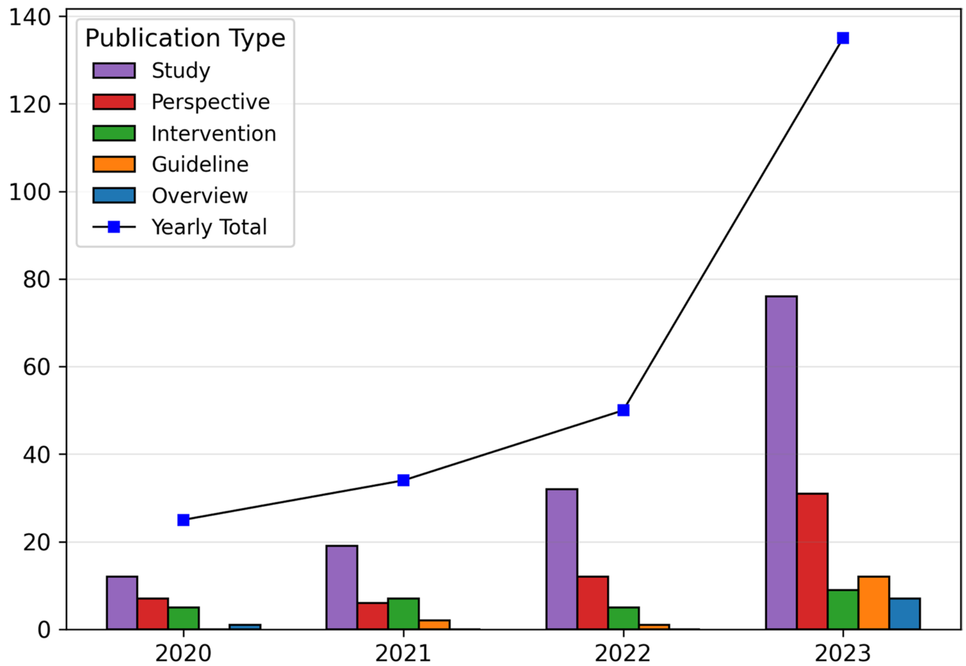

Fig. 1 Publications included in the corpus. The bars show the yearly count of examined publications of each type published from 1 January 2020 to 31 December 2023. The connected blue squares represent the annual sum across all publication types

= 66) were not included in the chart to avoid confusion. A significant increase was noted in 2022 compared with the two previous years, coinciding with the release of ChatGPT by OpenAI [8, 23], which was later surpassed by those published in 2023 (Fig. 1). The estimate of the publications most likely released during the whole of 2024, according to our data from the first third of the year (n = 66), suggests that the number continues to increase.

Geographical distribution of international collaborations

The geographical origin and the collaborations between the publication authors were also analyzed (Fig. 2), according to the UN classification, which divides the countries of the world into five groups: the African Group (AG), the Asia and Pacific Group (APG), the Eastern European Group (EEG), the Latin America and Caribbean Group (LAC), and the Western European and Others Group (WEOG), which includes North America and Australia.

We found that authors from WEOG were the primary contributors, participating—either independently or in collaboration with other groups—in 53% of the publications. This was followed by APG at 39%, and much smaller contributions from EEG, LAC, and AG, each participating in 3% of the publications. The connections between publications (blue nodes) and their individual set of originating UN country group(s) (orange nodes) are displayed in Fig. 2.

Most publications (n = 277, 89%) were authored by individuals originating from a single UN country group, primarily WEOG (n = 152, 49%) and APG (n = 107, 35%), with far fewer from EEG (n = 7, 2%), LAC (n = 6, 2%), and AG (n = 5, 2%). This is evident in Fig. 2, where large clusters of publications surround the WEOG and APG nodes in the network diagram.

In contrast, a small number of publications involved collaboration across two or more regional groupings: 28 (9%) spanned two groups, 4 (1%) spanned three groups, and one publication included authors from all five UN country groups. Those publications can be identified as (blue) nodes that are located along the borders between UN country group (orange) nodes.

AI perceptions and literacy among students and faculty

Attitudes and perceptions toward AI in general

Over fifty studies explored general perceptions and attitudes toward AI, sometimes in combination with either readiness to use AI or AI-related knowledge and skills. These studies involved faculty and mostly medical students, but also other health-related students from countries worldwide, including Europe, the Middle East, northern and sub-Saharan Africa, North America, Asia, Australia, and New Zealand [24–29].

The Medical Artificial Intelligence Readiness Scale for Medical Students (MAIRS-MS) [30] was utilized in a few studies to explore perceptions of AI [31–34]. This tool evaluates four domains of AI competencies and literacy: cognition, ability, vision, and ethics [35, 36]. Most of them, however, (>30) used other instruments, which were developed de novo for the respective studies [37]

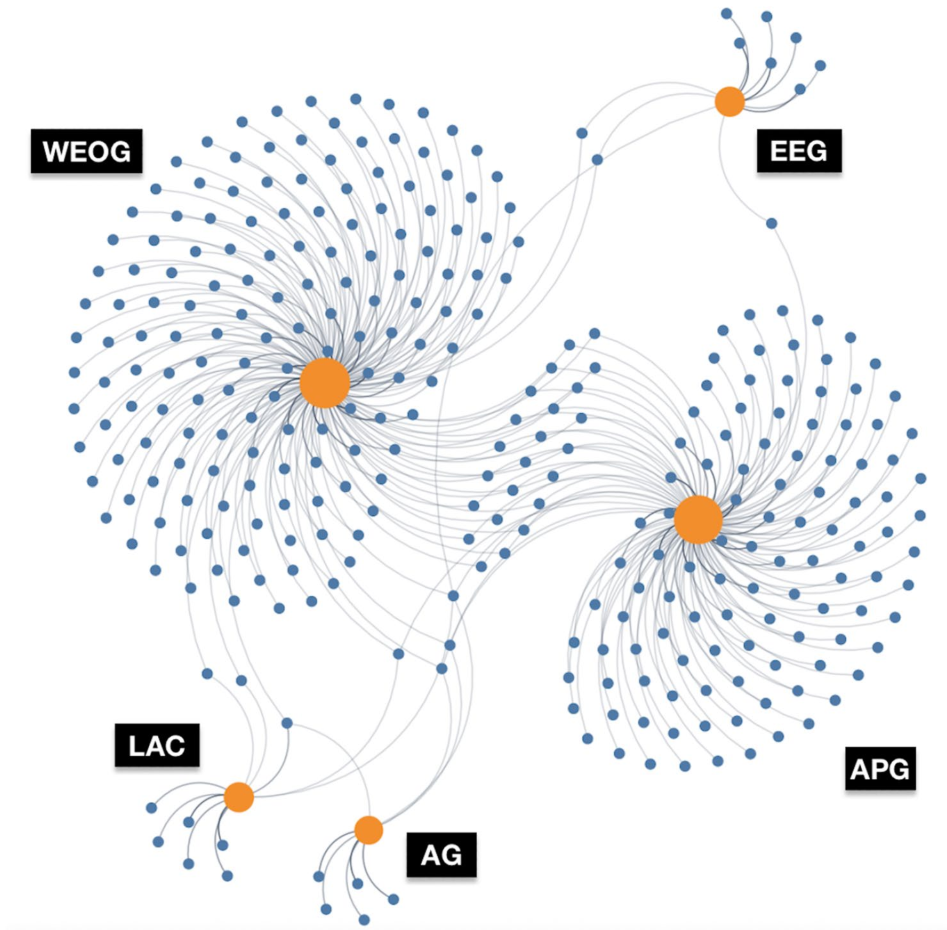

Fig. 2 Author collaboration network graph. The blue dots represent publications, and the orange dots represent the UN country groups: the African Group (AG), Asia and Pacific Group (APG), Eastern European Group (EEG), Latin America and Caribbean Group (LAC), and Western European Group and Others Group (WEOG). The graph visualizes the connections between publications and their respective author(s) originating UN country group(s)

(see Supplement E for the rest of the references). In contrast, a few of them employed either qualitative methods [38–40] or a mixed-methods approach [41–45]. All of them consistently reported that 75–80% of the participant medical students recognized the importance of AI in medicine and medical education, held positive attitudes toward it, identified a crucial role for it in the future of medicine, and expressed a strong desire to learn more about it.

In the absence of AI education in medical curricula, the media had been a significant source of AI-related information for students and faculty [46, 47]. Students were more likely to have utilized AI tools than lecturers; however, both groups had generally received little to no training in this area [48]. In addition, study participants did not believe AI would replace human teachers [49] but that the role of the teacher may change [3].

Finally, contributions elaborated mainly or solely by medical students strongly call for the inclusion of AI education in medical curricula [50–54]. Students were enthusiastic about learning AI and recognized its crucial role in the future of medicine [45, 55]. However, they reported a lack of formal AI training and insufficient AI-related learning opportunities in their medical education [46, 56, 57]. The call for the inclusion of AI in medical curricula was also being demanded by researchers and educators [51, 54, 58–69].

Impact on medicine and medical careers

Overall, in addition to positive attitudes toward AI, students generally expressed enthusiasm for integrating it into their future medical practice [70, 71]. Many believed AI had the potential to enhance and transform medicine by optimizing physicians' workloads and reducing healthcare costs [42, 72, 73]. Additionally, students viewed AI as a supportive tool that can assist physicians, help mitigate medical errors, and enhance patient care. Generally, rather than replacing human physicians, students perceived AI as a collaborative partner in medical practice [73, 74]. A study analyzing both medical and dental students' perceptions of AI reported that 72% of them believed that AI would revolutionize medicine and dentistry, a view held more often by students from developed countries than those from other countries [74]. Finally, a specific study examining students' willingness to integrate AI into their future medical practices reported that a strong belief in a future role of AI correlated with behavioral intentions to use AI [75].

However, enthusiasm was juxtaposed with concerns, including a lack of knowledge about AI's mechanisms, workings, specific applications, and firsthand clinical experience with AI [46, 76]. Some students worried that AI could reduce human interaction with patients and dehumanize healthcare [48]. Additionally, there were concerns about data protection [23], increased workplace surveillance [42], and the potential impact of AI on physician employment [46, 77, 78].

Student and faculty perspectives on LLMs

Eight studies examined the knowledge, attitudes, and skills of medical students and educators regarding LLMs, specifically ChatGPT [24, 26–29, 79–81]. Students generally expressed a more positive attitude toward LLMs than practicing physicians, showing optimism about their potential to support learners and educators [81]. Those who were more knowledgeable about LLMs tended to hold a more positive attitude toward them and were more likely to use them for educational purposes [80]. However, concerns were raised regarding the accuracy of AI-generated information, the risk of plagiarism, and the potential for overreliance on LLMs, which could hinder the development of critical thinking skills [79].

Areas in UGME where AI is being used

AI is being utilized across various stages of UGME – from basic sciences and preclinical years to clinical years – as well as in numerous fields and specialty areas. Sixty-six publications (21%) described the specific application of AI in one or more of the 21 areas identified in this study (see Table 1). The use of AI-assisted learning was a common theme in teaching visually oriented subjects such as anatomy, histopathology, radiologic image interpretation, and fundoscopic examination, as well as in supporting instruction in anatomy and clinical interviewing skills with chatbots. Other recurring themes involved the use of AI to create exams or assess whether an LLM could answer specific questions in a particular area of medicine. Additionally, AI served as a personalized feedback tool via automated assessment systems.

In the basic sciences, AI was reported most frequently in anatomy (n = 12). AI can support an interactive and visually immersive learning experience in anatomy, especially if it is integrated with virtual reality (VR) and augmented reality (AR). Asghar et al. proposed using a humanoid robot as a teaching assistant in anatomy classes [82]; however, some scholars raised concerns that AI might not capture individual anatomical variations [83]. Ethical concerns have also been raised [84], suggesting that AI-driven dissection simulations could undermine professional identity development, as traditional cadaver dissection serves as a student's first encounter with a patient, marking the beginning of the doctor-patient relationship.

In ophthalmology, AI-generated images of retinal disease improved students' diagnostic accuracy [85]. In surgery and surgical subspecialties [86], it has been used to learn and practice knot tying [87] and laparoscopy training based on motion analysis and machine learning (ML) [88]. AI can enhance VR for medical skills training [89]. One study reported unintended outcomes with both positive and negative consequences for learner competency in surgical skills, suggesting that intervention from human tutors may be necessary to optimize learning [90]. Unintended changes included improved procedural safety (e.g., healthy tissue damage) but worsened hand movement and efficiency metrics. The researchers recommended that any AI used in learning should include ongoing assessment.

In cardiology, AI-assisted teaching has been used to help learn how to perform echocardiography [91, 92] and to evaluate the determination of left ventricular ejection fraction (LVEF) [93]. In addition, AI helped accelerate progression from novice to expert with ultrasound use [93].

How AI is being used in UGME

LLMs in UGME

Since its launch in November 2022, ChatGPT and other LLM-based tools have had a significant impact on UGME, with ChatGPT being most frequently mentioned (43.6%) [48]. LLMs were being explored in various ways, including as personalized learning tools for interactive educational experiences, as aids for simplifying complex concepts, as research assistants, as writing support tools, and as generators of learning content and exam questions.

Fifty-two publications (17%) describing the use of LLMs were found during the study period [94]. These included several overview articles discussing the pros and cons of LLMs in UGME [95] as well as a systematic scoping review that examined LLMs' opportunities, challenges, and future directions in medical education, including in UGME [96]. (For the complete list of references on this topic, see Supplement G).

Several studies examined the performance of LLMs on various medical exams [97–99]. Comparisons between older and newer versions indicated that newer versions exhibited better accuracy, highlighting the need for ongoing assessment of AI tools in medical education [100–102]. One study comparing ChatGPT and Google's Bard

Table 1 Subject or medical field with AI-specific applications (for the complete list of 67 references for this table, see supplement F)

Field/Discipline	Specific Application
Anatomy	• Chatbot • Adaptive testing/feedback on quizzes or adjust material based on users' level • AI to act as an assistant to the teacher • Virtual dissection
Physiology	• LLM accuracy in answering test questions
Pathology	• AI online platform assists blood cell morphology learning • AI platform for teaching glomerulopathies using ML
Histology	• App to classify histology using artificial neural networks • ML and machine teaching in histopathology
Biochemistry	• Evaluating *ChatGPT* as a self-learning tool in medical biochemistry
Biostatistics	• Using *ChatGPT* as a biostatistical problem-solving tool
Clinical Skills	• AI support of Communication • Skills such as Chatbot as a Simulated Patient • AI assisted Intubation training • AI mixed reality to assist in learning injection techniques
Empathy	• Increased awareness and teaching of empathy skills as AI enhances rather than replaces the healthcare provider's role
Clinical Reasoning	• Virtual patient simulator with intelligent tutoring system for the clinical diagnostic process • Perceptions of AI assisted diagnosing program • Medical decision support system • AI training program for improving professional skills
Research	• Scientific Writing
Radiology	• AI assistance for medical imaging learning • AI integrated open-source medical image analysis platform 3D slicer - tool in medical imaging education
Oncology	• Comparison of case-based learning using Watson for oncology vs. traditional method teaching
Pharmacy	• Virtual Tutor • *ChatGPT* for generating multiple-choice questions • AI mobile-based learning of drug prescriptions
Ophthalmology	• AI tutoring problem-based learning (PBL) • LLM's ability to answer ophthalmology long answer questions • Automated grading and training system in education of manual diabetic retinopathy detection • Training platform using deep learning to educate inexperienced students in fundus image reading and labeling to screen pediatric retinopathy • AI generated retinal images to aid student performance of retinal disease detection
Surgery	• AI tutoring vs. expert instruction on learning simulated surgical skills • Simulation training with unintended outcomes for technical competencies • Role of *ChatGPT* in surgery education • Assessment and teaching for suturing and knot-tying • VR for knot tying skills training supervised by artificial neural network • Evaluation of laparoscopic surgical skills training based on motion analysis and ML
Obstetrics and Gynecology	• Using *ChatGPT* in Obstetrics and Gynecology of UGME Curriculum
Neurosurgery	• Assessment of learning curves on a simulated neurosurgical task using metrics selected by AI
Cardiology	• Using AI feedback to assess cardiac ultrasound performance • AI assistance to assessing LVEF on echocardiography
Dermatology	• Perceptions and attitudes of medical students regarding AI in dermatology
Endocrinology	• LLM performance in MCQ in Endocrinology, Diabetes, and Diabetes Technology
Psychiatry	• Using *ChatGPT* to Design Script Concordance Tests

in answering multiple-choice questionnaires (MCQs) related to endocrinology and diabetes found ChatGPT to be slightly superior; however, both models lacked up-to-date information in these fields [103]. Similarly, another study on ophthalmology and long-answer questions reported ChatGPT-3.5 and Bard to be unreliable as self-assessment tools for medical studies [104].

Personalized learning tools

AI is being used as a personalized learning tool [105]. It may enhance learning by adjusting material based on the user's level [106], guiding students through challenging tasks with chatbots [107], and acting as an ever-present virtual tutor [108].

In medical biochemistry, while ChatGPT was overall found to be a helpful, knowledgeable tool, some content quality and answer accuracy needed improvement [109], emphasizing the need for educators to validate AI tools for accuracy and reliability. ChatGPT was found to be a valuable tool for preparing for examinations, including the United States Medical Licensing Examination (USMLE), by clarifying complex physiological processes, creating mnemonics, and explaining clinical vignettes [110]. ChatGPT reportedly performed at or near passing levels for all three USMLE exams. Generative AI can also serve as a practical, personalized guide in case-based learning, assisting students in navigating clinical scenarios and adapting to their knowledge [111].

The use of chatbots has been increasingly reported [40, 112–115]. Gorashi et al. analyzed their strengths, weaknesses, opportunities, and threats in this context [107]. Chatbots have assisted students in history-taking practice [116] and preparing for objective structured clinical examinations (OSCE) [117]. In one study comparing the use of ChatGPT with a traditional textbook for learning medical terminology [118], ChatGPT provided more straightforward explanations, and AI-assisted students demonstrated superior posttest scores. AI has been explored as a personalized learning tool in flipped classrooms within the basic sciences [119]. This randomized study revealed that students using AI-assisted presentations with real-time feedback outperformed those using traditional PowerPoint.

Simulation

Fourteen studies (5%) examined the use of AI in simulations [90, 120–132]. Various uses were described, including surgical simulation with a virtual operative assistant [132], simulated patient physician medical interviews [120–123, 130], and interactions with avatars as standardized patients during clinical interviews [124–126]. AR helped teach medical students to identify abnormal heart sounds in standardized patients with normal heart sounds by using a digital stethoscope, utilizing AI deep learning to determine the placement of the stethoscope [127]. In one study, a wearable garment was transformed with sensors and interactive technology into a simulated device that could emulate a standardized patient, allowing students to assume the role of standardized patients by wearing the vest [122]. Ruberto and colleagues tested an adaptive patient simulation utilizing a deep multitask neural network powered by AI [129]. The AR patient's symptoms auto-adjusted to accommodate the student's cognitive load.

Assessment

AI assisted students in conducting self-assessments by generating questions or identifying key points [133], and aided teachers in creating tests such as MCQs [134, 135], and automating marking and grading while providing feedback [23].

Three studies reported the use of AI, particularly ChatGPT, for generating exam questions [133, 134, 136]. Overall, the tools were found to be valuable in this role, but some inaccuracies were noted. The authors emphasized the need for human oversight.

AI was also used to grade exams, particularly those that involve short-answer, long-answer, and essay-based responses [137–139]. NLP can automate the scoring of written responses, thereby reducing time and resource demands while tracking learner progress and providing individualized feedback. ML algorithms have demonstrated high reliability in grading short-answer questions, and in one study, 67% of students viewed this approach favorably [140]. ChatGPT correlated well with human assessors when grading short-answer questions, suggesting its potential as an assistive tool for grading [141].

Online AI-based examinations may serve as alternative tools for assessing specific nonpsychomotor competencies [142]. However, ensuring transparency in AI-generated assessments remained a challenge, and concerns persisted regarding algorithmic bias and its implications for academic integrity [143]. In one study, second-year medical students submitted videos of themselves performing simple interrupted suturing [87]. These videos were manually rated with a pass-fail rating, and two AI models based on convolutional neural networks were trained to identify errors and provide automated ratings; the overall accuracy was 83%.

Providing effective feedback to medical students can be challenging [144–147]. ReadMI, a tool that utilizes deep-learning-based speech recognition and NLP, was used to assess communication skills [144, 145], to reduce the cognitive load on instructors, and showed accuracy comparable to that of human raters in classifying student dialogue types. Another study analyzed feedback exchanges between students and clinical advisors, utilizing LLMs to assess sentiment and investigate potential biases in feedback [148]; as a result, students were found to use more negative language than their advisors did. Finally, ML effectively evaluated long-form written clinical reasoning in more than 400 third-year medical students; remarkably, semantically based machine scoring was able to capture the communicative aspects of clinical reasoning more accurately than faculty [138].

Developing teaching materials

AI can enhance teaching materials by creating slides, generating images for learning, or writing case vignettes [135]. Bakkum et al. used ChatGPT (OpenAI, GPT 3.5) to develop diverse and inclusive medical case vignettes for pharmacology education [149]. The researchers evaluated various approaches and identified a set of eight consecutive prompts that could be customized to accommodate local contexts and specific assignments. They

Table 2 Summary of the specific uses of AI in UGME until April 2024. References included in the table correspond to publications not explicitly discussed in the text

Areas of AI application in UGME	Specific uses of AI
Learning tool	• Personalized learning tool • Personalized tool in a flipped classroom • AI enhanced VR [108] • Case based learning/reasoning • Exam preparation • Gamification [155, 156]
Autonomous tutoring	• Educational chatbots
Simulation-based learning	• Skills training • Automation of simulation training and feedback • Immersive experiential simulations for development of compassion • History taking skills
Assessment generation (generate tests and examinations)	• Multiple-choice questions • Short narrative questions • Classroom plans
Assessment grading (marking tests)	• Automation of assessment grading • Short answer assessment • Precision Education - personalized education for each learner [143]
Self-Assessment	• Tool providing real-time feedback on cardiac imaging quality • Tool to provide feedback on anxiety and help with motivation
Clinical assessment	• Provide feedback for interview techniques
Procedural skills assessment	• Video based assessment of knot tying skills [87]
Predictive analytics	• Predict student performance on exams/tasks [157, 158]
Generating learning content	• AI enhanced teaching material • Generate images for learning • Create case vignettes [149]

then used an AI platform, Adobe Firefly beta, to create visual representations. AI notably accelerated the process of developing cases, reducing the time required to complete 30 cases to just 1 h.

Three additional studies explored the integration of AI in case-based learning [150–152]. In one, students were provided with AI-generated scenarios, and educators compared students' thought processes with AI-generated suggestions [150]. The approach facilitated critical reflections.

Unique AI uses

AI and LLMs can assist students in efficiently utilizing flashcards from existing libraries, such as *Anki* [153]. The AI tool can select the most relevant flashcards based on individual medical school curricula, thereby reducing the need for students to create their own. This allowed students to focus on reviewing rather than generating study materials. In a randomized study involving 246 medical students, both increased motivation and decreased anxiety were noted among participants who used an AI tool compared with those in the control group [154].

See Table 2 for a summary of how AI is being used in UGME.

AI competencies and learning aims for UGME

Multiple articles have recommended various AI-related competencies or identified areas for learning about AI literacy in UGME [39, 74, 159, 160].

Two studies used Delphi processes to determine AI competencies. Caliskan et al. identified 23 competencies with strong consensus among experts and four with weak consensus [161]. The authors emphasized the need for medical students to understand the principles of AI and discuss its ethical implications. The second one identified six domains and 36 AI competencies, including understanding digital health and changes driven by AI, fundamental knowledge and skills in medical AI, ethics and legal aspects of medical AI use, medical AI applications in clinical practice, and processing, analyzing, and evaluating medical data related to AI research and medical use [4]. Both studies called for further research to validate these competencies across different contexts and countries.

Various articles provided suggestions on competencies, which included the knowledge, understanding, and confidence needed to use AI in the clinical context [38]. Others emphasized the need for (1) instructing students to discern whether the information from the AI tool is accurate [162], (2) training students to be consumers and developers of AI [57], and (3) gaining knowledge about AI modes of operation, ethical use, appropriate areas of application, reliability, and possible risks [159]. Finally, some scholars argued that we must ensure that students understand the scope of AI tools, the engineering and design of AI solutions for clinical problems, and the role of data in AI development [163]. Moreover, the importance of avoiding attempts to turn medical students into computer coders was also stressed [162, 163].

Integration of AI in UGME curricula

In addition to the inclusion of AI in UGME curricula, the need for early exposure to AI literacy was highlighted [70, 77, 164]. AI was framed as a fundamental toolset of medical practice, shifting AI from being an optional to a core component of medical education [165]. Strategies such as incorporating AI from the first year and as a longitudinal thread across existing subjects were suggested to build knowledge but avoid further burdening an already packed curriculum [57, 165, 166].

Universities from the United States, Canada, France, Germany, and Taiwan have integrated AI into their UGME curricula through various courses and strategies, providing valuable feedback for other medical schools to observe how their implementation efforts were carried out [167]. These publications offer significant insights into initial challenges and forthcoming recommendations for AI integration into curricula. A compilation of these references, along with descriptions of the respective courses or programs implemented at each university, is included in Supplement H.

Various methods were used or suggested to incorporate AI learning, such as experiential learning, as a widely recommended approach that allows students to work directly with AI tools [5]. Case-based learning was highlighted as an effective method using real-world AI scenarios or applications to correlate medical technical knowledge [70, 150, 168]. Flipped classroom models were also described, where students reviewed theoretical material independently and class time was used for active engagement, allowing students to apply learned concepts and develop higher-order clinical skills with faculty guidance [169]. Other strategies described team-based projects with hands-on application activities using real-world medical data, creating a learner-centered education [166], and combining "experience-based medical education" with AI literacy education [170], or putting them in the role of designers through theoretical and practical teaching with case studies, asking them to design an AI Clinical Decision Support System [171].

The Master Adaptive Learner model, where learning about AI is a continuous lifelong learning process using a scaffolding approach as technologies evolve, was highlighted by Cutrer et al. [172]. Finally, some suggested a "time out" approach, based on implementation science, to step back and reflect more on how to integrate AI in education, relying more on best evidence to inform practice [173].

Challengers and barriers to integrating AI into UGME curricula

Numerous challenges were described regarding the integration of AI in curricula. These included a lack of standard definitions for AI [38, 39], no formal guidance from oversight bodies for UGME [163], a lack of consensus on core competencies [5, 174, 175], uncertainty about AI's real-world applicability in medicine [150] and limited space in already full curriculum [176–178]. In addition, the rapid evolution of AI technology might render current knowledge and materials quickly obsolete, necessitating ongoing updates to the curriculum [179]. Furthermore, medical educators are challenged to teach complex AI concepts to medical students [179].

Challenges related to faculty members, such as the lack of AI knowledge and expertise [56, 180], resistance to adopting new technologies [5, 77, 180], and struggles with staff shortages, were also acknowledged in several studies [174]. Abdekhoda and Dehnad specifically highlighted the challenge that arises when technology is misaligned with the tasks it is intended to support and provided strategies to ensure successful technology adoption [180].

Finally, several studies pointed to the infrastructure, financial resources, and investments necessary to implement AI-driven education methods [9, 50, 181], as the costs of servers, faculty training, tool development, and technical personnel could be substantial [182–184].

Ethical considerations

Several ethical concerns regarding the use of AI in UGME are described [183]. There are concerns related to algorithmic bias [159] and safeguarding the privacy of students and patients [185, 186]. LLMs can generate what are termed "hallucinations," or fabricated data, wherein the responses presented may appear convincing yet are fundamentally flawed [187]. A lack of transparency and accountability in AI algorithms may hinder the understanding of their operational mechanisms [159]. Alternatively, a lack of workplace responsibility is another concern, with some experts calling for legislation and oversight processes to prevent this [167]. Plagiarism is another issue where students may submit AI-generated work as their own [169]. AI plagiarism detection tools are not entirely reliable and carry a substantial risk of unjust accusations of academic dishonesty [188]. Others worry that AI could give some students an unfair advantage over their peers who are not using it [189].

While many of the overviews and perspectives referred to ethical considerations concerning the use of AI in medical education [77], 15 publications focused explicitly on this topic [7, 38, 84, 97, 186, 190–199].

Chen and colleagues reported that the accuracy of ChatGPT in answering bioethical questions and assessing ethical scenarios targeting medical students was suboptimal, with an overall accuracy of 60% [97]. The authors emphasized the importance of medical professionals and educators using AI systems judiciously in ethical decision-making.

Limited awareness among students of ethical dilemmas associated with AI use was identified in some studies. Themes such as privacy, consent, data ownership, bias, and accountability were highlighted in Jordanian research [191]. An extensive study across Germany, Austria, and Switzerland revealed that less than 5% of students received formal AI ethics education [7].

The incorporation of AI ethics into UGME was emphasized in two scoping reviews, as well as in multiple other publications. A lack of empirical research and foundational definitions of AI ethics was noted as a barrier to guiding curriculum development [190, 195, 198–200].

Various opinions existed on how to approach AI-ethics education in UGME. One view is that AI education should be based on the four principles of biomedical ethics: autonomy, justice, nonmaleficence, and beneficence [197]. Another approach is principle-based, advocating for the teaching of core principles alongside the three principles of public health ethics: efficiency, common good orientation, and proportionality [193]. Others highlighted the importance of incorporating ethical considerations, including data collection, anonymity, privacy, informed consent, data ownership, security, bias, transparency, responsibility, and the core principles of autonomy and beneficence [196].

AI and critical thinking

Concerns about AI undermining critical thinking and cognitive development were raised [179]. The competitive nature of medical education, pressure to excel in exams, and ever-expanding medical knowledge prompt students to use technology as a shortcut when learning [201]. Mental dependence on AI remains underexplored, and unconscious reliance may hinder cognitive growth [202]. As medical students become physicians, independent problem-solving and quick decision-making are crucial for managing life-threatening situations [113]. A decline in these skills could compromise patient safety [203]. Proponents advocated for learning environments that prohibit the use of generative AI to enhance higher-order cognitive skills [204].

Educators at Université Paris Cité have developed an elective course to foster critical thinking in digital health [171]. Among other things, medical students learned to evaluate and integrate emerging healthcare technologies effectively.

Other insights

Numerous articles (5%) provide guidelines and “tips” on AI in medical education [57, 83, 94, 135, 136, 162, 179, 186, 195, 196, 202, 205–210]. Most of these resources focused on ChatGPT or LLMs, exploring how educators can harness the power of generative AI, including using LLMs to generate clinical scenarios or tests. In addition, they provided guidance on how to use an LLM effectively, such as crafting prompts, how to use an AI system ethically, and how to help teachers rethink assessment methods. Finally, some of these articles offered guidance on how to integrate data science and AI into the curriculum.

Discussion

This scoping review reassesses the current state of knowledge on AI in UGME, given the global revolution sparked by the advent of LLM tools in late 2022. This review builds upon the synthesis on this topic conducted by Lee et al. prior to the public release of LLM tools [5]. This pre-LLM study suggested creating a standardized set of core competencies for AI training, developing flexible evidence and theory-informed AI curricula, and increasing efforts to publish AI curricular content. Since that study, which included 22 publications, the number of publications on AI in UGME has increased dramatically, necessitating another examination of the AI landscape in UGME.

Our review also refines the UGME-specific implications of Gordon et al.’s study, which evaluates the whole spectrum of medical education [8]. In fact, 161 reports on the use of AI in UGME were published from 2023 until April 2024, none of which were part of Gordon et al.’s analysis. Those publications comprised 52% of all studies included in this review, reflecting a marked post-LLM acceleration. This rapid growth underscores the need for timely, UGME-focused synthesis to provide an update and capture the post-LLM surge.

With respect to the main themes highlighted in this review concerning the use of AI in UGME, many align with those described by Gordon et al. concerning extended medical education. These include the rapid growth of the literature, which is still in the early stages, with most studies being small or conducted at a single site, focusing on student satisfaction and short-term knowledge gains rather than proven changes in learners’ real-world outcomes. There is also a strong and consistent call for AI literacy within curricula, along with concerns about ethics, bias, and governance as AI tools become more integrated into learning and assessment. The evidence shows significant activity around AI in tutoring, simulation, feedback, and automated or assisted evaluation. Additionally, there is a notable geographic concentration of research in North America and Europe. Finally, this review, like that of Gordon et al., emphasizes the need for faculty development to transform enthusiasm into responsible and effective curriculum and assessment practices.

Despite these common themes, because Gordon et al. analyzed the entire medical education continuum, evaluating how AI specifically impacts UGME is difficult at present. Furthermore, we expanded the timeframe to include literature from the post-LLM surge until April 2024, leading to a larger and recent collection of studies.

A critical issue raised by this review, after the geographical and global analysis of the literature on the use of AI, was the striking difference in the research, use, and integration of AI among countries and continents. These data allow us to glimpse the risk of a widening of the digital divide. Few research collaborations and fewer than 10% of the publications were noted to come from Latin America, Africa, or Eastern Europe. This is consistent with the conclusions of the UN report, “*Governing AI for Humanity*”, which indicates that the global South is almost entirely excluded from AI governance discussions, with only seven countries involved in global AI governance efforts and 118 countries participating in none [22].

Based on this review and the synthesis of extensive recent literature on AI in UGME, we have outlined several recommendations to support medical institutions globally in addressing the significant disruptions to education observed as of late 2022.

Our analysis has identified eight concrete areas *(highlighted below in italics)* that can help medical education educators effectively implement AI in UGME. *(1) To establish a consensus on AI competencies* [38] and (2) *Embedding AI literacy through a flexible, longitudinal approach into existing subjects* [166]. Institutions can improve efficiency by sharing curricular frameworks and outcome data, minimizing redundancy [41]. *(3) Establish clear guidelines on AI ethics and professionalism* to ensure that students understand both the benefits and responsibilities of AI in learning and in their future clinical practice [38] with institutions establishing committees or review boards focused on ethical AI issues related to the implementation of AI in medical education [195]. *(4) Evaluate AI-based teaching with a focus on its ethical implications*, which has been an area that remains underexamined [196]. *(5) Focus medical education on developing uniquely human skills* [211], such as empathy [5], in response to AI-driven changes. The incorporation of disciplines like the arts [164] or theater-based training can enhance students' ability to engage empathetically in clinical practice [212]. *(6) Assess the impact of AI interventions on medical students* using rigorous research methods, such as natural experiments [213] to assess learning outcomes [23], critical thinking, and clinical decision-making [11]. Structured reflection exercises and practice opportunities should be incorporated to encourage active engagement with AI-generated outputs, fostering critical thinking [150]. *(7) Systematic evaluations of AI applications*, such as automated assessments, predictive analytics, and simulations, should be conducted to determine their effectiveness in medical education [90] with the development of open-access repositories of best practices which can help institutions select AI tools suited to their educational needs [214]. *(8) Establish AI professional development programs for educators* designed to equip educators with essential AI knowledge, ethical considerations, and practical experience in clinical applications [11].

The final recommendation is based on the World Health Organization (WHO), which anticipates a global shortage of over 14 million healthcare workers, including physicians, by 2030, with the African region facing the most severe deficits [215]. AI could democratize medical education by supporting the training of future physicians with high-quality medical education in areas with high disease burdens and low densities of healthcare professionals [9].

Limitations

This review included only studies published in English and Spanish; therefore, relevant studies in other languages may have been missed. Access limitations to specific educational platforms and the sheer volume of literature may have also contributed to omissions. Additionally, this review focused on undergraduate medical education, potentially excluding relevant AI-integrated teaching approaches from postgraduate or continuing medical education. Student researchers assisted with data collection. However, this was accomplished through training and under close supervision to ensure consistency.

Conclusions

This scoping review examined the integration of AI into UGME, highlighting the rapidly growing literature base in this area and the broadening use of AI. The growth of AI tools, particularly LLMs, presents both opportunities and challenges. There are increasing calls to ensure that medical students and faculty are trained on how to use AI. Students generally have positive perceptions of AI, but often lack sufficient knowledge and proficiency in using these technologies. The literature emphasizes the necessity of establishing AI competencies, embedding AI education consistently across UGME years, and addressing ethical considerations such as bias, data security, and responsible AI use as essential components for effective implementation. Systematic evaluations of the impact of AI on critical thinking and decision-making skills among medical students are needed. Adequately preparing faculty through targeted training is crucial for fostering effective educational practices and promoting the broader adoption of AI-based methods.

Abbreviations

AI	Artificial intelligence
UGME	Undergraduate Medical Education
LLMs	Large Language Models
ML	Machine Learning
NLP	Natural Language Processing

Supplementary Information

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Additional file 1: Supplement A. PRISMA-ScR. Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Review.

Additional file 2: Supplement B. Search Strategies. Detailed search strategy including MeSH terms and keywords.

Additional file 3: Supplement C. PRISMA process. Summary of the PRISMA process.

Additional file 4: Supplement D. Summary of the corpus.

Additional file 5: Supplement E. List of references of studies on the knowledge, attitudes, and skills of AI.

Additional file 6: Supplement F. Table 1, with a list of references.

Additional file 7: Supplement G. List of publications about LLMs.

Additional file 8: Supplement H. Examples of the integration of AI in UGME courses worldwide.

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