"THE AGE OF CODE AND SIMULATION. HOW AI IS TRANSFORMING MEDICAL EDUCATION": Commentaries/ Descriptive, declarative

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Table of Contents

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Abstract

Generative Artificial Intelligence has raised profound questions about learning models and teaching methodologies, including those in medicine. Universities are currently evolving and adapting to these changes, which requires a rapid capacity to adapt to a new paradigmatic context in knowledge and education.
This article summarizes the main current lines of development impacting medical education, including new teaching approaches, emerging capabilities derived from a digital and interconnected world, simulation as a learning method, the challenges inherent to scientific and academic research and publishing, tutoring and personalized student monitoring systems, and the integration of certain AI tools into medical practice—tools that students are expected to use. While the topic is broad, our objective is to describe the current state of transformation and adaptation to AI, highlighting the areas that require further development and improvement in teaching. It is still unknown which of these changes will persist and which could ultimately be discarded.

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ABSTRACT

Generative Artificial Intelligence has raised profound questions regarding learning models and teaching methodologies, including those in medicine. Universities are currently undergoing a process of evolution and adaptation to these changes, largely within a two-year timeframe, which demands a rapid capacity to adjust to a new paradigmatic context in knowledge and education. This article summarizes the main current lines of development impacting medical education, including new teaching approaches, emerging capabilities derived from a digital and interconnected world, simulation as a learning method, challenges inherent to scientific and academic research and publishing, tutoring and personalized student monitoring systems, and the integration of certain AI tools into medical practice—tools that students will be expected to use. Although the topic is broad, our aim is to outline the present state of transformation and adaptation to AI, highlighting areas that require further development and improvement in teaching. It remains uncertain which of these changes will persist and which may ultimately be discarded.

Keywords: Artificial Intelligence; University Medical Education; Simulation; medical training.

A. INTRODUCTION

The emergence of artificial intelligence (AI), particularly generative models such as large language models (LLMs)—for example, "ChatGPT"—has brought about a significant transformation in the clinical and scientific education of medical students (Gehrman, 2023; Duan, 2025). [1,2] Some of the leading universities focused on medical education are early adopters of these technologies, reorganizing curricula, teaching and assessment methods, and directly addressing ethical dilemmas and regulatory challenges. The integration of AI into education is driving substantial changes in medical curricula. It is impossible to remain indifferent to technological advancement and cultural shifts in society; however, adapting traditional teaching methods—historically associated with valuable and, above all, predictable outcomes—presents challenges. While the incorporation of new technologies has long been a part of medicine, artificial intelligence constitutes a paradigm shift in the learning process, particularly within the medical field, and it also prompts far-reaching societal changes. It is therefore essential to understand how to integrate AI appropriately into educational methodologies (Holmes, 2025) [3].

The aim of this work is to analyze the ongoing changes emerging in medical education following the advent of artificial intelligence, and to present the progress made by some of

the leading universities in this domain.

B. METHODS

This article is based on a brief review of recent literature (2020–2025) concerning the use of generative artificial intelligence in medical education. Additionally, we examined the principal initiatives published and disseminated by two of the most traditional universities in this area of medical training.

The bibliographic search was conducted in Scopus and PubMed using combinations of terms such as "AI" and "medical university education," "generative artificial intelligence," and "medical training." A total of 126 articles were initially identified, of which 12 were selected based on the following criteria: publications from the last five years that analyze general aspects of the integration of AI into medical education, excluding anecdotal projects or those lacking evidence of implementation. Were included in the analysis review and systematic review articles, with full-text availability, in English or Spanish.

In addition, we examined also other analytical articles with a high level of citation and the websites and publications of the universities selected for our study to identify changes and developments in their programs related to the incorporation of AI into medical education.

C. RESULTS

Recent web-based sources have reported substantial changes in medical education across several universities worldwide, including institutions with a long-standing tradition in the training of physicians. These universities are regarded as paradigmatic examples of contemporary trends in medical education. A summary of selected measures that have been implemented is provided in Table 1.

X**Comparative Table of Changes in Medical Education with Artificial Intelligence**		
University	**Main Changes in Teaching**	**Reference(s)**
Harvard Medical School (HMS)	**Mandatory AI in Health course in the Health Sciences and Technology (HST) program. Use of tutorbots (ChatGPT) and AI models for feedback. Launch of a PhD track in AI in Medicine. Implementation of “ambient scribes” in affiliated hospitals.**	**1–6**
Stanford University	**“AI in Medical Education” symposium (2025). Stanford AIMI (Artificial Intelligence in Medicine Initiative) Center supporting AI projects in medical imaging. Bootcamp courses on AI in Healthcare.**	**9**

University of Oxford	**Five-year collaboration with OpenAI (2025). Deployment of ChatGPT Edu for teaching. iCARE (Innovative Clinical AI Resources for Education) portal with AI-based health materials. Projects in medical imaging and mental health.**	**8**
University of Cambridge	**Development of AI-powered virtual patients (87% perceived usefulness). Use of conversational avatars for clinical training.**	**7**
Johns Hopkins University (JHU)	**Biomedical Engineering track with a focus on AI in Medicine. Implementation of AI-powered scribes for clinical documentation.**	**19**
University of Toronto	**Course "AI in Clinical Medicine" (CSC490/2600). Mandatory Minor in Medical Bioinformatics. Practical projects using TensorFlow, PyTorch, and IBM Watson.**	**16**
Karolinska Institutet (KI)	**15-credit online course on AI in Health Care. SMAILE (Stockholm Medical AI Lab for Education) group delivering practical workshops. Strong focus on ethics and regulation.**	**12**
University of California, San Francisco (UCSF)	**Bridges Curriculum including generative AI policies. Appointment of a Director of AI and Medical Assessment. "UCSF Versa" platform offering AI-generated clinical guidelines. Interprofessional symposium on AI and education (2025).**	**10**
Imperial College London (ICL)	**Digital guide "Navigating Digital Health." AI4Health CDT (Centre for Doctoral Training) program. Clinical AI projects for breast cancer screening (mammography) and cardiac MRI.**	**8**
National University of Singapore (NUS)	**Mandatory Minor in Biomedical Informatics including AI. Collaboration with SingHealth and Duke-NUS Medical School. 13-week online course "AI for Healthcare" using Python, Watson, and computer vision.**	**16**

4. DISCUSSION

4.1. Curricular and Competency Changes

It is currently considered essential to integrate basic content on artificial intelligence (AI) and medical informatics into undergraduate medical education (Civaner, 2022) [(4)]. Interdisciplinary initiatives are being promoted, and various universities have created new organizations, programs, courses, and degrees aimed at training "physician-scientists" proficient in data management, AI, and machine learning. Simultaneously, postgraduate programs and awards for innovative teaching projects involving AI have emerged. The overarching goal is to prepare medical professionals capable of formulating and solving clinical problems using digital tolos In the near future, multidisciplinary teams composed of physicians, mathematicians, computer engineers, and statisticians are likely to become commonplace.

In parallel with this evolution in healthcare training, society itself is advancing, with a growing population acquiring digital skills and basic medical knowledge. This shift will transform the traditional doctor–patient dynamic and demand specific training for future healthcare professionals (Topol, 2019) [(5)].

One of the changes already being observed in several institutions is the consideration of replacing some traditional lectures with practical activities supported by AI. Maintaining conventional educational models is becoming increasingly difficult when new generations of physicians will have access to digital tools that provide immediate support for knowledge acquisition and clinical decision-making (Montague, 2023) [(6)]. While these applications still require refinement, they have already demonstrated impressive levels of accuracy in medical knowledge assessments and examinations (Aljindan, 2023) [(7)]. AI also influences how students are evaluated, as well as their development of clinical competencies. In terms of academic assessment, "ChatGPT" and similar platforms have raised concerns about the validity of traditional evaluation methods (Vega Jiménez,2023) [(8)]. Due to their ability to generate coherent responses in written assignments, many educators believe it is essential to diversify assessment strategies. Suggested alternatives include oral examinations, group projects, and practical exercises that cannot be completed solely with the help of AI. It is also necessary to implement anti-plagiarism systems and to define clear standards for the use of these tools to uphold academic integrity.

Conversational assistants or chatbots such as “ChatGPT,” “BingGPT,” or “Bard,” trained on vast amounts of textual data, are capable of generating educational materials, producing academic texts, answering clinical questions, and summarizing bibliographic information (Preiksaitis, 2023) [(9)]. Other applications based on large language models (LLMs) are specifically designed for scientific evidence search and literature review, including tools such as “Open Evidence,” “Consensus,” and “Elicit,” among others.

Their application extends to intelligent simulation environments (Hamilton, 2024) [(10)]

including virtual or augmented reality scenarios that realistically replicate clinical situations. These settings not only incorporate virtual patients, but also integrate artificial intelligence into sophisticated simulators that provide immediate and objective feedback. In such immersive contexts, AI can detect technical errors and dynamically adjust the level of difficulty based on user performance. Several studies indicate that AI-powered simulators contribute to the development of clinical skills and diagnostic reasoning within a safe environment, thereby reducing risks to real patients. For instance, AI-enhanced virtual patients enable practice in communication and decision-making skills, offering real-time feedback. In surgical training, specific models have been developed to support the acquisition of surgical techniques.

AI also facilitates gamification through educational games that adapt to the student's progress, maintaining high levels of motivation throughout the learning process (Carn Bennet, 2025) [(11)]. Similarly, augmented reality tools and intelligent 3D objects are being used to enhance anatomical visualization and guide surgical procedures. These models can be customized by linking them with AI systems.

Various LLMs and conversational assistants have opened new opportunities for integration into medical education and the simulation industry. Notable platforms include "ChatGPT," "Gemini 2.5," "LLaMA 2," "Bard," "Aleph Alpha," and "Claude". Complementing these tools are devices such as the "Android XR smart glasses." Companies like "PCS.ai," which specialize in patient communication simulators, have developed AI-based training solutions to strengthen clinical competencies. Similarly, the integration of smart speakers—such as "SimVox"—into simulation mannequins enhances the realism of educational interactions with students. Table 1 presents some of the most widely recognized AI-powered simulation products.

TABLE 1.

Company	AI-Enabled Products	AI Application	Advanced Technology
CAE Healthcare (Canada)	**CAE Ares, Lucina, Vimedix**	-Adaptive scenarios -Intelligent debriefing	- Detection of response patterns, clinical decision analysis, and automatic adaptation of scenario complexity. - Autonomous evolution of the clinical case.
Laerdal Medical (Norway)	**SimMan 3G PLUS, SimCapture, vrClinicals for Nursing**	-Automated feedback -AI analysis of sessions	-Enables automatic evaluation of clinical and technical skills, providing immediate feedback based on intelligent algorithms. -*SimCapture* is used to record, assess, and analyze simulation sessions. - Partnership with *B-Line Medical* to incorporate

			automated video analysis. -AI integration in neonatology simulators in collaboration with *SIMCharacters* to predict complications and reactions.
3D Systems (USA)	**RobotiX Mentor, GI Mentor, ANGIO Mentor**	-Real-time surgical assessment with AI	-Real-time feedback during simulated surgical procedures. -Analyzes motion patterns, applied force, and precision of surgical gestures. -Simulation based on real-case data and machine learning to adapt scenarios. -Uses neural networks trained on thousands of recorded surgical procedures.
VirtaMed (Switzerland)	**ArthroS, GynoS, UroS™, LaparoS**	-Personalized simulation -Learning curve analysis	-Uses AI algorithms to adapt the difficulty of procedures (e.g., arthroscopies, laparoscopies, gynecology). -Analyzes the user's learning curve to suggest personalized training. -Hybrid physical simulators and VR with AI that evaluates accuracy, speed, trajectory, and applied pressure.

New teaching–learning strategies are being explored that are more adaptive and student-centered, with a personalized approach. The educational process is expected to be enhanced through algorithms capable of analyzing individual progress and adjusting content, pacing, and instructional style to meet each student's specific needs. Personalized learning materials can then be provided, tailored to previously identified gaps or learning requirements.

Another developing functionality involves intelligent tutoring systems, also known as tutorbots. These AI-based tools assess students' past performance, identify knowledge gaps, and offer targeted recommendations (e.g., "ChatPDF," "Bard" in tutor mode) (Mayol, 2023) [(12)]. Tutorbots can be trained using curriculum content and course plans for each subject, acting as intelligent assistants with in-depth familiarity with the academic program. This enables tutoring to focus more effectively on the student's most challenging topics.

In some universities, automated grading systems are also being evaluated. These tools help students identify their strengths and weaknesses and recommend specific instructional strategies. Automated assessment and performance analysis tools can evaluate multiple-

choice tests or short-answer questions in near real time, providing immediate feedback. This innovation accelerates the grading process and frees up teaching resources, which is especially beneficial in courses with large student cohorts (Domínguez, 2025) [13]. Additionally, facial and voice recognition technologies are being tested to validate student identity and ensure participation in remote assessments.

3.2. Teaching Practices in Clinical Care Settings.

Teaching practices that students will experience in clinical care services are also beginning to undergo transformation. The use of clinical tools based on artificial intelligence is becoming increasingly common, including computer vision algorithms capable of analyzing radiological or echocardiographic images. Numerous applications have been documented in clinical practice, particularly in the areas of predictive medicine (Ahmed, 2020; Canabal, 2024) [14,15] personalized treatment, and the monitoring of complex conditions, such as mental health disorders (Canabal, 2025) [17]. These technologies have achieved diagnostic accuracy levels equal to or even exceeding those of specialists in fields such as radiology and dermatology (Salinas, 2024) [18].

Intensive Care Units (ICUs) and related services are environments in which data management plays a critical role in patient care, with substantial implications for patient safety (Barea, 2025) [19]. In these settings, the implementation of AI technologies has been particularly profound, making the use of data management systems and predictive models virtually indispensable (Beunza, 2024; Greco, 2021) [20,21]. We believe this field should be especially emphasized in the training of both medical and biomedical engineering students.

Nevertheless, questions arise as to whether this new way of practicing medicine may foster excessive technological dependence among professionals, and whether it may promote increased ordering of diagnostic tests for conditions with multiple possible causes, without applying probabilistic reasoning or relying on clinical judgment developed through experience—judgment that allows the clinician to identify the most common and plausible explanations for a given set of symptoms and signs.

Artificial intelligence could also help reduce the administrative burden on physicians in training. For example, automated language transcription tools can facilitate data entry into electronic health records and the drafting of clinical notes, freeing up time for more patient-centered care. In this regard, such technologies may promote the humanization of care, allowing physicians to focus more on direct interaction and less on routine tasks in front of a screen. However, some educators caution that the intensive use of these tools could hinder the development of essential skills—such as manual interpretation of lab results—lead to technological dependence, and diminish the human aspect of medical care (Verghese, 2018) [22]. Therefore, it is proposed to include in the curriculum training in new skills, such as the ability to detect errors or deviations in results generated by AI systems.

2.3. Knowledge of Limitations, Ethical, and Regulatory Content

Having reviewed some of the main applications of artificial intelligence in medical education, it is equally essential that future healthcare professionals receive training on the current limitations of this technology, as well as on the ethical dilemmas it entails (Coeckelbergh,2021) [23]. These issues must be well understood by physicians, as they can significantly impact patient health and well-being. It is crucial to recognize the existence of algorithmic biases, the risks to privacy, the responsibility for decisions made with the

support of automated systems, and the frequent lack of transparency in how these systems operate—all of which can lead to technological dependency and a disadvantaged position in relation to the technology.

Furthermore, important considerations include the ethics of generating academic texts and publications, conflicts over patents and intellectual property rights stemming from research and clinical trials, and the digital divide affecting human resources, which can result in dysfunctions at both personal and organizational levels.

Understanding the regulatory framework is also highly relevant, as it provides legal certainty for both professionals and citizens. To reach this level of preparedness, it is essential that students receive training in these areas as part of their academic programs (Wartman, 2019) [(24)]. Only in this way can they become informed, responsible, and ethically grounded professionals.

2.4. Summary Analysis of Two Leading University Institutions in Medical Education.

2.4.1. Harvard Medical School (HMS): Curriculum and Use of AI-Supported Tools.

Harvard has implemented a mandatory one-month introductory course on artificial intelligence in healthcare for all incoming students in the program. The course, Health Sciences & Technology Intelligence in Medicine, covers topics ranging from statistical fundamentals to deep learning, including concepts such as neural networks, Transformers, and Large Language Models (LLMs) (Harvard, 2023) [(25)]. Additionally, since August 2024, all students enrolled in the Health Sciences and Technology (HST) pathway have participated in a compulsory course—unique worldwide—delivered during their first month of training (Collins, 2024) [(26)].

A doctoral program in Medical AI has also been launched, following a transdisciplinary approach that integrates data science and medicine. Harvard promotes interdisciplinary collaboration across fields such as computer science, medicine, and ethics, both internally and through international academic AI networks.

Students use tools such as ChatGPT and the Harvard Clinical Training Companion, an LLM developed as an intelligent tutor and incorporated into the curriculum to provide personalized support. AI-generated simulated patients are also employed, acting as conversational avatars to simulate clinical interviews for diagnostic training. Automated self-assessment systems using open-ended responses offer immediate feedback to learners.

While IBM Watson was previously in use, the platform Pathway is now being employed. Its proprietary LLM has achieved 96% accuracy on a validated set of questions from the U.S. Medical Licensing Examination (USMLE)—the highest performance recorded thus far by a specialized medical AI (Kung, 2023) [(27)]. These outcomes are currently undergoing independent academic validation. Pathway has become the first generative medical AI to receive accreditation for continuing medical education, giving it a competitive advantage in certification processes.

AI-based systems are also being explored to assess student performance in basic science subjects and to synthesize feedback from clinical rotations. At affiliated hospitals, such as Brigham and Women’s Hospital, automated transcription of clinical conversations is being

piloted to facilitate the writing of clinical notes, thereby allowing physicians to spend more time in direct interaction with patients.

Harvard's institutional perspective is to view AI as a complementary tool to be integrated into the educational process, enabling students to learn its use responsibly and in harmony with traditional clinical skills. Mastery of these technologies must be accompanied by critical thinking and a solid understanding of their limitations and prevailing ethical challenges.

2.4.2. Stanford School of Medicine

At Stanford School of Medicine, a dedicated strategy has been established to integrate Medical Education in Artificial Intelligence into the curriculum (Stanford Medicine, 2025) [(28)]. Augmented reality is employed as a teaching tool through devices such as HoloLens, enabling interaction with three-dimensional holograms projected onto the physical environment, including 3D anatomical models superimposed on the human body. Evaluations have shown significant improvements in students' spatial understanding and overall satisfaction (Han, 2019) [(29)].

Another major advancement involves the use of Intelligent Tutoring Systems, which provide individualized instruction with real-time feedback. Students who engage with these systems demonstrate better academic performance and report higher satisfaction with the assessment process. Stanford has developed more than 30 AI applications to support clinical diagnosis, patient monitoring, outcome prediction, and administrative processes.

Additionally, the institution has implemented ethically focused programs and guidelines for the responsible use of AI, particularly through the collaborative initiative RAISE Health, which brings together Stanford University and the Human-Centered AI Institute. This initiative aims to promote the ethical and responsible integration of AI into biomedical research, healthcare, and medical education. Academic leadership stresses that students must understand the limitations and biases inherent in these technologies. The curriculum encourages the inclusion of courses on AI validation and ethics, preparing future physicians to recognize potential biases in the tools they will utilize.

Stanford has implemented more than 30 AI-based tools for diagnosis, clinical monitoring, outcome prediction, and administrative support (Dreher, 2024) [(30)]. It also hosts the AIMI (Artificial Intelligence in Medicine & Imaging) center—an advanced platform that collaborates with hospitals to apply AI in areas such as medical imaging and pathology. These innovations positively influence clinical education by enabling students to engage with cutting-edge technologies.

General-purpose AI tools, such as ChatGPT, are permitted for use in research and instruction within Stanford's continuing education programs, subject to clearly defined usage policies. The internal AIMI platform also provides access to specialized medical imaging databases and software interfaces, supporting experimentation and practical learning in healthcare applications of AI.

4. CONCLUSIONS

Universities are currently undergoing significant transformations to integrate artificial

intelligence (AI) into both undergraduate and postgraduate medical education. Based on this brief review of the current state of the art, several conclusions can be drawn:

AI is reshaping both the content and methodology of medical education. Specific topics—such as AI principles, medical informatics, machine learning, and data management—are increasingly being incorporated into curricula at all levels. A paradigm shift is underway: traditional lectures are gradually being replaced by practical, AI-enhanced experiences, including the use of simulators, automated tutoring platforms, and systems for real-time self-assessment. This transformation often necessitates the creation of interdisciplinary structures within universities, bringing together educators, clinicians, data scientists, engineers, and representatives from the simulation and educational technology industries to collaboratively address the evolving demands of medical training.

AI significantly enhances clinical simulation and the development of procedural and diagnostic skills. AI-powered virtual patients, advanced surgical simulators, and augmented reality tools provide safe, immersive, and highly realistic environments for clinical learning and practice.

The integration of AI also demands a rethinking of traditional assessment methods. The emergence of generative AI tools has prompted a diversification of evaluation strategies, including oral examinations, collaborative assignments, and in-person assessments supported by biometric identity verification systems.

Furthermore, AI is already present in real clinical settings. Medical students increasingly encounter predictive models, computer vision applications, and diagnostic algorithms during their clinical rotations. This reality calls for the development of dual competencies: mastering technological tools while also preserving independent clinical reasoning and avoiding overreliance on automation.

AI has the potential to improve both the efficiency and the humanization of medical care. By automating routine administrative tasks—such as documentation and data entry—AI can allow physicians to dedicate more time to direct patient interaction and personalized care.

Nonetheless, the adoption of AI is not without ethical and legal risks. Future healthcare professionals must be trained to understand the limitations of AI, including algorithmic biases, opacity in decision-making processes, intellectual property concerns, and disparities linked to the digital divide or institutional governance models. Ethical and regulatory literacy in AI is therefore essential to ensure a responsible and critically informed medical practice that acknowledges the opportunities and limitations of emerging technologies.

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