AI education for clinicians

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Summary

Rapid advancements in medical AI necessitate targeted educational initiatives for clinicians to ensure AI tools are safe and used effectively to improve patient outcomes. To support decision-making among stakeholders in medical education, we propose three tiers of medical AI expertise and outline the challenges for medical education at different educational stages. Additionally, we offer recommendations and examples, encouraging stakeholders to adapt and shape curricula for their specific healthcare setting using this framework.

Keywords: **Artificial intelligence; Machine learning; Medical education; Clinicians; Framework**

Introduction

Artificial intelligence (AI), specifically machine learning, is on the brink of revolutionizing medicine and healthcare. Advancements such as GPT-4 have showcased potential,[1] and initial AI solutions have gained regulatory approval.[2] Our view is that AI will not, and should not, replace clinicians; but we see remarkable potential for AI in augmenting their abilities. To produce clinically sound and effective tools, clinicians must be actively engaged in the development and implementation of AI solutions. Training for the use of AI is also a key facilitator for the acceptance of new tools.[3] Clinicians consequently need an appropriate understanding of AI. However, medical schools and postgraduate clinical training programs have been slow to integrate AI education into their curricula. Most medical students currently lack understanding of the basic technical principles underlying AI, and medical education accreditation standards typically exclude AI competencies.[4,5] Thus, there is a pressing need to consider how to equip future clinicians with the skills necessary to capture the value of AI for improving healthcare delivery and patient outcomes.[6,7] In this viewpoint, we articulate key questions that establish a framework for stakeholders to discuss and implement AI education within their respective healthcare settings. While we propose several recommendations, the framework also articulates clear questions and definitions and is intended to facilitate adaptation but also disagreement within a common structure.

Main

What are the AI skills that future clinicians should be equipped with?

Historically, the integration of new technologies into medical practice has necessitated upskilling of practitioners. Like the integration of computers across medical domains, AI will be leveraged in a broad spectrum of clinical contexts. While it is reasonable to assume that all physicians will need some basic skills to use AI technologies, the depth and extent of knowledge required beyond that will depend on their role.

As a foundation for discussing skill sets, we propose several levels of medical AI expertise that partly overlap with the TUCAPA model of AI literacy.[8] The model describes three factors of AI literacy: technical understanding (TU), critical appraisal (CA), and practical application (PA). To guide medical education, we propose three tiers of medical AI expertise: 1) basic skills, i.e., the practical ability to use the appropriate AI tools based on the clinical context and specialty; 2) proficient skills, i.e., the ability to critically assess the utility of AI tools and their outputs (e.g., through randomized controlled trials like[9]) as well as the ethical implications of integrating AI in medicine; and 3) expert skills, i.e., deeper technical understanding of AI and machine learning combined with clinical expertise, resulting in the ability to drive change. An overview of these tiers is provided in Table 1.

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	Definition	Prerequisites	Key Question(s) for Medical Education
Basic skills	Practical ability to use clinical AI tools	Intuitive and user-friendly AI interfaces, and training that involves basic concepts alongside practical experience; Knowledge about specific AI tools used within the clinician's work environment	What foundational training is needed to be able to use clinical AI tools in medical practice? What are the minimum educational requirements to allow a clinician to operate the AI tools that are in use in their specific clinical setting?
Proficient skills	Ability to critically assess the utility of clinical AI applications and their outputs as well as the ethical implications of integrating AI in healthcare (in addition to basic skills)	Additional knowledge and scientific skills for interpreting (and conducting) clinical trials and evaluating AI tools according to their value proposition, model performance, potential bias, ethical implications, and healthcare economics	How can clinicians be trained to critically assess AI applications and establish that tools are safe and effective in specific contexts of medical practice? How can clinicians be trained as key stakeholders in ensuring that AI is implemented in healthcare in accordance with ethical and societal values?
Expert skills	Deep technical understanding of machine learning combined with clinical expertise that enables experts to drive meaningful advancements in medical AI (in addition to proficient skills)	Deep technical understanding of machine learning combined with clinical expertise; Ability to explain clinical challenges to machine learning scientists and understand both potential and limitations of AI for interdisciplinary collaboration OR dual competency for autonomous work	How can clinicians be enabled to proactively foster meaningful innovation in the field of AI in medicine?

We propose three tiers of medical AI expertise alongside definitions, prerequisites, and the key questions for stakeholders in medical education.

Table 1: **Tiers of medical AI expertise.**

To shape AI education, it is important to define which level of expertise is needed depending on clinicians' individual roles. Will the basic expertise to utilize AI tools be sufficient for the majority of clinicians, or will they need proficient expertise before AI can be integrated safely? A pivotal argument in support of the latter is ethical considerations. Briefly, ethical issues with integrating AI in healthcare arise in three categories: epistemic (e.g., lacking oversight of how algorithms reach decisions), normative (e.g., unfair outcomes, often related to biased ground truth data), and issues related to traceability (i.e., how to determine the cause of harm or assign responsibility).[10]

Also, should (some) clinicians be technically trained to acquire expert skills, foster innovation, and develop methods themselves (with dual competency) or is the goal for proficiently skilled clinicians to work in conjunction with machine learning scientists?

We believe that for most clinicians, basic skills would be sufficient to leverage AI in daily practice. However, training all clinicians that will use AI to have proficient skills is preferable, particularly from a broader, societal perspective, since clinicians will be the key stakeholders determining where and how AI tools are utilized. Proficient skills, which include AI ethics, interpretability and the ability to critically appraise AI technologies, would also empower clinicians to better communicate about AI and its outputs to patients.[11] The average clinician will not need to code; instead a conceptual understanding combined with practical experience and critical appraisal skills is required.[12–14] It is reasonable to invest in training a select group of physicians[11] to acquire expert skills, enabling close collaboration with machine learning researchers to drive meaningful advancements in medical AI.

The integration of AI in medical education will presumably not be approached uniformly but will depend on the country, setting, and specialty. The overarching challenges and skill tiers, however, are rather homogenous. We explain unique considerations below.

Country-specific considerations are related to cultural nuances but also available resources. Low- and middle-income countries (LMICs) have unique challenges in healthcare access and AI has been integrated into applications ranging from low-cost portable ultrasound systems for fast breast cancer triage by minimally trained workers in Mexico[15] to chatbots for low-barrier preliminary consultations in China.[16] Conversely, resource-abundant settings already start to afford a broader range of applications and tools. Given that less infrastructure, high-quality data, and focused AI initiatives may be available in LMICs, with respect to the three-tier model, clinicians there may on average need higher skill levels to augment data, adapt models created elsewhere, and critically assess AI solutions and their applicability. If clinicians in LMICs can acquire the necessary expertise, AI can serve as an equalizer in healthcare; unlike other medical technologies that require significant financial investment—such as MRI machines or robotic surgical systems—AI solutions are usually more affordable.[17]

Next, consider different care settings. Primary care settings contain a broad variety of factors and therefore need more generalist AI, while tertiary care, which entails specific care being delivered in specific contexts, will benefit from specialized AI solutions. For instance, most AI applications in primary care are rather general tools for diagnostic decision support,[18] whereas tertiary care can make use of bespoke AI applications, e.g., for surgery.[19] Again, the general challenges and tiers of medical AI expertise remain, but for a specific group of clinicians, education needs to be aligned with their specific role in their healthcare setting.

When considering medical specialties, the set of available AI tools will be more clearly defined. While some tools may be specialty-agnostic, many will be tailored to specific specialties. On a higher level, however, we see similarities across specialties. Most specialties (e.g., cardiology[20]) work with multi-modal data (e.g., images, tables, etc.). Moreover, classes of tasks are shared across most specialties (e.g., diagnosis, clinical note-taking, treatment decisions, etc.). The implication for medical education is that most specialists will require a broad range of common foundational knowledge to understand the intricacies of data and fundamental concepts like risk prediction or causality. Considering the actual tools that will be used, there will likely be bespoke methods for each specialty in addition to more generalist medical AI.[21] Fundamental concepts and generalist AI applications should be part of foundational training, while the use of bespoke methods will not only depend on the specialty but also the specific workflows of a given hospital. Therefore, it seems most appropriate to organize this training locally.

How should medical schools incorporate AI training into their existing curricula?

At many universities, medical education follows fairly rigid curricula, has limited flexibility to cater to student interests, and aims to cover a vast amount of knowledge. Both (under)graduate training (i.e., medical school) and potential (post)graduate training (i.e., additional formal education leading to a master's degree or similar) are delivered by universities. Introducing AI education in medical schools presents both a logistical challenge—where does one find room in an already packed program?—and a curricular one—which specific skills should be taught, at what stage, and how?

Given that medical schools already struggle to maintain curricular hours,[12] this logistical challenge warrants a re-evaluation of the goals of medical education. With the ever-increasing amount of available medical data and knowledge, methods for handling large datasets and extracting intelligence for data-informed clinical decision-making are growing in relevance compared to factual knowledge. While in previous eras medical knowledge evolved rather gradually over a clinician's career, today, medical knowledge and available data are increasing rapidly.

This implies the need for a paradigm shift from training doctors to be masters of memorizing information toward developing their expertise in knowledge navigation and management, which will enable them to use data for clinical decision-making. This educational shift would require elevating the importance of certain skills while diminishing that of others. We acknowledge that this proposal may be met with some resistance from traditional medical educators; however, we contend that this evolution of medical curricula is necessary and calls for constructive collaboration among all stakeholders. To mitigate resistance, we suggest engaging faculty early in curriculum development, addressing workload concerns, and demonstrating benefits through pilot programs.

Clearly, such change will require educators who can teach AI skills to medical students. Who will deliver this teaching? Healthcare professionals, data scientists, engineers, dual-career clinician-scientists, or a combination of the above?

We propose bringing together multidisciplinary expertise, a proven enabler for successful implementations of AI education in medicine.[22–24] Multidisciplinary expertise could be utilized through joint programs or courses between medical schools and computer science departments, interdisciplinary advisory committees, and joint appointments for faculty who can bridge gaps between medicine and AI.

Regarding timing, students should be exposed to fundamental concepts early in undergraduate education to cultivate broad awareness and to more specific content at a later stage after acquiring fundamental medical knowledge, when they are better able to assess the utility of different technologies. An integrated learning approach may also be taken where, instead of creating standalone courses, educators infuse AI content into existing subjects.

From a curricular point of view, specific competencies and learning outcomes must be defined, building on the tiers of medical AI expertise (see Table 1). While every physician will need certain core competencies, various roles emerge after graduation, and with them, different, specific AI applications may play a distinct part in their professional lives. Many graduates go on to work in direct patient care, while others take on research positions as clinician-scientists, or pursue other roles. The competencies needed will necessarily differ depending on the career paths. For medical education, this leads to the requirement of defining which AI competencies to integrate into mandatory core curricula and which competencies to leave for student-selected components, electives, or postgraduate studies. A summary of these challenges and questions is provided in Table 2.

As a minimum requirement, aligned with the "basic skills" and "proficient skills" defined in the previous section, we and others[22] propose teaching the fundamentals of AI, focusing especially on what AI can offer, how it can be used in clinical practice, how models can be assessed for specific clinical uses, and how clinicians should safely and ethically deploy AI. Students should

	Definition	Prerequisites	Key Question(s) for Medical Education
Logistical challenge	Space needs to be carved out in existing curricula for AI education and new courses must be implemented	Evaluation of student and faculty workload; Review of current curricula at institutions to identify replaceable or modifiable content; Training and/or recruiting AI-literate educators	Can the overall workload in medical education be increased or can parts of the curriculum be replaced? Is a shift from memorization to knowledge management necessary in medical education? At which stage in their education can and should students be exposed to AI? Who will teach AI in medical schools?
Curricular challenge	Crucial skills, the targeted students, and educational methods need to be identified	Identification of overlapping mandatory competencies and optional competencies (building on tiers of medical AI expertise; see Table 1), and suitable educational methods for various future roles.	How can students be empowered to develop the necessary level of expertise for their desired career path?

This table highlights challenges for medical schools alongside definitions, prerequisites, and the key questions for stakeholders in medical education.

Table 2: **Challenges for incorporating AI training in medical schools.**

be particularly equipped to understand the context-dependent applicability of AI tools, interpret their outputs to enhance clinical decision-making, and effectively communicate these insights to patients. Initial implementations of AI education in medical curricula are presented in Panel 1 as illustrative examples without any claim to completeness. For a detailed overview of potential curriculum topics, we direct readers to Ng et al.[25]

What should we do to ensure that practicing clinicians are empowered with the knowledge, tools, and confidence to improve patient outcomes through AI?

Medical schools teach future doctors until graduation but are not always responsible for continuing professional development. Ongoing education is vital for clinicians throughout their professional careers, and familiarization with emerging technologies is an enduring commitment. AI should be integrated as a topic into physician training programs, fellowships, and continuing education. A few existing programs are highlighted as illustrative examples in Panel 1.

In professional contexts, the required AI expertise and knowledge of specific areas can be specified more precisely since it can be tailored to suit selected career paths. While the necessary level of expertise and the requirement for some skills may overlap, the additional skills required will depend on the clinician's role and should be specified. Specialty-specific skills are discussed further in section 1. Continuing education programs should contain shared content relevant to all specialties, complemented by more specific training where appropriate.[6]

With regard to the frequency and content of continuing professional education, a challenge lies in distinguishing transient trends from impactful AI applications[14] that will improve patient outcomes, clinician well-being, operational efficiency, and/or yield benefits for the broader healthcare system. Since different fields will progress at distinct speeds, continuing education should be dynamic, adaptable, and informed by specific advancements within the domain.

The above challenges and related questions are summarized in Table 3.

In practice, training for healthcare professionals can be delivered through continuing medical education (CME) programs, massive open online courses (MOOCs), or workshops at conferences adapted to the specialists present at the conference. Additionally, training can be arranged by hospitals to educate their clinicians on the specific tools being used by the institution during onboarding and when new tools are introduced into hospital workflows. For a better overview of the few already existing programs, beyond those mentioned in Panel 1, we refer readers to Charow et al.[22] As mentioned above, just as clinicians must update their knowledge on a regular basis, CME programs and other courses also need to be refreshed to reflect the latest advancements. These updates can be delivered by professional societies, academic institutions, or healthcare organizations to ensure that clinicians stay up to date with best practices—including those in AI.

Aside from physicians, other healthcare workers (e.g., nurses, technicians, and administrative personnel) will be increasingly exposed to AI and benefit from educational initiatives. AI tools tailored to clinicians other than physicians can be empowering.[15] Student nurses perceive moderate barriers to accessing AI and require more technical training in nursing education to overcome these challenges.[26]

Where do we go from here?

To foster confidence in AI tools, methods need to be interpretable and safe. They will be subject to scrutiny and oversight from regulatory bodies, but also require understanding by individual clinicians and their patients. Interdisciplinary dialogue among clinicians, machine learners, educators, and ethicists is pivotal for

Panel 1. **Examples of existing AI education programs for clinicians.**

Undergraduate education

- **University of Illinois College of Medicine:** Developed a curriculum that was tested on two cohorts of students and is planned to become a standard part of the medical curriculum. The course introduces AI in preclinical years focusing on foundational knowledge, vocabulary, and concepts. This transitions into the clinical years with an emphasis on applying core knowledge to real-world scenarios.[33]
- **University of Münster:** Integrated AI and data science into its medical curriculum in the form of a "Medical Informatics" block, covering foundations of neural networks, AI evaluation and regulation, alongside interactive hands-on sessions.[34]
- **University of Cambridge:** AI principles are being woven into the core curriculum in collaboration with the 'AI in medicine' student group. The underlying principles of AI are introduced in year 4. Efforts include using tools like ChatGPT for clinical decision-making and discussion on the proper use of AI in the context of clinical reasoning (Dr. Lillicrap, personal communication).

(Post)graduate education

- **University of Toronto:** While all students are introduced to AI concepts in their preclinical years, interested students are offered an additional two-year "Computing for Medicine" certificate program.[13]
- **National University of Singapore:** Offers a Master of Science in Precision Health and Medicine (MScPHM) to students from medical and STEM backgrounds. The course is led by an interdisciplinary team of academics, clinicians, and industry leaders.[35]

Continuing medical education

- **Northwestern University:** The Feinberg School of Medicine offers an in-depth fellowship to trainees in cardiology, cardiac surgery, and internal medicine. The curriculum begins with foundational courses in computation and statistics, before advancing to AI, machine learning, and data science. Fellows have worked on projects like AI systems to detect COVID-19 from chest x-rays.[36]
- **University of Pennsylvania:** The Penn Radiology Imaging Informatics Fellowship offers specialized training in imaging informatics to fourth-year residents and clinical fellows. The program includes lectures, discussion, and hands-on lab sessions. Fellows complete at least one project.[37]
- **University of Cambridge:** Offers an online summer school on AI in medicine dedicated to clinicians and medical students. Machine learning knowledge is built from fundamentals and participants are empowered to use AI even without coding knowledge.[38]

We highlight a few of the early initiatives offering AI education to clinicians at various stages of medical education as illustrative examples without any claim to completeness. With many leading institutions in medical education currently starting to work on their own solutions (Dr. Stevens, personal communication), these examples could offer inspiration.

the future of AI in medical education, and forums should continue to be formed. To drive meaningful innovation, clinicians must be able to effectively communicate their needs and insights to AI researchers and developers, while being aware of technical constraints.

At the current stage, it seems that most efforts have been directed toward extracurricular or elective components.[22] However, mandatory coursework and assessments will increase the likelihood of AI actually being leveraged effectively in clinical settings.[22–24,27] Given that radiology pioneered the usage of AI algorithms,[12] imaging plays a large role in current programs. Cutting-edge topics like causal machine learning, which is poised to offer substantial advancements for treatment effect estimation and early diagnosis,[28,29] and large language models, which open a whole new chapter for digital health,[30] must not be missed.

	Definition	Prerequisites	Key Question for Medical Education
Specialization- and hospital- specific AI skills	Tailoring AI education to the clinician's specialty and work environment	Understanding of the clinician's role, the needs of the specific specialty, and technology used at their institution	What specific AI tools and methods are most relevant for practicing clinicians in specific settings?
Frequency and contents	Distinguishing AI applications that promise improved clinical and systemic outcomes from temporary trends	Awareness of the evolving AI landscape and rationales for evaluating tools	How can the long-term impact and utility of emerging AI technologies be estimated?

This table highlights challenges for continuing medical education alongside definitions, prerequisites, and the key questions for stakeholders in medical education.

Table 3: **Challenges for incorporating AI training in continuing education.**

While not the focus of this viewpoint, we would like to highlight that AI-powered tools themselves can be used to further individualize medical education, e.g., as "personal tutors".[31] In addition, a broader societal debate is required regarding the ethical implications of using AI in medicine (reviewed elsewhere[10]). To ensure AI benefits doctor-patient relationships, two main solutions have been proposed by Sauerbrei and colleagues: a) AI should be used to assist rather than replace doctors, e.g., by freeing up time for empathetic patient interaction, and b) medical education needs to focus on both AI literacy *and* relational skills like empathy and communication.[32]

Finally, building AI education courses requires not only clinical and technical perspectives but also input from fields like education science, cognitive psychology, and health policy.

Since the need for AI education tailored to clinicians is clear, the community should act and identify actionable, pragmatic steps to incorporate useful AI training. Taking these steps will enable stakeholders in medical education to ensure that present and future clinicians are equipped with the skills to enhance healthcare delivery and patient outcomes through AI. We hope this framework will guide the discussion among educators, students, clinicians, and AI experts.

Contributors

TS and TO jointly wrote the original draft of this paper (equal contribution). RDS, PHW, and MvdS reviewed and edited the manuscript. TS and TO have accessed and verified the data in this manuscript.

Data sharing statement

Not applicable.

Declaration of interests

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