

Artificial Intelligence in Medical Education: Curriculum Design, Assessment Models, and Educational Infrastructure Across Undergraduate and Residency Training – A Narrative Review

Tıp Eğitiminde Yapay Zekâ: Lisans ve Uzmanlık Eğitimi Boyunca Müfredat Tasarımı, Değerlendirme Modelleri ve Eğitim Altyapısı – Anlatı Derlemesi

ABSTRACT

Artificial intelligence (AI) is rapidly becoming an integral part of everyday clinical practice, including cardiology and cardiovascular surgery. As AI increasingly influences diagnostic and therapeutic decisions, physicians are expected to interact with these systems in a critical, safe, and ethically grounded manner. This narrative review aims to explore how AI can be systematically integrated into undergraduate and residency medical education, with a particular focus on curriculum design, teaching strategies, assessment models, and educational infrastructure, while considering the context of the Turkish medical education system. A narrative synthesis of international medical education literature, policy documents, and institutional reports was conducted without quantitative meta-analysis. The review was guided by the principles of human-in-the-loop clinical reasoning, ethical AI use, and patient safety. Effective integration of AI into medical education requires a longitudinal and staged curriculum spanning preclinical, clinical, and residency training. Assessment strategies must explicitly address AI-assisted decision-making and be supported by transparent institutional policies governing AI use in examinations, as well as by secure, regulation-compliant digital infrastructure. Educational approaches should encourage learners to critically appraise and contextualize AI outputs rather than accept them uncritically. The reviewed literature supports a competency-based educational framework that integrates AI literacy, ethical reasoning, and context-aware clinical judgment. AI education should be viewed as a core clinical competency that strengthens rather than replaces human judgment. Particularly in high-risk cardiovascular disciplines, a standardized, ethics-centered, and competency-based educational framework is essential to prepare future physicians for AI-augmented healthcare environments.

Keywords: Artificial intelligence, assessment, clinical decision support, ethics, medical education, residency training

ÖZET

Yapay zekâ (YZ), kardiyoloji ve kardiyovasküler cerrahi dâhil olmak üzere günlük klinik uygulamanın ayrılmaz bir parçası hâline hızla gelmektedir. YZ'nin tanınal ve terapötik kararlar üzerindeki etkisi arttıkça, hekimlerin bu sistemlerle eleştirel, güvenli ve etik temellere dayalı bir şekilde etkileşim kurmaları beklenmektedir. Bu anlatı derlemesi, YZ'nin lisans ve uzmanlık düzeyindeki tıp eğitimine nasıl sistematik olarak entegre edilebileceğini; müfredat tasarımı, öğretim stratejileri, değerlendirme modelleri ve eğitim altyapısı açısından incelemeyi amaçlamakta ve bunu Türkiye'deki tıp eğitimi sistemi bağlamında ele almaktadır. Uluslararası tıp eğitimi literatürü, politika belgeleri ve kurumsal raporlar, nicel bir metaanaliz yapılmaksızın anlatı sentezi yöntemiyle değerlendirilmiştir. Derleme; insan denetimli klinik akıl yürütme, etik YZ kullanımı ve hasta güvenliği ilkeleri doğrultusunda yönlendirilmiştir. YZ'nin tıp eğitimine etkili biçimde entegre edilmesi, prelinik, klinik ve uzmanlık eğitimi kapsayan uzunlamasına ve aşamalı bir müfredat gerektirir. Değerlendirme stratejileri, YZ destekli karar verme süreçlerini açıkça ele almalı; sınavlarda YZ kullanımını düzenleyen şeffaf kurumsal politikalar ve güvenli, mevzuata uygun bir dijital altyapı ile desteklenmelidir. Eğitim yaklaşımları, öğrenenlerin YZ çıktılarının eleştirel değerlendirilmesi ve bağlamsallaştırılması becerilerini geliştirmeli, bu çıktıları sorgulamadan kabul etmelerini engellemelidir. İncelenen literatür, YZ okuryazarlığını, etik akıl yürütmeyi ve bağlama duyarlı klinik yargıyı bütünleştiren yetkinlik temelli bir eğitim çerçevesini desteklemektedir. YZ eğitimi, insan yargısını ikame eden değil, güçlendiren temel bir klinik yetkinlik olarak değerlendirilmelidir. Özellikle yüksek riskli kardiyovasküler alanlarda, YZ destekli sağlık hizmeti ortamlarına hekimleri hazırlamak için standartlaştırılmış, etik temelli ve yetkinlik odaklı bir eğitim çerçevesi gereklidir.

Anahtar Kelimeler: Yapay zekâ, değerlendirme, klinik karar destek, etik, tıp eğitimi, uzmanlık eğitimi

REVIEW DERLEME

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Artificial intelligence (AI) has become an increasingly integral component of modern healthcare systems. Across disciplines such as radiology, pathology, cardiology, cardiovascular surgery, oncology, intensive care, and primary care, AI-based tools are influencing how clinicians diagnose disease, assess risk, and plan treatment.^{1,2} Advances in machine learning-driven diagnostics, predictive models derived from electronic health records, and generative AI systems capable of producing clinical documentation are now affecting everyday clinical decision-making.

In cardiovascular medicine and surgery, AI is being explored for imaging interpretation, perioperative risk assessment, surgical planning, and postoperative follow-up. As these systems become more embedded in clinical workflows, physicians are expected not only to use AI tools but also to understand their limitations, potential biases, and implications for patient safety. This shift creates new expectations for medical education.³

In Türkiye, interest in AI within medical education is increasing; however, current initiatives remain fragmented and are often limited to elective courses or short-term educational activities. The absence of a nationally standardized framework highlights the need for a coherent and pedagogically grounded approach. This narrative review therefore examines how AI can be integrated into medical education in a way that strengthens clinical reasoning, protects patient safety, and supports professional accountability.

Against this background, there is an urgent need for a structured, ethically grounded, and pedagogically sound framework for integrating AI into medical education. Rather than positioning AI as a replacement for clinical expertise, educational strategies should emphasize augmentation, critical appraisal, and shared decision-making between human clinicians and intelligent systems. This review aims to synthesize current evidence on AI in medical education, critically evaluate existing training models, and propose guiding principles for responsible and sustainable integration aligned with both educational theory and clinical practice.

However, there remains a lack of assessment-aligned, longitudinal, and nationally adaptable frameworks that systematically span both undergraduate and residency medical training.

Materials and Methods

This study was designed as a narrative review. Relevant literature on artificial intelligence in medical education was identified through searches of major medical and educational databases, including PubMed, Scopus, Web of Science, and ERIC, as well as policy reports from organizations such as the World Health Organization and the Organization for Economic Co-operation and Development. Position statements from leading medical education bodies were also reviewed. The search strategy combined keywords including "artificial intelligence," "medical education," "curriculum," "assessment," "clinical decision support," and "ethics." The literature search primarily focused on publications between 2018 and 2024, reflecting the period during which clinically applicable AI systems and educational frameworks have rapidly expanded. English-language sources were prioritized, with additional consideration given to Turkish policy documents and institutional reports relevant to national

ABBREVIATION

AI Artificial intelligence

medical education. Source selection prioritized conceptual relevance, educational applicability, and ethical considerations rather than quantitative outcomes. Findings were synthesized thematically, with a focus on curriculum structure, assessment strategies, and educational infrastructure, guided by the principles of human-in-the-loop clinical reasoning, ethical AI deployment, and patient safety. Neither formal quantitative quality scoring nor meta-analytic synthesis was performed, in keeping with the narrative design of the review.

Results

The identified themes can be conceptualized within a staged educational framework aligned with progressive clinical responsibility and increasing exposure to AI. The synthesis of the literature revealed several consistent and interrelated themes across studies.^{3,4}

First, successful AI education requires longitudinal integration across all stages of medical training, including preclinical, clinical, and residency phases, rather than isolated instructional units or elective courses. This approach ensures that AI literacy develops as a continuous professional competency.

Second, traditional assessment models are inadequate in the context of AI-augmented clinical practice. Assessment strategies must evolve to evaluate higher-order competencies such as clinical reasoning, ethical judgment, and the critical appraisal of AI outputs within authentic or simulated clinical scenarios. Reliance on rote memorization is no longer an adequate proxy for clinical competence.⁵

Third, institutional preparedness is essential. This includes the establishment of transparent policies governing appropriate AI use in education and assessment, alongside robust, secure, and regulation-compliant digital infrastructure capable of supporting simulation, data protection, and equitable access to AI tools.⁶

Across the literature, a consistent finding was the importance of fostering critical engagement with AI. Educational models that emphasize the contextual interpretation and validation of AI-generated recommendations are associated with improved clinical reasoning and a reduction in harmful automation bias among trainees.^{4,7}

Discussion

The following sections synthesize the reviewed evidence into a practical and educationally grounded framework, translating conceptual findings into actionable components for curriculum design, teaching, and assessment.

Integrating AI into medical education represents an educational and cultural challenge rather than a purely technical one. Early and repeated exposure to AI concepts helps demystify these systems and supports the development of balanced clinical judgment. Embedding AI within existing curricula allows learners to perceive it as a natural component of routine clinical reasoning rather than as a disruptive external force.^{3,8}

Table 1. Representative table mapping specific AI competencies to existing accreditation standards

| AI competency domain | Description of Competency | Relevant accreditation / qualification criteria | Example evidence for accreditation |
|---|---|--|---|
| AI literacy and conceptual understanding | Knowledge of fundamental AI concepts, including machine learning, natural language processing, and data-driven systems | Program learning outcomes requiring advanced disciplinary knowledge within the national qualifications framework | Written examinations, conceptual quizzes, theoretical assignments |
| Data literacy and analytical skills | Ability to collect, process, analyze, and interpret structured and unstructured data for informed decision-making | Analytical thinking and problem-solving competencies emphasized in program accreditation standards | Data analysis reports, statistical projects, applied research assignments |
| Algorithmic and computational thinking | Capacity to understand, evaluate, or design algorithms used in AI systems and digital technologies | Technical and methodological competencies required in computing and engineering-related programs | Programming assignments, algorithm design projects, coding assessments |
| AI tool application | Ability to effectively use AI-based tools (e.g., large language models, predictive analytics systems) for academic and professional tasks | Digital competency and technology integration outcomes in higher education programs | Practical laboratory exercises, tool-based coursework, applied projects |
| Human-AI collaboration | Ability to critically evaluate AI-generated outputs and integrate them into human decision-making processes | Critical thinking and professional judgment competencies in quality assurance frameworks | Scenario-based evaluations, case studies, reflective analyses |
| Ethical and responsible AI use | Understanding ethical considerations including algorithmic bias, data privacy, accountability, and transparency | Ethical responsibility and professional conduct criteria in accreditation frameworks | Ethics reports, policy analyses, reflective essays on responsible AI |
| AI in professional practice | Application of AI technologies within discipline-specific contexts such as business, healthcare, engineering, or education | Applied knowledge and real-world problem-solving requirements in program outcomes | Capstone projects, internships, applied industry collaborations |
| AI-supported teaching and learning (education programs) | Ability to design AI-enhanced learning environments and integrate AI into instructional strategies | Pedagogical competence and instructional design outcomes in teacher education accreditation | Instructional design projects, lesson plans integrating AI tools |
| Research and innovation with AI | Ability to conduct research using AI methodologies or develop innovative AI-driven solutions | Research competence and innovation capacity expected in undergraduate and graduate programs | Research papers, thesis projects, experimental studies |
| Lifelong learning and adaptability | Capacity to continuously update knowledge and skills in response to rapidly evolving AI technologies | Lifelong learning competency emphasized in national qualifications frameworks | Professional development portfolios, independent learning projects |

The Turkish context presents both opportunities and challenges. Centralized governance of medical education may facilitate coordinated implementation of national AI competency standards. Aligning AI education with existing accreditation frameworks from the Turkish Council of Higher Education and the National Medical Specialty Education Board (TUSED, Türkiye) could promote consistency, quality, and sustainability.⁹ However, successful implementation depends on substantial investment in faculty development and institutional infrastructure. Although discussed within the Turkish context, these principles are transferable to other centrally governed or resource-constrained medical education systems. The integration of AI competencies into higher education curricula requires alignment with existing accreditation and quality assurance frameworks. In Türkiye, universities design program learning outcomes in accordance with national higher education standards established by the Council of Higher Education (Türkiye) and monitored through quality assurance processes coordinated by the Higher Education Quality Council of Türkiye. To illustrate how emerging AI-related skills can be incorporated within these established frameworks, Table 1 presents a representative mapping between key AI competency domains and corresponding accreditation criteria.⁹ The table demonstrates how competencies such as AI literacy,

data analysis, ethical AI use, and human-AI collaboration align with widely recognized learning outcomes, including analytical thinking, professional responsibility, research competence, and lifelong learning. This alignment highlights that integrating AI competencies into higher education programs does not require entirely new accreditation structures; rather, these competencies can be embedded within existing outcome-based quality assurance systems through curriculum design, assessment strategies, and program evaluation practices.

It is important to acknowledge that this review is limited by its narrative design and by the rapidly evolving nature of AI technologies, which may outpace curricular adaptations. Additionally, much of the available literature consists of conceptual frameworks, expert perspectives, or early educational initiatives rather than fully implemented and outcome-validated curricula.

The relative scarcity of Türkiye-specific empirical studies on AI integration in medical education further limits the generalizability of localized recommendations. Future research should focus on outcome-based evaluations of AI education, particularly its impact on clinical performance, patient safety, and professional behavior in high-risk fields.

Conceptual Foundations: AI Literacy for Medical Students and Residents

AI literacy in medicine extends beyond basic familiarity with digital tools. Medical trainees must understand that most contemporary AI systems rely on probabilistic pattern recognition rather than causal reasoning.¹⁰ Without this understanding, clinicians may become vulnerable to automation bias, excessive trust in algorithmic outputs, and subsequent diagnostic or therapeutic errors.⁴

Foundational AI education should therefore include core concepts such as supervised and unsupervised learning; model performance metrics, including sensitivity, specificity, and area under the curve; external validation; and common failure modes such as dataset bias and hallucinations in generative models.¹¹ These topics should be taught using clinically relevant examples and analogies, without requiring programming skills, to ensure accessibility and relevance.

Upon achieving foundational AI literacy, learners should be able to critically evaluate AI-generated clinical recommendations, recognize scenarios in which AI performance may be compromised, and integrate algorithmic outputs with clinical judgment and patient-specific context.

Curriculum Design Across Educational Stages

Undergraduate Medical Education

During the preclinical years, AI concepts should be integrated into existing courses such as biostatistics, epidemiology, and evidence-based medicine. Early exposure to AI-assisted case discussions and algorithmic risk scores helps students develop essential conceptual familiarity.³

During clinical clerkships, students should encounter AI tools within real or simulated clinical workflows, such as clinical decision support alerts or radiology assistance systems. These encounters should be supported by structured supervision and guided reflection, enabling learners to critically evaluate the role, benefits, and limitations of AI in patient care.¹²

Residency Training

Residency programs require more advanced and specialty-specific AI education. In cardiovascular surgery and interventional cardiology, AI-enhanced simulations can provide valuable training in preoperative decision-making, complication prediction, and postoperative monitoring.¹³

Residents should also be trained to communicate AI-supported decisions transparently to patients, clearly explaining the role of these technologies in clinical care.⁷

Teaching Methods in AI-Enhanced Medical Education

Effective AI education necessitates a shift from purely didactic instruction toward learner-centered approaches. Case-based discussions, flipped classrooms, and critical appraisal exercises, in which trainees audit AI-generated outputs, promote active learning and deeper engagement.³ Interdisciplinary teaching involving collaboration among clinicians, data scientists, and ethicists further enriches the educational experience by integrating technical, clinical, and ethical perspectives.¹⁴

Assessment and Examination Models

Traditional closed-book examinations, which primarily assess factual recall, are poorly suited to evaluating the competencies required for AI-augmented clinical practice.⁵ AI-aware assessment models should include open-book examinations permitting the use of artificial intelligence tools with mandatory disclosure and justification; AI-enhanced Objective Structured Clinical Examinations, in which candidates must interpret or communicate AI-generated findings; and portfolio-based assessments documenting reflective and responsible AI use during clinical training. These approaches provide more authentic measures of clinical competence, particularly in high-risk disciplines such as cardiovascular medicine.¹⁵

Maintaining examination integrity in the era of artificial intelligence requires carefully designed assessment environments that balance authentic AI-supported practice with safeguards against inappropriate reliance on automated tools. In high-stakes assessments, unrestricted use of AI systems may introduce risks such as automation bias, where trainees defer to algorithmic outputs rather than demonstrating independent clinical reasoning.¹⁶ To mitigate this risk, institutions should establish transparent policies defining when and how AI tools may be used during examinations. Structured formats—such as supervised open-book assessments and mandatory disclosure of AI assistance, or scenarios in which learners must explicitly critique AI-generated recommendations—can help ensure that evaluation focuses on higher-order competencies rather than passive acceptance of algorithmic outputs. In addition, secure digital testing environments, proctoring protocols, and clear academic integrity guidelines are essential to prevent unauthorized AI use. Together, these strategies help preserve the validity of assessments while reinforcing the educational objective that AI should augment, rather than replace, human clinical judgment.

Ethical, Legal, and Professional Considerations

Ethical instruction must be embedded throughout AI education rather than treated as an add-on. Core issues requiring longitudinal attention include data privacy and informed consent, algorithmic bias and health equity, professional accountability for AI-influenced decisions, and transparency in patient-clinician communication.^{17,18} Teaching the technical aspects of AI without a strong ethical foundation may risk undermining patient trust and safety.^{6,11} To support safe interaction with AI-assisted clinical tools, trainees require practical strategies for identifying algorithmic bias and mitigating automation-related risks. The checklist presented in Table 2 provides a structured approach that medical students and residents can apply during real-world clinical encounters to critically evaluate AI-generated recommendations and preserve patient safety.

Integration Strategies for AI Education in Medical Curricula

Rather than introducing AI as a standalone discipline, a more feasible and sustainable strategy is to integrate AI-related competencies into existing components of the medical curriculum. Foundational concepts such as algorithm performance metrics, predictive modeling, and data interpretation can be incorporated into courses already devoted to biostatistics and evidence-based medicine, where students learn to evaluate diagnostic

Table 2. Checklist detailing how trainees can proactively identify and mitigate these biases when interacting with real-world clinical tools

| Stage of AI interaction | Key questions for trainees | Practical actions |
|---|---|--|
| Before using the AI tool | Is the AI system validated for the patient population and clinical context? | Review the intended use, validation population, and known limitations of the AI system before applying it in clinical decision-making. |
| | Does the tool rely on datasets that may exclude certain populations? | Consider whether demographic groups such as older patients, women, or minority populations may be underrepresented in the training data. |
| | Is the clinical question appropriate for AI assistance? | Use AI tools as supportive decision aids rather than replacements for clinical reasoning. |
| During AI-assisted decision-making | Does the AI recommendation align with the patient's clinical presentation? | Compare the AI output with clinical findings, established guidelines, and differential diagnoses. |
| | Could automation bias be influencing your interpretation? | Avoid accepting AI outputs automatically; actively question unexpected or unusually confident recommendations. |
| | Are there inconsistencies between AI outputs and clinical judgment? | Reassess patient data, review alternative diagnoses, and consult senior clinicians when discrepancies arise. |
| After receiving the AI output | Could dataset bias explain the AI recommendation? | Evaluate whether patient characteristics (age, comorbidities, socioeconomic factors) may fall outside the algorithm's training distribution. |
| | Is the AI output explainable and clinically interpretable? | Prefer outputs that provide transparent reasoning or supporting variables rather than opaque predictions. |
| Patient communication and documentation | How should the AI contribution be communicated to the patient? | Explain the supportive role of AI in decision-making and emphasize that clinical responsibility remains with the physician. |
| | Was the AI tool influential in the final decision? | Document when AI-assisted recommendations were considered and how they were integrated with clinical reasoning. |
| Reflection and quality improvement | Did the AI tool perform as expected in this case? | Reflect on discrepancies and discuss them during case reviews or morbidity and mortality meetings. |
| | Could the system demonstrate systematic bias? | Report repeated inconsistencies or potential biases through institutional quality and safety channels. |

tests, risk prediction models, and clinical research methodology. For example, discussions of sensitivity, specificity, and receiver operating characteristic curves can be expanded to include the evaluation of machine learning models and clinical decision-support algorithms. Similarly, epidemiology and population health courses can address issues such as dataset bias, representativeness, and fairness in algorithmic systems. During clinical clerkships, AI-supported tools—such as imaging interpretation software or clinical risk calculators—can be introduced within supervised case discussions, enabling trainees to critically assess algorithmic outputs alongside traditional clinical reasoning. This integrative approach minimizes curricular disruption while promoting longitudinal exposure to AI concepts across training stages. By embedding AI literacy within familiar educational contexts, medical schools can foster critical engagement with emerging technologies while maintaining alignment with established competency-based educational frameworks.

Conclusion

Artificial intelligence is no longer a speculative addition to healthcare; it is an operational reality that is reshaping clinical workflows, diagnostic pathways, and health system governance. Medical education must therefore evolve proactively to prepare future physicians not only to use AI tools but also to critically evaluate, ethically govern, and responsibly integrate them into patient care.

Artificial intelligence should be integrated into undergraduate and residency medical education as a core clinical competency. A staged, human-centered, and ethics-driven educational framework can ensure that AI functions as a powerful adjunct that supports and strengthens, rather than replaces, human clinical judgment. This integration is particularly important in cardiovascular and other high-stakes disciplines, where AI-assisted decision-making increasingly influences patient outcomes. Such frameworks are essential to preserve professional accountability, enhance patient safety, and sustain trust in AI-augmented healthcare systems. Future research should focus on evaluating the educational and clinical outcomes of AI-integrated curricula, including their impact on clinical reasoning, patient safety, and professional decision-making in real-world healthcare environments.

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