ISSN: 2538-5887; Pathobiology Research. 2026; 29 (4): 53-69
DOI: 10.48311/mjms.2026.123621.82640

Digital Transformation in Medical Education: A Narrative Review of Technologies, Integration, and Challenges

Review History:
Received: 2026-09-10
Revised: 2026-09-30
Accepted: 2026-10-24

Article Type:
Narrative Review Articles

Authors:
Mohsen Saffar[1]
Nahid Moradi[2]
Azam Saffar[3*]

1. Department of Information Technology, Faculty of Industrial Engineering, K. N. Toosi University of Technology, Tehran, Iran.
2. Applied Cell Sciences Division, Department of Hematology, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
3. Department of Biostatistics, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.

**** Corresponding author:***
Azam Saffar

ORCID: 0000-0002-6381-7726
E-mail:
azam.saffar66@modares.ac.ir

ABSTRACT

Digital transformation is fundamentally altering the structure and delivery of medical education through changes in educational technologies, teaching practices, and institutional processes. This narrative review synthesizes the literature on seven domains of digital transformation in medical education: artificial intelligence, immersive technologies, digital learning platforms and blended learning, telemedicine education, learning analytics, digital assessment, and mobile learning. Relevant literature published between 2015 and 2026 was identified through searches of Web of Science, PubMed, and Scopus, and findings were synthesized narratively. Across these domains, reported applications include personalized learning, clinical simulation, flexible access to educational resources, virtual clinical training, and digital assessment. However, the reported educational benefits vary across technologies and study outcomes. While some studies indicate improvements in knowledge acquisition and selected assessment outcomes, others primarily examine feasibility, usability, learner perceptions, and engagement. Evidence regarding sustained clinical competence and transfer of learning to clinical practice remains limited. The review highlights the importance of integrating digital technologies with curriculum development, digital competency development, faculty readiness, adequate infrastructure, and institutional support. Persistent barriers include resource constraints, unequal access, curriculum rigidity, technical limitations, and ethical and reliability concerns. Overall, digital transformation in medical education represents a systemic educational and organizational process rather than technology adoption alone. Sustainable implementation requires alignment between technological innovation, educational objectives, and institutional capacity, alongside rigorous evaluation of long-term educational outcomes.

Keywords: Digital Transformation, Medical Education, Artificial Intelligence, Digital Health, Educational Technology.

Copyright© 2026, TMU Press. This open-access article is published under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License which permits Share (copy and redistribute the material in any medium or format) and Adapt (remix, transform, and build upon the material) under the Attribution-NonCommercial terms.

1. Introduction

Medical education is undergoing a substantial transformation as digital technologies increasingly influence the way knowledge is delivered, clinical skills are developed, and learning processes are organized. This transformation represents a shift from traditional standardized educational models toward more flexible, technology-mediated, and learner-centered approaches. However, digital transformation in medical education extends beyond the simple adoption of electronic tools; it requires the integration of digital technologies into educational processes, curricula, and institutional practices to create sustainable changes in teaching and learning (1,2).

The emergence of advanced digital technologies has accelerated this transformation. Artificial intelligence (AI), large language models (LLMs), immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), as well as digital learning platforms and learning management systems (LMS), have introduced new possibilities for personalized learning, clinical simulation, flexible knowledge delivery, and data-supported educational decision-making. AI-driven learning systems, for example, have demonstrated the ability to adapt educational content according to learner performance, while conversational AI tools have

been applied as virtual patients to support clinical communication training and self-directed learning (3,4). Similarly, immersive technologies have enabled risk-free clinical practice environments and enhanced students' understanding of complex anatomical and clinical concepts through three-dimensional interactive experiences (5,6).

Despite these advances, successful digital transformation requires more than technological implementation. Evidence indicates that effective transformation depends on curriculum integration, development of digital competencies among students and educators, and institutional readiness. Current medical curricula often lack systematic integration of digital health competencies, including digital communication, data management, telemedicine applications, and artificial intelligence literacy, leaving many students insufficiently prepared for digitally enabled healthcare environments (1,7). In addition, faculty readiness remains a critical factor, as educators require structured training and institutional support to effectively incorporate digital tools into teaching practices (2,8).

Furthermore, significant challenges continue to limit the widespread implementation of digital transformation in medical education. These challenges include technological and infrastructure limitations, unequal access to digital resources, curriculum rigidity, faculty workload constraints, ethical concerns, and risks associated with inappropriate use of emerging technologies. In resource-limited settings, inadequate internet access, financial barriers, and insufficient technical support can prevent sustainable adoption of digital educational approaches (9,10).

Therefore, this narrative review aims to summarize the current landscape of digital transformation in medical education by examining emerging technologies, their educational applications, implementation challenges, and the organizational and human factors required for successful integration.

2. Literature Search Strategy

A structured literature search was conducted to identify relevant studies examining digital transformation and technology integration in medical education. The databases Web of Science, PubMed, and Scopus were searched for studies published between 2015 and 2026. The search strategy was developed using combinations of keywords related to digital transformation, medical education, emerging educational technologies, and implementation-related factors.

The search terms included concepts related to digital transformation (e.g., "digital transformation," "digitalization," "digital education," and "technology-enhanced learning"), medical education (e.g., "medical education," "health professions education," and "clinical education"), digital technologies (e.g., artificial intelligence, large language models, VR, AR, learning analytics, adaptive learning, mobile learning, and learning management systems), and implementation factors (e.g., adoption, integration, digital readiness, governance, and organizational change).

Inclusion was restricted to studies available in the English language, available as full-text articles, and focused on the application, implementation, evaluation, or challenges of digital technologies within medical or health professions education. Review articles, book chapters, non-English publications, and studies unrelated to educational applications of digital technologies were excluded.

Retrieved records were screened through title/abstract assessment followed by full-text evaluation. Duplicate records were removed before screening. Studies were selected based on their relevance to the objectives of this narrative review, and findings were synthesized narratively according to major themes, including digital technologies, educational integration, implementation challenges, and future directions.

3. Digital Technologies Enabling Transformation in Medical Education

Digital transformation in medical education is increasingly supported by emerging technologies that modify how medical knowledge is delivered, clinical skills are practiced, and learning experiences are personalized. Among the major technological drivers identified in the literature are AI, immersive technologies including virtual reality, augmented reality, and mixed reality, as well as digital learning platforms and blended learning environments. These technologies represent different but interconnected pathways through which medical education is moving

toward more adaptive, interactive, and flexible learning models (2,4,5).

3.1. Artificial Intelligence and Personalized Learning

Artificial intelligence applications in medical education include different approaches, such as adaptive learning systems, LLMs, and generative AI. These applications have different educational purposes and should be evaluated according to the type of outcome assessed. Current evidence includes studies evaluating personalized learning, conversational AI applications, assessment generation, and learner perceptions; however, the strength of evidence varies across these domains.

Adaptive learning systems have been investigated for personalized education by modifying learning pathways, resource recommendations, or educational activities according to learner needs. A prospective cluster randomized trial evaluating an AI-driven personalized learning platform reported higher post-test scores and increased study duration compared with conventional learning approaches (4). However, available evidence remains limited by factors such as small sample sizes, single-center designs, and limited information regarding long-term outcomes.

Large language models, including ChatGPT-based applications, have been explored as educational tools for virtual patient simulation, communication training, and learning support. A pilot mixed-methods study evaluating ChatGPT as a virtual patient for history-taking practice reported an improvement in objective structured clinical examination (OSCE) history-taking scores alongside positive usability findings (3). Other studies evaluating conversational AI systems have mainly focused on feasibility, usability, and learner perceptions, reporting acceptable usability and motivation outcomes but without objective assessment of clinical performance (11). Therefore, current evidence supports the educational feasibility of LLM-based tools, while evidence regarding broader clinical competence remains limited.

Generative AI has been explored for creating educational materials, including clinical cases, rubrics, and feedback prompts (12,13). It has also been used for curriculum development. In one reported application, GPT-4.0 produced an initial nephrology point-of-care ultrasound fellowship curriculum, including learning objectives, instructional methods, and assessment strategies. The curriculum was iteratively expanded and refined using multiple language models across 12 rounds before review and final refinement by clinical experts (14). Generative AI has also been used to develop personalized curriculum-enhancement models within a nursing ethics course, including individualized learning-path recommendations based on learner behavior and assessment performance (15). These examples illustrate potential applications in curriculum development and instructional design but do not establish improved learner outcomes or educational effectiveness. Outputs may be incomplete, inaccurate, culturally misaligned, or biased, making human review necessary before educational implementation (12). Evidence should therefore be interpreted as application-specific, with broader effectiveness remaining to be established.

Overall, evidence regarding AI in medical education remains heterogeneous. While some controlled studies have reported improvements in objective learning outcomes, many studies have primarily examined usability, acceptance, perceptions, and concerns related to AI implementation (16–19). Reported challenges include concerns regarding hallucination, reliability, ethical issues, and the potential risks associated with inappropriate use. Importantly, current evidence does not establish long-term effects on clinical competence or transfer of learning to clinical practice. Therefore, AI should currently be considered an educational support tool, with further research required to determine its sustained educational effectiveness.

3.2. Immersive Technologies for Clinical and Experiential Learning

Immersive technologies, including virtual reality, AR, and MR, provide interactive three-dimensional environments that have been applied to clinical simulation, anatomical visualization, and procedural training in medical and health professions education (5). However, the reported educational outcomes vary considerably across studies, ranging from feasibility and learner perceptions to objectively measured knowledge and clinical skills.

Objective evidence suggests potential benefits for selected learning outcomes, although findings are not consistent across applications. In a randomized controlled trial of VR-based

resuscitation training, participants demonstrated greater theoretical knowledge retention at 12 weeks, while no significant difference was observed in overall OSCE clinical skill performance compared with the control group (20). Similarly, a mobile AR intervention for fracture recognition was associated with significant improvement in objective examination scores in a one-group pre-test/post-test study (21). In contrast, a comparative pilot study of abdominal physical examination training found that collaborative 360° VR produced lower objective clinical skill scores than video-based instruction combined with structured peer discussion (22). These findings indicate that improvements in knowledge or engagement should not be assumed to translate directly into superior clinical skill performance.

Other studies have primarily evaluated feasibility, usability, and learner perceptions. A HoloPatient mixed-reality study reported perceived improvements in clinical reasoning, confidence, and engagement, but these outcomes were self-reported and no objective performance measures were included (23). HoloLens-based applications used for clinical pathway and small-group clinical teaching have similarly demonstrated feasibility and acceptable usability in educational settings (5,6,24). These findings support the practical applicability of immersive technologies but do not independently establish improvements in clinical competence.

Overall, the evidence for immersive technologies is strongest for feasibility and usability, while evidence for objective learning and clinical skill improvement remains mixed. Available studies are frequently limited by small samples, single-center designs, lack of comparison groups, or reliance on self-reported outcomes. Evidence regarding long-term skill retention, transfer to real-world clinical practice, and subsequent clinical outcomes remains insufficient. Implementation is additionally constrained by hardware requirements, technical support needs, costs, and the need for faculty preparation (24,25).

3.3. Digital Learning Platforms and Blended Learning Models

Digital learning platforms and learning management systems represent an important component of digital transformation in medical education. Blended learning combines online activities, including electronic educational resources, digital case materials, and online discussions, with face-to-face teaching and clinical training. Platforms such as Moodle and Blackboard provide structured environments for content delivery, communication, and learner support, while asynchronous access can increase flexibility in how students engage with educational resources (2). Digital platforms may also support a shift in the educator role from information provider toward learning facilitator (2,16).

Evidence regarding objective learning outcomes is variable. A quasi-experimental study of a medical knowledge graph-supported flipped classroom reported higher course examination scores than traditional lecture-based instruction, although the comparison involved non-randomized cohorts from consecutive academic years (26). Similarly, a prospective study of an e-learning module for focused ultrasound preparation found significant improvement in theoretical knowledge scores among medical students, but did not assess practical ultrasound skills during the e-learning phase (27). Moodle-based modular learning has also demonstrated high completion rates and measurable examination performance, although single-arm designs limit causal interpretation (28).

Other studies have primarily evaluated feasibility, usability, engagement, and learner perceptions rather than objective educational performance. A survey of medical students using Blackboard found extensive use of the platform for examination preparation and access to lecture materials, but 58.7% of participants identified lack of integration with active clinical bedside teaching as a major limitation (29). These findings highlight the distinction between learner acceptance or perceived benefit and objectively measured educational improvement.

Overall, the available evidence supports the feasibility, usability, and perceived flexibility of digital learning platforms, while evidence for objective learning improvement remains less consistent. Evidence for improvement in objectively assessed clinical skills and long-term educational outcomes is insufficient within the reviewed studies. The educational value of LMS, mobile learning, and blended learning therefore appears to depend on effective curricular integration and appropriate combination with

face-to-face and clinical teaching rather than platform use alone.

3.4. Telemedicine Education in Medical Education

Telemedicine represents remote interaction between medical professionals and patients and can support the continuous process of medical education (30). Telemedicine education is being integrated into health-professions curricula to equip learners with the competencies required to manage clinical processes in remote-care settings (31). Clinical training provides opportunities for learners to develop remote consultation skills using videoconferencing systems, electronic examination technologies, and confidential digital communication channels (31). Video consultations have become an important component of telemedical patient care, but training remains inconsistently represented in medical curricula (32). Medical students have therefore acquired video-consultation competencies unevenly, often through fragmented exposure or without formal instruction (32).

Several models have been used to incorporate telemedicine into clinical education (32,33). Distance seminars can place students in synchronous video consultations with patients in their home environments (32). In one model, each consultation was remotely observed by a family physician and another student (32). Robotic hospital rounds have also provided a patient-centered approach to video consultation training (32). During clinical clerkships, teleconferencing, virtual case discussions, and virtual ward rounds supported continuity of training despite limitations in physical examination and patient communication. Teleneurology has similarly been used to teach adaptations in communication and examination for video-based encounters. It also helps learners recognize which parts of patient interaction can and cannot be adequately understood through video (33).

Learner preparedness remains inconsistent. Fifty-eight percent of surveyed German medical students envisioned offering video consultations in future practice despite reporting limited prior knowledge (32). These students favored blended learning models for developing telehealth expertise (32). A significant gap in knowledge transfer regarding video consultations was also identified within German medical faculties (32). Telemedicine and video consultations were taught in 12 departments of general medicine in Germany and Austria and planned in two others. Among surveyed department leaders, 76.5% identified remote patient monitoring and telemedicine as necessary teaching topics (34).

The continued integration of telemedicine into clinical education has been constrained by unreliable internet access and the unavailability of secure digital platforms (35). Technical requirements for distance seminars can also create financial challenges for universities (32). Some clinical educators prefer face-to-face patient interactions because digital formats may be less effective for rapport and meaningful communication (35). Digital communication channels have therefore been described as useful supplements that cannot fully replace direct physician-patient interaction (36). The acquisition of physical examination competencies also makes complete replacement of face-to-face teaching by digital means questionable. In addition, a notable gap remains in the pedagogy of teaching video consultations (32).

3.5. Learning Analytics and Educational Data Mining in Medical Education

Learning analytics refers to the systematic examination and visual representation of data traces produced by learners as they engage with digital educational systems. These platforms can capture a range of behavioral indicators, including login timestamps, the proportion of learning activities completed, assessment submission attempts, and specific points at which learners discontinue their progress through instructional modules. Video-based platforms can also capture viewing sequences and pausing behaviors. However, high website traffic does not necessarily correspond to meaningful learner engagement. Generic measures such as click frequency and average visit duration may provide limited information for educational refinement (37).

Nonreactive tracking of a mobile learning application identified continuous low-intensity use, examination-oriented use, and early-semester use as separate engagement profiles. Examination-oriented use was associated with more favorable learning outcomes. However, Prior academic attainment was the main determinant of examination performance,

whereas application use had only a limited independent contribution to predicting scores (38). Learning analytics have also been combined with behavioral interventions. Personalized reminders increased resource-engagement clicks, while digital nudges aligned with learner motivation profiles improved engagement (39).

Artificial intelligence integrated into LMS can monitor engagement, quiz scores, and discussion forum participation. These data can be used to identify curriculum modules that consistently challenge students. Predictive analytics and machine-learning techniques can flag learners who may require additional academic support (40). Real-time behavioral tracking in an AI-driven personalized learning platform monitored knowledge mastery and reading speed. These data were used to optimize resource acquisition and dynamically adjust learning paths (4). Knowledge graph systems have also used embedded competency metrics to generate progress reports and map knowledge mastery and conceptual errors (26).

Systematic implementation of learning analytics in medical education remains limited (39). Most health professions education studies focus on early planning and data-gathering stages of the learning analytics lifecycle. Few examples evaluate data analysis or subsequent data-informed educator actions. Educators may lack the time, training, or technical expertise needed to implement and interpret learning analytics effectively and ethically (37). Predictive analytics and targeted behavioral nudges also remain uncommon in medical education platforms (39). Research on AI-based personalized learning includes few prospective randomized controlled trials assessing core learning outcomes against traditional teaching (4). Reported methodological limitations include small samples, unclear experimental designs, unvalidated platforms, and insufficient control of confounding factors. Algorithmic transparency is an additional concern when adaptive learning-path changes are not explained to learners (4).

3.6. Digital Assessment in Medical Education

Learning management system-based formative e-assessment can provide immediate feedback and support continuous improvement in medical education. Interactive digital question types have also been used to foster self-directed learning among first-year medical undergraduates. Virtual learning environments have enabled remotely proctored anatomy spot examinations using digital cadaveric images and online multiple-choice questions. Paper-based written tests, by contrast, do not provide the same immediate feedback with scores and timely educational interventions (41).

Digital assessment has also been applied to clinical and skills-oriented education (3,42). Practicing history-taking with ChatGPT as an AI virtual patient was associated with a statistically significant increase in class-wide Objective Structured Clinical Examination scores (3). Interactive video platforms allow instructors to evaluate recorded clinical procedures asynchronously through time-stamped feedback (42). Technology-enhanced problem-based learning has incorporated virtual Objective Structured Clinical Examination environments and simulation-based tools for summative evaluation. It has also used digital interaction tracking and automated collaboration analysis to provide objective participation metrics (43). Short-answer and multiple-choice theory tests within e-learning platforms have measured objective knowledge gains before practical clinical workshops (27).

AI-driven capabilities can automate scoring and feedback within digital assessment systems, with natural language processing enabling the evaluation of performance in OSCEs, multiple-choice tests, and written responses. Large language models can assist educators in generating standardized clinical cases, evaluation rubrics, and examination items. Automated systems can also benchmark student performance against expert evaluations (40). Artificial intelligence scoring has been embedded in assessment systems combining theoretical examinations, case analysis, and situational simulations (15). Criteria-based evaluation of feedback text has also been implemented using vector embeddings and a support vector machine classifier (42).

Quality, validity, and reliability remain central concerns in artificial intelligence-assisted assessment. The same concerns apply to technology-enhanced competency assessment in high-stakes settings (44). Artificial intelligence-generated examination items and evaluation tools may involve algorithmic bias, variability, and

limited transparency. External expert review and pilot testing are required before their use in high-stakes examinations. Automated proctoring can also raise surveillance and data-privacy concerns (40). Overreliance on technology may narrow assessment and neglect interpersonal or professional skills best observed in authentic clinical environments (44). Technical and logistical problems can further complicate e-assessment implementation (41). Repeated digital theory assessments may also introduce test-retest recall bias (27).

3.7. Mobile Learning in Medical Education

Mobile learning describes engagement with educational content across different contexts, locations, and time boundaries (38). Integrated mobile platforms can support individualized and group learning regardless of geographic location or timing. Medical students and physicians primarily use smartphones for quick look-ups and micro-learning, while laptops or desktop computers are used more often for sustained study (45). Mobile applications can provide ongoing formative assessment and continuous learning opportunities (44). They can also deliver microlearning modules within clinical workflows for continuing professional development (39). Mobile platforms have additionally supported examination preparation and access to clinical reference materials (38,46).

In clinical education, mobile learning has been integrated with bedside teaching through online group discussions and tutor feedback. Students reported opportunities to practice communication, structured writing, comprehension, critical thinking, and problem-solving through these discussions (45). Mobile learning during practice placements also provides portable access to reference materials and enables virtual sharing of clinical experiences (46). Handheld augmented reality extends mobile learning by using smartphone cameras and sensors to overlay three-dimensional digital models onto physical surroundings. This approach avoids the need for specialized head-mounted hardware (21).

Access and learner characteristics may shape participation in mobile learning. Smartphone and laptop ownership were statistically significant independent predictors of engagement in assessment-related e-learning (47). The study of voluntary app use also raised potential equity concerns, indicating that usage patterns alone may not capture differences in learners' capacity to benefit (38).

Students reported distraction from constant messaging, app misuse, and social media browsing during bedside teaching. They also described mobile platforms as more suitable for quick reference and short note-taking than for in-depth learning (45). Offline availability remains important where internet connectivity is intermittent (48). Product design constraints, limited cultural acceptance, and absent institutional policies can impede mobile technology adoption in practice placements (46). Mobile augmented reality can also be restricted by operating-system compatibility, processing capacity, software problems, and faculty training requirements (21). Heterogeneity in interventions, content, outcomes, and study populations limits generalizable conclusions in mobile learning research. Reliance on quantitative usage data without qualitative interviews can also limit interpretation of learner motivations (38).

Across the seven domains reviewed, digital approaches support diverse educational applications, including personalized learning, clinical training, telemedicine, learning analytics, digital assessment, and mobile learning. However, the available evidence varies in study design and outcome type. Feasibility, usability, learner perceptions, and short-term knowledge gains are reported alongside mixed findings for objectively measured clinical performance. Evidence regarding sustained learning outcomes and transfer to clinical practice remains limited (4,22). Furthermore, the educational value of these approaches depends on effective curricular integration, faculty preparation, adequate infrastructure, and appropriate oversight. Overall, digital technologies should be evaluated according to their specific educational outcomes and methodological limitations rather than assumed to improve clinical competence through adoption alone.

These technologies differ in their educational applications, potential benefits, and implementation limitations, as summarized in Table 1.

Table 1. Applications, Educational Evidence, and Limitations of Major Digital Technologies in Medical Education.

Technology / Domain	Main Applications	Educational Evidence	Main Limitations and Evidence Gaps
Adaptive Learning Systems	• Personalized learning pathways • Resource recommendations • Adaptive learning activities (4)	• Higher post-test scores and increased study duration reported in a cluster-randomized trial (4)	• Small, single-center evidence base • Limited long-term follow-up • Transfer to clinical practice not established (4)
Large Language Models	• Virtual patients and history-taking practice (3) • Communication training and learning support (11)	• Improved OSCE history-taking scores reported in one pilot study (3) • Feasibility, usability, and motivation reported in conversational AI studies (11)	• Hallucination and reliability concerns (16) • Frequent reliance on usability or perception outcomes and limited evidence for broader clinical competence (11)
Generative AI	• Educational content, clinical cases, and rubrics (12,13) • Curriculum development (14)	• Applications reported in educational content creation (12,13) • Iterative multi-LLM curriculum development demonstrated in one fellowship program (14)	• Outputs may be incomplete, inaccurate, culturally misaligned, or biased (12) • Human expert review remains necessary (12,14)
Virtual, Augmented, and Mixed Reality	• Clinical simulation (20,23) • AR-based visualization (21) • Procedural/skills simulation (49)	• Feasibility and usability reported (6,23) • Objective knowledge gains reported in selected studies (21) • Clinical-skill outcomes remain mixed (20,22)	• Small samples and single-center designs (20,22) • Limited evidence for long-term skill retention (20,49) • Hardware/software and faculty-training requirements (6,21)
Digital Learning Platforms and Blended Learning	• LMS-supported and asynchronous learning (28,29) • Flipped classroom learning (26) • E-learning preparation (27)	• Higher examination performance reported in a flipped-classroom study (26) • Improved theoretical knowledge reported with e-learning (27) • High completion rates reported in modular LMS learning (28)	• Non-randomized and single-arm designs limit causal interpretation (26,28) • Limited evidence for practical clinical skills (27) • Incomplete integration with clinical teaching (29)
Telemedicine Education	• Video consultations and virtual clinical encounters (32) • Remote clinical communication and virtual ward activities (33)	• Learners reported interest in future video-consultation practice and further training (32) • Teleconference and virtual clinical activities supported clinical teaching (33)	• Video-consultation competencies remain inconsistently taught (32) • Physical examination and patient communication remain limitations (33) • Connectivity and secure-platform barriers affect implementation (35)
Learning Analytics and Educational Data Mining	• Learner-behavior and engagement tracking (37,39) • Resource-use and performance monitoring (39) • Personalized behavioral tracking (4)	• Distinct engagement patterns and associations with examination performance identified (38) • Personalized reminders increased resource engagement (39) • Real-time analytics supported adaptive learning processes (4)	• Prior academic performance may confound observed associations (38) • Generic activity metrics may not reflect meaningful engagement (37) • Systematic implementation remains limited (39)
Digital Assessment	• Online and formative e-assessment (41,50) • Automated scoring and AI-supported assessment (40) • AI-generated assessment items (51)	• Feasibility and learner acceptance reported for digital assessment (41,50) • Objective performance outcomes reported in selected applications (3,27) • Psychometric evidence reported for AI-generated items in imaging specialties (51)	• Technical and logistical barriers (41) • Validity and reliability require careful evaluation in high-stakes assessment (40,44) • Algorithmic bias, limited transparency, and need for expert review (40)
Mobile Learning	• Mobile case discussions and clinical learning support (45) • Educational-resource access during placements (46) • App-based examination preparation (38)	• Positive learner perceptions reported in bedside mobile learning (45) • Examination-oriented app use was associated with better learning outcomes (38) • Portable access supported learning during clinical placements (46)	• Prior academic performance and self-selection may influence outcomes (38) • Distraction and information overload reported (45) • Device access may influence participation (47) • Objective clinical-skill evidence remains limited (45)

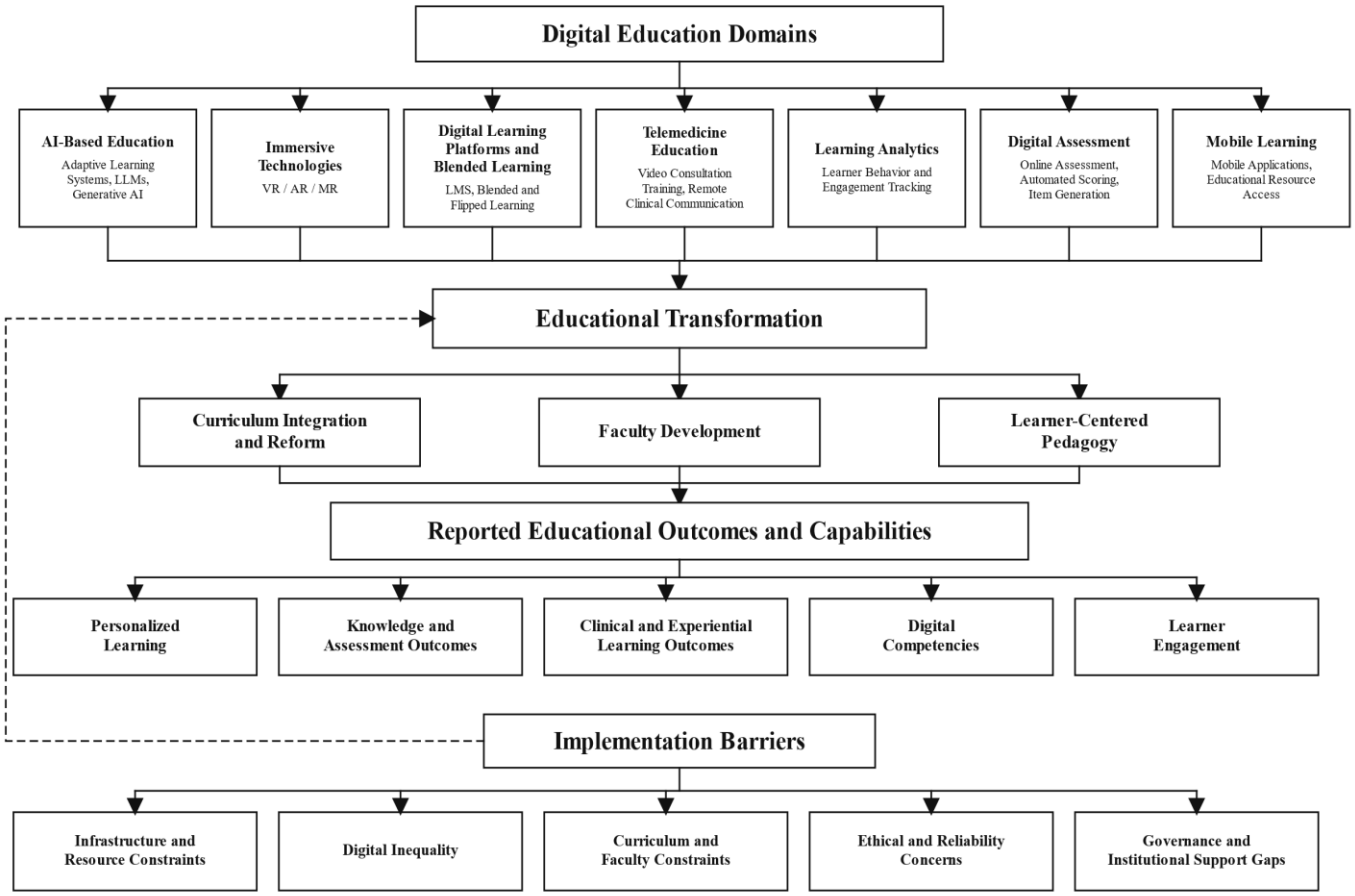

Figure 1. Conceptual Framework of Digital Transformation in Medical Education.

Note: The framework was developed by the authors based on a synthesis of the reviewed literature. The arrows represent conceptual relationships and do not imply established causal effects or consistent improvements in educational outcomes.

Figure 1 provides a conceptual overview of the seven digital education domains discussed in this review, alongside the educational processes, reported outcomes, and implementation barriers relevant to their integration.

4. Transforming Educational Systems Beyond Technology

Although emerging technologies provide important opportunities for medical education, evidence indicates that digital transformation cannot be achieved through technology adoption alone. Sustainable transformation requires changes in educational systems, including curriculum design, development of digital competencies, and preparation of educators to effectively integrate digital approaches into teaching and clinical training (1,2).

These broader systemic requirements include curriculum integration, faculty readiness, infrastructure support, and governance structures, all of which influence whether digital initiatives can be effectively implemented and sustained. Table 2 summarizes the major systemic requirements for achieving sustainable digital transformation in medical education.

These requirements demonstrate that digital transformation represents a systemic educational change rather than a technology-driven process alone. Addressing curriculum, faculty, infrastructure, and governance dimensions is essential for moving from isolated digital initiatives toward sustainable integration within medical education systems. The following subsections focus on curriculum and faculty-related dimensions, while infrastructure and broader implementation barriers are addressed in Section 5.

Table 2. Key Factors Influencing Sustainable Digital Transformation in Medical Education.

Domain	Current Challenges	Required Strategies
Curriculum Integration	• Inconsistent integration of digital competencies • Limited longitudinal curricular coverage	• Embed digital health competencies across curricula • Ensure longitudinal integration
Faculty Development	• Variable digital skills • Limited training opportunities • Educator workload constraints	• Structured faculty development • Institutional support for technology-enhanced teaching
Infrastructure and Resources	• Limited internet access • Insufficient devices and funding • Limited technical support	• Sustainable digital infrastructure investment • Continuous technical support
Institutional Governance	• Limited strategic planning • Ethical concerns • Insufficient implementation frameworks	• Clear institutional policies • Governance frameworks • Responsible technology adoption

4.1. Curriculum Transformation and Digital Competencies

A central component of digital transformation in medical education is the integration of digital competencies into formal medical curricula. These competencies extend beyond the ability to use digital tools and include areas such as digital communication, data management, telemedicine applications, and artificial intelligence literacy. Current evidence suggests that medical students require structured preparation to work effectively within increasingly digitized healthcare environments (1).

However, the integration of digital competencies into medical education remains inconsistent. A descriptive analysis of medical faculties demonstrated that digital competency courses are often limited to elective components rather than being systematically incorporated into core curricula, restricting access for many students (1). Similarly, a European survey of medical students identified a gap between students' positive attitudes toward digital health and their actual knowledge and training in areas such as eHealth, data management, and artificial intelligence, highlighting the need for curriculum revision (7). More recent work has also addressed the curricular integration of artificial intelligence, including the DEGRO consensus framework for undergraduate radiation therapy teaching (51) and a survey examining the integration of digitalization and AI into general medicine curricula in German-speaking Europe (52). Together, these findings indicate that digital and AI-related competencies remain unevenly integrated across medical curricula.

The transformation of curricula is also challenged by the traditional structure of medical education. Medical curricula are often highly static and difficult to modify rapidly, creating barriers to the integration of rapidly evolving digital technologies (36). In addition, curriculum overload, limited availability of qualified educators, and insufficient resources make the introduction of new digital health content difficult within existing educational frameworks (52).

Therefore, effective digital transformation requires a shift from isolated digital courses toward longitudinal integration of digital competencies across medical education. Curriculum mapping and structured competency frameworks can support alignment between digital skills and clinical education objectives, reducing fragmentation and improving preparation for digital healthcare practice (1,53).

Assessment of digital competencies should distinguish objectively measured knowledge from self-reported readiness and perceived skills. In a single-center pre–post study of a digital health curriculum, mean theoretical test scores increased from 4.0 to 8.3 ($p < 0.001$), although the study included only 20 participants and assessed selected curriculum content (54). The 22-item Medical Artificial Intelligence Readiness Scale for Medical Students (MAIRS-MS) has also been used to assess AI readiness across cognition, competency, vision, and ethics. However, it measures self-reported readiness rather than objectively demonstrated clinical performance (55). These findings illustrate complementary approaches to assessing digital competencies while highlighting the need to distinguish knowledge acquisition and perceived readiness from demonstrated clinical competence.

4.2. Faculty Readiness and Digital Skills

Faculty educators represent a critical factor in determining whether digital transformation

becomes embedded in educational practice. The successful use of digital technologies depends not only on availability of platforms and tools but also on educators' digital skills, pedagogical understanding, and willingness to incorporate new approaches into their teaching activities (2).

Studies have demonstrated variation in digital competency among different groups of medical educators. Basic science educators often show greater familiarity with digital teaching tools, including learning management systems, multimedia resources, and interactive educational applications. In contrast, clinical educators may face greater difficulties integrating advanced digital technologies into patient-centered education and bedside teaching environments (35).

Faculty development programs have shown potential in improving educators' confidence and ability to use digital educational tools. Structured training initiatives, including customized e-tutorials and digital teaching workshops, have been reported to improve educators' skills in developing and implementing technology-enhanced learning activities (8). However, training alone may not be sufficient, as educators continue to face workload constraints, limited institutional support, and difficulties balancing clinical responsibilities, research activities, and educational duties (56).

A major barrier to faculty engagement is the lack of recognition and support for digital teaching activities. Development and maintenance of digital educational resources require considerable time and effort, yet institutional policies may not adequately account for these activities within academic workload and promotion systems (2,56).

Overall, the evidence suggests that digital transformation in medical education is fundamentally a systemic change involving curriculum reform and educator development. Technologies can facilitate transformation, but meaningful and sustainable change requires digitally competent educators, structured competency frameworks, and institutional strategies that support long-term implementation (1,35).

Beyond individual technological applications and organizational requirements, digital transformation in medical education can also be understood as a gradual evolution rather than a sudden replacement of traditional educational models. As educational systems increasingly incorporate digital technologies, medical education has moved from conventional teaching approaches toward more flexible, blended, and personalized learning environments. Figure 2 summarizes this conceptual evolution, illustrating the transition from traditional education models through e-learning adoption and blended learning approaches toward AI-assisted personalized education and integrated digital medical education ecosystems.

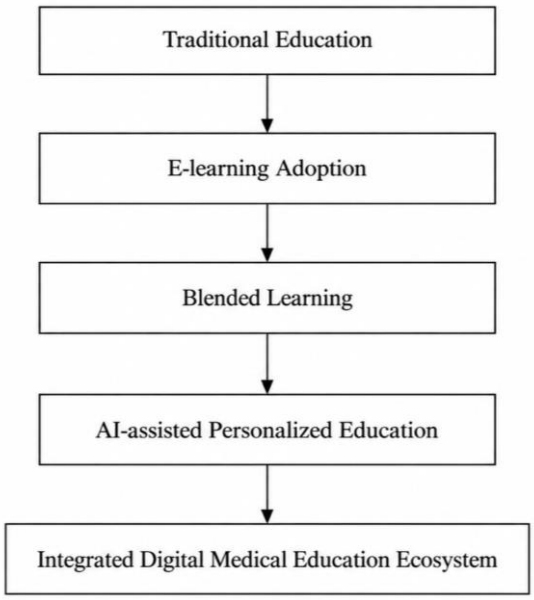

Figure 2. Evolution from Traditional Medical Education Toward Digital Transformation.

Note: This conceptual figure illustrates the progressive transition of medical education models from traditional approaches toward integrated digital learning ecosystems.

5. Challenges and Implementation Barriers

Despite the increasing availability of digital technologies in medical education, successful implementation of digital transformation remains challenging. Evidence indicates that transformation is not determined solely by technological capability; rather, it depends on the interaction between infrastructure, institutional capacity, educational design, and the ability of medical education systems to sustain long-term digital initiatives (1,10).

One of the most important barriers is the digital divide, which creates unequal opportunities for technology-enhanced learning across different educational settings. Institutions in low- and middle-income countries frequently experience limitations related to internet connectivity, electricity stability, access to devices, and financial resources required for digital implementation. These structural limitations can significantly restrict the adoption and sustainability of digital medical education initiatives (9,10).

Studies from resource-constrained environments demonstrate that positive attitudes toward digital education do not necessarily translate into successful implementation. In a survey of medical students and faculty members, poor internet access, financial limitations related to device availability, and insufficient technical support were identified as major barriers to effective use of digital learning platforms (9). Furthermore, long-term analyses of e-learning initiatives in resource-limited settings have highlighted the problem of short-term, isolated projects that fail after initial implementation because of inadequate maintenance, insufficient financial planning, and lack of integration into broader healthcare education systems (10).

Another major challenge is the gap between technological availability and meaningful educational integration. Digital platforms and advanced technologies may remain underused when they are implemented as isolated tools rather than being aligned with curriculum objectives and institutional strategies. For example, many learning management system initiatives remain limited to individual courses instead of becoming integrated components of medical education programs (29). Similarly, digital learning approaches may fail to replace essential clinical experiences when they are not appropriately combined with face-to-face and practical training (57).

Emerging technologies such as artificial intelligence and immersive learning tools introduce additional implementation challenges. AI-based systems require careful governance because inaccurate generated information, lack of clear usage guidelines, and excessive dependence on AI tools may affect learning quality and clinical reasoning development (3,30). Likewise, immersive technologies including VR, AR, and MR face barriers related to high acquisition costs, technical requirements, maintenance needs, and the necessity for dedicated support systems and trained educators (24,25).

Sustainable digital transformation therefore requires moving beyond short-term technology adoption toward coordinated implementation strategies. These strategies should address infrastructure development, long-term resource planning, curriculum alignment, technical support, and institutional commitment. Without addressing these interconnected barriers, digital initiatives may remain fragmented projects rather than becoming sustainable components of medical education systems (1,10).

6. Discussion

The findings of this narrative review indicate that digital transformation in medical education is developing through the interaction of technological innovation and broader educational system change. Artificial intelligence, immersive technologies, and digital learning platforms offer distinct opportunities to support personalized learning, clinical simulation, and flexible access to educational resources. However, the evidence varies according to the technology investigated and the outcomes assessed. Studies of AI-based learning have examined personalized education and clinical communication training, while immersive technologies have been evaluated in simulation and interactive learning environments. Digital platforms and blended learning have primarily addressed content delivery, knowledge acquisition, and learner access (2–5,26,27). These findings indicate that the availability of digital technologies should not, by itself, be interpreted as evidence of sustained educational improvement.

The broader range of digital education

domains also demonstrates that transformation extends beyond the delivery of learning materials. Telemedicine education addresses virtual clinical interaction and video-consultation training (32,33), while learning analytics examines learner activity and engagement (37,39). Digital assessment encompasses formative e-assessment and AI-supported assessment applications (40,41), and mobile learning extends educational activities to bedside teaching and clinical placements (45,46). Nevertheless, these domains involve different educational objectives and assessment approaches. Their findings should therefore be interpreted according to the specific outcomes measured rather than treated as evidence of a uniform effect across digital medical education.

A recurring issue across the reviewed literature is the gap between the availability of digital technologies and their systematic integration into medical curricula. Digital learning initiatives may remain restricted to individual courses or elective components rather than being incorporated longitudinally into formal education (1,29). This limitation is closely related to the development of digital competencies, which extend beyond the ability to operate digital tools and include digital communication, data management, telemedicine, and artificial intelligence literacy. A European survey identified gaps between students' perceived skills and the training they received (7). Furthermore, assessment findings illustrate the importance of distinguishing objectively measured knowledge from self-reported readiness. One single-center pre–post study reported an increase in mean theoretical test scores from 4.0 to 8.3, although it included only 20 participants and assessed selected curriculum content (54). The MAIRS-MS provides a complementary approach to assessing perceived AI readiness, but self-reported readiness should not be equated with demonstrated clinical competence (55). Together, these findings support the need for structured curricular integration and assessment methods aligned with the competencies being evaluated.

Faculty readiness and institutional conditions further influence whether digital innovations become meaningful educational practices or remain underused tools. Differences between basic science and clinical educators suggest that familiarity with digital teaching tools does not necessarily translate into effective integration within clinical education (35). Workload pressures, limited institutional support, and insufficient recognition of digital teaching activities may also constrain faculty development and implementation (2,8,56). These challenges are compounded by differences in infrastructure, connectivity, device availability, and technical support, particularly in resource-constrained settings (9,10). Consequently, sustainable implementation depends not only on technology selection but also on the institutional capacity to support its continued use.

Ethical, technical, and reliability concerns also require attention. AI-based educational applications may generate inaccurate information or encourage inappropriate dependence, while immersive technologies involve hardware, financial, and technical requirements that can limit implementation (3,24,25,30). More broadly, the experience of short-lived or poorly coordinated digital initiatives indicates that initial adoption does not necessarily ensure sustainability when maintenance, financial planning, technical support, and institutional integration are insufficient (10). These limitations reinforce the importance of evaluating digital technologies in relation to their educational purpose, implementation context, and potential risks rather than assuming that technological innovation automatically improves learning.

Digital transformation may also influence the direction and conduct of medical education research by expanding the digital data and learning environments available for investigation. Learning analytics can support the study of learner activity and engagement (37,39). Digital assessment can provide additional opportunities to examine assessment processes and learning outcomes (40,41). AI-supported virtual patients and telemedicine training may allow researchers to investigate communication and clinical learning in digitally mediated settings (3,32). Mobile learning may further enable investigation of learning activities across bedside teaching and clinical placements (45,46). These developments may broaden research questions and data sources, but digitally recorded activity, engagement, or assessment performance should not automatically be interpreted as evidence of sustained clinical competence. Future studies should therefore validate digital measures and examine whether

observed changes are maintained over time and translate into clinical practice.

Taken together, the reviewed evidence supports an interpretation of digital transformation as an interconnected educational and organizational process rather than a collection of independent technological interventions. Its sustained implementation requires alignment among digital technologies, curriculum development, faculty capability, infrastructure, and institutional support. Future investigations should prioritize comparative evaluation of educational approaches, longer-term learning outcomes, transfer of learning to clinical practice, and the assessment of digital and clinical competencies. Greater attention to implementation sustainability and differences in available resources is also needed to determine how digital education can be integrated appropriately across diverse educational settings.

7. Conclusion and Future Directions

Digital transformation in medical education is best understood as a systemic educational change rather than the adoption of digital technologies in isolation. This narrative review brings together seven domains of digital education: artificial intelligence, immersive technologies, digital learning platforms and blended learning, telemedicine education, learning analytics, digital assessment, and mobile learning. Although these domains offer different opportunities to support personalized learning, clinical training, educational flexibility, and assessment, the reviewed evidence does not demonstrate uniform or consistently sustained improvements across technologies and educational settings.

A central finding of this review is that the educational contribution of digital technologies depends on their alignment with curricular objectives, the development of digital competencies, faculty readiness, adequate infrastructure, and institutional support. The distinction between technological availability, learner perceptions, measured knowledge gains, and demonstrated clinical competence is particularly important when interpreting reported benefits. Accordingly, digital transformation should be evaluated not simply by the adoption of new tools, but by the educational outcomes achieved and the conditions under which implementation can be sustained.

Future research should prioritize comparative and longitudinal evaluations of digital educational interventions, with greater attention to objective competency assessment, retention of learning, and transfer to clinical practice. Further investigation is also needed into implementation sustainability, cost-effectiveness, resource requirements, and differences in access across educational settings. In particular, research should clarify how learning analytics and digital assessment can inform educational decisions while accounting for the validity, reliability, and limitations of the data generated.

Ultimately, sustainable digital transformation requires the integration of technological innovation with sound educational design, institutional capacity, and equitable access. Digital technologies should complement rather than displace the human-centered dimensions of medical education. Their contribution should be judged by the quality and durability of educational outcomes, the appropriateness of their implementation, and the strength of the evidence supporting their use.

Proclamation regarding generative AI and AI-enhanced technologies in the composition process

The authors utilized ChatGPT (OpenAI) sparingly for linguistic enhancement during the creation of this paper. Subsequent to utilizing this tool/service, the writers evaluated and refined the text as necessary.

References

1. Aulenkamp J, Mikuteit M, Löffler T, Schmidt J. Overview of digital health teaching courses in medical education in germany in 2020. GMS J Med Educ. 2021;38(4):1–13.
2. Bhardwaj A, Nagandla K, Swe K, Abas A. Academic Staff Perspectives Towards Adoption of E-learning at Melaka Manipal Medical College: Has E-learning Redefined our Teaching Model? Kathmandu Univ Med J. 2015 Oct 20;13(1):12–8.
3. Abraham R, Mohanlal D. The role of artificial intelligence (AI) in medical education: A pilot study on ChatGPT's impact on history-taking skills and objective structured clinical examination (OSCE) preparedness in undergraduate medical students. African J Heal Prof Educ. 2026 Apr 20;18(1):e2711.
4. Chen Y. Evaluation of the impact of AI-driven personalized learning platform on medical students' learning performance. Front Med. 2025 Sep 12;12(September):1–16.

5. Pieterse AD, Hierck BP, de Jong PGM, Kroese J, Willems LNA, Reinders MEJ. Design and Implementation of "AugMedicine: Lung Cases," an Augmented Reality Application for the Medical Curriculum on the Presentation of Dyspnea. Front Virtual Real. 2020 Oct 28;1(October).
6. Johnston M, O'Mahony M, O'Brien N, Connolly M, Iohom G, Kamal M, et al. The feasibility and usability of mixed reality teaching in a hospital setting based on self-reported perceptions of medical students. BMC Med Educ. 2024 Jun 27;24(1):701.
7. Machleid F, Kaczmarczyk R, Johann D, Balčiūnas J, Atienza-Carbonell B, von Maltzahn F, et al. Perceptions of Digital Health Education Among European Medical Students: Mixed Methods Survey. J Med Internet Res. 2020 Aug 14;22(8):e19827.
8. Sadiq N, Fatima SH, Shabnam N, Rauf A. Empowering health professions educators: enhancing curriculum delivery through customized e-tutorial training on fundamental digital tools. Front Med. 2024 May 28;11(May):1–12.
9. Hassoun S, Dashash M, Baddour A. Technology Integration in Syrian Medical Education From the Perspective of Students and Faculty: A Cross-Sectional Evaluation. JMIR Form Res. 2025 Aug 8;9:e76958–e76958.
10. Barteit S, Jahn A, Banda SS, Bärnighausen T, Bowa A, Chileshe G, et al. E-Learning for Medical Education in Sub-Saharan Africa and Low-Resource Settings: Viewpoint. J Med Internet Res. 2019 Jan 9;21(1):e12449.
11. Jacobs C, Johnson H, Tan N, Brownlie K, Joiner R, Thompson T. Application of AI Communication Training Tools in Medical Undergraduate Education: Mixed Methods Feasibility Study Within a Primary Care Context. JMIR Med Educ. 2025;11.
12. Sánchez-Mendiola M, Anakin M, Findyartini A, Levine R, Da Silva A, Vakani FS. Applied insights for using Generative Artificial Intelligence in Faculty Development in Health Professions Education. MedEdPublish. 2026;15:279.
13. Shimizu I, Kasai H, Ozaki N, Nishiuchi H, Shikino K, Araki N, et al. Expanding the Roles of Medical Educators in the Generative Artificial Intelligence Era: A Qualitative Study. Med Sci Educ. 2026;1523–31.
14. Sheikh MS, Kashani KB, Gregoire JR, Thongprayoon C, Miao J, Craici IM, et al. Digital transformation of nephrology POCUS education—Integrating a multiagent, artificial intelligence, and human collaboration-enhanced curriculum with expert feedback. Digit Heal. 2025;11.
15. Jing Z, Mouhong Z. Exploring the integration of AI and national quality courses in China: a study on teaching practices in nursing smart education. BMC Med Educ. 2025;25(1).
16. Aljamaan F, Mubarak MF, Altamimi I, Alanteet AA, Alsalman MA, Dasuqi SA, et al. Generative Artificial Intelligence Integration in Medical Education: A Cross-Sectional Survey of Medical Students' Perceptions and Attitudes in Saudi Arabia [Internet]. Vol. 9, Research Square. 2025. Available from: https://www.researchsquare.com/article/rs-6222830/v1
17. Ratajczak P, Słowik O, Cynar J, Kopciuch D, Paczkowska A, Zaprutko T, et al. Perceptions of AI-based tools among polish medical university students. BMC Med Educ. 2025;25(1).
18. Güler MA, Dağ S, Kayal S, Can M, Şimşekkaya SN. Physiotherapy students' acceptance of AI-based chatbots (including ChatGPT) in education: a multi-institutional study from Turkey. BMC Med Educ. 2026;26(1).
19. Li C, Hu F, Qiao Y, Zhang M, Gao Q, Wang F, et al. The role of AI-mediated learning contexts in the personality–self-directed learning relationship among Chinese medical undergraduates: a cross-sectional study. BMC Med Educ. 2026;1–15.
20. Tannemann N, Tsarenko O, Herbstreit F, Gestmann M, Brenner T, Szalai C. Enhancing theoretical BLS knowledge with virtual reality: a randomized controlled trial in medical students. Resusc Plus. 2026;27(September).
21. Mastour H, Choubdaran E, Abbasi B, Emadzadeh A, Khadem-Rezaiyan M. Augmented reality for training on commonly missed extremity fractures: a study on the efficacy of technology-enhanced health professions education in learning outcomes and experience. BMC Med Educ. 2025;25(1).
22. Krishnasamy R, Hansen MP, Schmidt Arenholt LT, Davidsen JG. Evaluating the impact of video-only, video with group discussion, and collaborative 360VR on abdominal examination training for first-semester medical students and medicine with industrial specialization. BMC Med Educ. 2025;25(1).
23. Almagharbeh WT, Alanzi A, Dkhil AA, Abuduhair E, Almuwallad F, Alfaifi M, et al. Undergraduate nursing students' perceptions of using holopatient in learning and clinical training: An exploratory-descriptive qualitative study. Nurse Educ Today. 2026 Jul;162(September 2025):107073.
24. Murphy KJ, O'Brien N, Connolly M, Iohom G, Gibson J, Shorten G. An Evaluation of the Microsoft HoloLens2 in the Clinical Teaching of Pain Pathways for Undergraduate Medical Students. J Educ Perioper Med. 2025 Jun 1;27(2):E745.
25. Yu TW, Rowe M, Frantz J. Virtual Reality in Health Professions Education: Qualitative Descriptive Study of Educators' Perspectives. JMIR XR Spat Comput. 2026 Jun 26;3:e52925–e52925.
26. Wei H, Liu X, Cao H, Qin W, Ma Q, Kong L. Research on the construction and application of pathology knowledge graph. BMC Med Educ [Internet]. 2025 Jul 1;25(1):877. Available from: https://bmcmededuc.biomedcentral.com/articles/10.1186/s12909-025-07566-0

27. Ruppert J, Krüger R, Göbel S, Wolfhard S, Lorenz LA, Weimer AM, et al. The effectiveness of e-learning in focused cardiac ultrasound training: a prospective controlled study. BMC Med Educ. 2025;25(1).

28. Omarbekova N, Koichubekov B, Abdikadirova K, Sorokina M, Kharin A, Nurmaganbetova M. An Ai-Supported Biostatistics E-Course Based on the Successive Approximation Model: Evaluation in Medical Education. Adv Med Educ Pract. 2026;17(May):1–13.

29. Back DA, Behringer F, Haberstroh N, Ehlers JP, Sostmann K, Peters H. Learning management system and e-learning tools: An experience of medical students' usage and expectations. Int J Med Educ. 2016;7:267–73.

30. Khafizova AA, Galimov AM, Kharisova SR, Grebenshchikova LY, Yagudina RI, Smirnova LM. The impact of healthcare digitalization on the medical education curricula and programs: Points of convergence and divergence. Contemp Educ Technol. 2023 Oct 9;15(4):ep479.

31. Rodić B, Labus A, Marković L. Designing a course for healthcare professionals: examining readiness for adopting emerging technologies into education and practice. Adv Heal Sci Educ. 2026;31(3):927–47.

32. Särchen F, Springborn S, Mortsiefer A, Ehlers J. Digital learning about patients: An online survey of German medical students investigating learning strategies for family medical video consultations. Digit Heal. 2024;10.

33. Nurhidayati IR, Findyartini A, Menaldi SL. Learning Model to Achieve Clinical Reasoning Competency Using Technology-Enhanced Learning in Neurology Clinical Rotation: An Exploratory Study. Educ Med J. 2022;14(4):63–78.

34. Botha-Ravyse C, Blignaut S. Does the early adopter catch the worm or choke on it? A reflective journey of the challenges of technology adoption in a health sciences education institution. Educ Heal Chang Learn Pract. 2017;30(2):176–81.

35. Saad S, Ahmed S, Ayub Khan MN, Khan MI. Exploring the digital competencies of clinical educators: a framework-based qualitative study. BMC Med Educ. 2025 Dec 5;26(1):55.

36. Baumgartner M, Stadler M, Samwald M, Fischer MR. Systemic Barriers to Curriculum Adaptation for Rapidly Changing Knowledge in Medical Education: Qualitative Study. JMIR Med Educ. 2026 Jul 15;12:e96244–e96244.

37. Xu Z, Coleman J, Atrey A, Chau N, Hunter B, Brydges R. Applying a learning analytics lifecycle framework to identify gaps in digital learning design: a worked example in health professions education. Acad Med. 2026;1–9.

38. Holzhäuer JPH, Backhaus J, Lâm TT, König S. Mobile Learning in Medical Education: Quasi-Experimental Realist Evaluation of Usage, Context, and Examination Performance in a Curricular Setting. JMIR Med Educ. 2026;12:1–16.

39. Ekstrom V. Digital Choice Architecture in Medical Education: Applying Behavioral Economics to Online Learning Environments. JMIR Med Educ. 2026;12.

40. Nguyen TA, Nguyen TB, Nguyen DC, Vu AD, Dang KL, Le NQ, et al. What Are the Opportunities and Challenges of Using AI in Medical Education in Vietnam? JMIR Med Educ. 2025;11:1–12.

41. Paunikar VM, Barapatre SA, Rawekar A. Contextualized Perspective on Introduction of a Formative E-assessment Module in Physiology to Phase I MBBS Students - A Cross-sectional Study. J Datta Meghe Inst Med Sci Univ [Internet]. 2025 Jan;20(1):145–54. Available from: https://www.ovid.com/10.4103/jdmimsu.jdmimsu_833_24

42. Villagran I, Hernandez R, Schuit G, Neyem A, Fuentes-Cimma J, Miranda C, et al. Implementing Artificial Intelligence in Physiotherapy Education: A Case Study on the Use of Large Language Models (LLM) to Enhance Feedback. IEEE Trans Learn Technol. 2024;17(Llm):2079–90.

43. Sánchez-Redroban JD, Romero-Duran MV. A comprehensive framework for integrating modern educational technologies with problem-based learning in medical education. Discov Educ. 2025;4(1).

44. Asadi M, Karimian Z. Advancing Medical Education: Assessing Technology-Enhanced Learning Through the Lens of the Canadian Medical Education Directions for Specialists (CanMEDS) Framework—A Perspective Study. Heal Sci Reports. 2025;8(8):1–6.

45. Oo MS, Schofield S, Aung ST, Thwin MM, Oo SS, Yee KT, et al. Integrating a Mobile-Learning Platform for Enhancing Clinical Teaching: The Learners' Perspective. Int J Learn Teach Educ Res. 2022;21(11):87–111.

46. Martínez-Gaitero C, Dennerlein SM, Dobrowolska B, Fessl A, Moreno-Martínez D, Herbstreit S, et al. Connecting Actors With the Introduction of Mobile Technology in Health Care Practice Placements (4D Project): Protocol for a Mixed Methods Study. JMIR Res Protoc. 2024;13(1).

47. Jamil M, Akhtar H, Barman B, Barman E. Device Access, Gender, and Academic Year Influence E-Learning Patterns in Indian Medical Education. Cureus. 2026;18(4).

48. Weimer JM, Recker F, Vieth T, Kuon S, Weimer AM, Menke JW, et al. Ultrasound Training in the Digital Age: Insights from a Multidimensional Needs Assessment. Appl Sci. 2026;16(1):1–19.

49. Shamim Khan M, Ahmed K, Gavazzi A, Gohil R, Thomas L, Poulsen J, et al. Development and implementation of centralized simulation training: Evaluation of feasibility, acceptability and construct validity. BJU Int. 2013;111(3):518–23.

50. Cullinane DP, Barry DS. Dyad pedagogy in practical anatomy: A description of the implementation and student perceptions of an adaptive approach to cadaveric teaching. Anat Sci Educ. 2023;16(1):99–115.

51. Linde P, Pal Singh B, Neu M, Gollrad J, Bischoff M, Sarria GR, et al. DEGRO consensus framework for undergraduate radiation therapy teaching in Germany: a white paper with integrated guidance on artificial intelligence in medical education. Strahlentherapie und Onkol. 2026 Jul 22;

52. Zahn A, Mücke M, Sellin J, Ateş G. Assessing the integration of digitalization and AI in general medicine curricula in German-speaking Europe: a comprehensive survey. Med Educ Online. 2026 Dec 31;31(1).

53. Kondo T, Onoue T, Kou S, Asada Y, Isobe M, Nishigori H. Implementing digital transformation in the revision process for Japan's Model Core Curriculum: A qualitative document analysis. Med Teach. 2024;46(sup1):S53–60.

54. Kröplin J, Maier L, Lenz JH, Romeike B. Knowledge Transfer and Networking Upon Implementation of a Transdisciplinary Digital Health Curriculum in a Unique Digital Health Training Culture: Prospective Analysis. JMIR Med Educ. 2024;10.

55. Abbasi Montazeri E, Zarei J, Ghavami Hoseinpour B, Bahadori A. Assessing the level of readiness for digital transformation in medicine: students' perspectives on the use of artificial intelligence in health : a cross-sectional study. BMC Med Educ. 2026;26(1).

56. Müller C, Füngerlings S, Tolks D. Teaching load – A barrier to digitalisation in higher education? A position paper on the framework surrounding higher education medical teaching in the digital age using bavaria, germany as an example. GMS J Med Educ. 2018;35(3):1–18.

57. Yu CH, Hsiao CT, Hsu CM. Digital learning effectiveness and strategies in medical training: perspectives on motivation and attitude among interns and PGY trainees. BMC Med Educ. 2026 Feb 16;26(1):474.