


The Evolving Role of AI in Simulation-Based Medical Education: A Narrative Review

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Purpose: A growing body of literature has emerged on the topic of Artificial Intelligence (AI) use in Simulation-Based Medical Education (SBME) in recent years, but most studies have focused on isolated applications of AI to components of simulation, making it difficult for educators and decision makers to make informed decisions on the use of AI. Therefore, this narrative review aims to condense the current literature on the use of AI in the SBME, its influence on experiential learning, explore challenges, and future directions in this rapidly evolving field.

Methods: A targeted literature search was conducted for this review on PubMed and Google Scholar, with combinations of keywords. Articles were selected from 2019 to 2025, based on their relevance to the use of AI in SBME, in areas of teaching, learning, and assessment. Studies without educational outcomes were excluded.

Results: The search produced 2019 papers, out of which 45 were analyzed after applying the exclusion criteria. These showed that AI has been applied across multiple dimensions of the SBME, including scenario development, enhancing realism, personalized and collaborative learning, developing communication and psychomotor skills, and automated and AI augmented feedback. Several challenges have been raised, like ethical and privacy concerns, lack of AI literacy among users, lack of transparency, undesired outcomes, infrastructure cost, and environmental effects.

Conclusion: Benefits of AI in SBME stem from AI-augmented human teaching rather than unsupervised usage of AI tools. Additionally, the potential for personalized and accessible learning warrants further research.

Keywords: artificial intelligence, healthcare simulation, virtual reality, augmented reality, ChatGPT

Introduction

Simulation-based medical education (SBME) is a core component of healthcare professions education that helps the learners develop clinical skills in a safe, controlled, and reproducible environment.¹ Simulation is defined as a technique used

to replace or amplify real experiences with guided experiences, often immersive in nature, that evoke or replicate substantial aspects of the real world in a fully interactive fashion.²

It enables clinicians, nurses, and other health care professionals to practice technical and non-technical skills in realistic settings before treating patients.

Based on Kolb's *Experiential Learning Theory*,³ SBME's pedagogical strength lies in "concrete experience" of performing and making mistakes in a simulation, followed by "reflective observation" in the post-simulation debriefing, "abstract conceptualization" of this learning, until "active experimentation" in the clinical setting. Limited trained faculty is a recognized barrier to implementation of SBME despite its known improvements to patient outcomes.⁴⁻⁷ To overcome this, there is an increase in experimentation with Artificial Intelligence (AI) in SBME.

In recent years, the integration of AI has complemented the design and delivery of SBME, particularly in areas such as scenario development, feedback, and assessment.⁸ It is being readily incorporated into various simulation modalities,

producing several new and innovative learning solutions like virtual patients, mixed reality, adaptive simulations, and immersive environments. These AI-enhanced simulation modalities have improved realism, scalability, scope of learning, and offer more personalized approaches, blurring the gap between simulation and reality.^{9–12}

At the same time, the introduction of AI has also brought new challenges for simulationists, faculty administrators, and learners, highlighting the need to critically evaluate the implications of using AI within SBME.^{11,13,14} While a growing body of literature has emerged on the topic of AI in SBME, most studies have focused on isolated AI applications within specific simulation components or disciplines.¹⁰ This fragmentation makes it difficult for educators and decision makers to make informed decisions on the use of AI in SBME. Therefore, this narrative review aims to condense the current literature on the use of AI in the SBME, its influence on experiential learning, the challenges in using it, and future directions.

A glossary of key terms frequently used in the paper is provided at the end.

Methods

A targeted literature search was conducted for this review on PubMed and Google Scholar, due to their comprehensive coverage of relevant literature, accessibility, and free nature compared to other databases with restricted access and paywalls. PubMed was selected to find peer-reviewed literature in medical journals, while Google Scholar was used to include emerging research in interdisciplinary journals covering AI, education, and simulation; that may not be indexed in biomedical databases.

The following Boolean search was used: (“artificial intelligence” OR “machine learning” OR “generative AI” OR “large language model” OR “ChatGPT”) AND (“simulation” OR “virtual reality (VR)” OR “augmented reality (AR)” OR “clinical simulation” OR “VR” OR “AR” OR “manikin” OR “virtual patient”) AND (“medical education” OR “health professions education” OR “clinical education” OR “healthcare training”) with a filter to include publications from 2019 to 2025 in English. This search was conducted in October 2025.

Results

The search yielded 19 papers on PubMed and 2000 on Google Scholar. Conceptual papers, peer-reviewed studies, randomized controlled trials, and reviews were included. Papers that focused on clinical application of AI without any educational outcome, or those about medical education without any simulation, VR/AR, or virtual patient, or highly technical papers without a clear learner focus, were excluded. Duplications were deleted, and if two papers spoke about the same content, the latest publication was prioritized. Abstracts without full access to articles, conference submissions, or papers in languages other than English were also excluded. This produced a collection of 45 high-value papers for this narrative review. Two independent researchers (SH and AA) extracted data from the papers based on the type of AI application, simulation modality, educational purpose, and main findings. Literature was organized by themes, identifying patterns, opportunities, and challenges in AI applications in SBME.

Discussion

The primary purpose of this narrative review was to search existing literature to identify the areas in which AI is having influence in SBME. Our results are presented in three broad themes: using AI for simulation, for learning, and in feedback and assessment.

AI for Simulation

SBME is contingent upon creating realistic clinical scenarios for healthcare professionals to learn skills through experience and reflection. One of the primary hurdles for faculty adoption of simulation has been the need for specialized scenario design training.¹⁵ Our literature search found increasing use of AI and experimentation to support scenario development and improve realism in simulated clinical situations.

Scenario Development

AI-powered scenario generation enables educators to design dynamic, realistic clinical simulation cases while reducing the time required to develop simulation activities. By automating case development, AI makes the simulation design

process more efficient and scalable, especially in low-resource clinical settings, where educators face a high workload with time restrictions.⁹ When implemented correctly, these AI-generated scenarios can closely mirror real-world clinical complexities and offer diverse patient presentations.^{14,16} But such scenarios require a rigorous review process to ensure clinical accuracy, contextual relevance, and educational appropriateness for the intended learners.^{14,16}

Realism of Simulation

AI has also transformed the realism and visualization of educational content, particularly for foundational disciplines like anatomy.¹² The incorporation of Mixed Reality (MR) and AR technologies enables students to explore simulated anatomical structures in dynamic three-dimensional models, rather than solely relying on static, two-dimensional images and text.^{17,18} This shift towards immersive, experiential learning of basic science disciplines promotes engagement, improves spatial understanding, and supports deeper comprehension of the complex human body.^{12,17} Furthermore, AI-enabled simulators, integrated with AR and VR technologies, continue to advance the fidelity of clinical simulations by improving the verbal, environmental, and physiological realism of patient interactions. These systems improve physical, psychological, and functional fidelity, allowing learners to experience more authentic clinical encounters that closely resemble real-world settings.⁹

AI for Learning

SBME encompasses various learning formats that support both individual and team development for better patient care and enhance the behavioural and psychomotor domains of learning. AI has had a notable impact on these formats of learning by introducing creative, adaptive, and immersive learning environments. These AI innovations serve as new add-ons to simulation that are specialized for various forms of learning, like personalized and collaborative experiences, communication, and psychomotor skills training.

Personalized Learning

Through adaptive intelligent systems, AI personalizes simulation-based learning experiences, allowing learners to progress at their own pace, which is associated with higher self-efficacy and motivation to learn, particularly among students using generative AI tools like ChatGPT for supplemental learning.^{12,19} In addition, personalized AI-powered tools demonstrate potential to enhance clinical reasoning by aligning learning challenges with each student's developing competence.^{20,21} However, this personalized learning often occurs in isolation and may reduce opportunities for collaborative learning, which is integral to healthcare students.¹²

Collaborative Learning

The emergence of the Metaverse with AI features introduces social and collaborative dimensions to virtual SBME. These immersive and shared learning spaces promote social interaction, teamwork, and communication building while transcending the physical and temporal constraints of a traditional classroom.¹⁰ Additionally, AI-enabled VR simulations can enhance Interprofessional education (IPE) by enabling healthcare teams to be trained remotely for better teamwork assessment scores, leading to improved patient-centred care.^{9,13}

Communication Skills

AI-enabled communication practice provides healthcare providers with an opportunity to develop and refine communication skills through interacting with a virtual patient, especially in scenarios that require high empathy, emotional sensitivity, and complex decision-making.²² This approach is particularly promising in fields such as psychiatry, where learners can safely rehearse challenging patient encounters like suicide risk assessment and acute psychosis, without compromising patient safety. Unlike human simulated participants (SP), AI-enabled virtual patients can perform in consistent and repeatable patterns, promoting standardized training for healthcare providers. Additionally, including SP in emotionally distressing scenarios may raise ethical concerns regarding their emotional and psychological safety, which can be mitigated with AI.²³ Communication practice sessions with AI-virtual patients have led to reduced anxiety and improved confidence among students during actual patient interactions. While these tools have the potential to improve

the translation of simulation training into clinical practice, successful implementation requires thoughtful and ethical integration into training.²⁴

Psychomotor Skills

By integrating AI into haptic technology, robotics, VR, and AR, learners can engage in realistic tactile simulations that closely replicate the physical feel of clinical procedures and surgeries, providing consistent, high-fidelity practice opportunities in a safe, risk-free environment.^{25–27} Studies on AI-enabled VR or AR technologies across various surgical fields demonstrate improved performance in simulated procedures, improved assessment scores, and surgical precision.²⁸

AI-Based Feedback and Assessment

There is growing attention toward the development of AI-based tools for feedback and assessment in SBME. This becomes particularly relevant for surgical performance evaluation, which traditionally relies on subjective and qualitative feedback from expert human assessors. AI can introduce objective, quantitative feedback, promoting standardization that is scalable, with its capacity to process large amounts and different types (visual, text, etc) simultaneously. This trend is reflected in the findings of this narrative review, which yielded substantially more studies on the use of AI in surgical simulation than in SBME in other clinical domains.

Automated Feedback

Visual rating scales, such as the Objective Structured Assessment of Technical Skills (OSATS), serve as the gold standard for standardized feedback in simulated tasks; however, their scalability is limited by the requirement for human examiners. To address this, Mirchi et al in Canada developed the Virtual Operative Assistant (VOA), an objective, machine learning-based system that provides automated feedback on trained metrics for subpial brain tumour resection using the NeuroVR simulator, effectively classifying learners as skilled or novice.²⁹

A similar continuous evaluation and feedback deep learning application, the Intelligent Continuous Expertise Monitoring System (ICEMS), has been developed by Yilmaz et al for neurosurgical trainees. It provides continuous assessment of psychomotor skills in virtual reality neurosurgical simulation and can provide real-time action-oriented feedback based on visual, auditory, and haptic clues.³⁰ This paves the way for scalable, real-time, objective feedback and assessment tools applicable to psychomotor skills in other clinical specialties.

AI-Augmented Feedback

Human feedback combined with AI feedback can provide a more holistic view of the learner's performance that includes both qualitative and quantitative components. The development of the above-mentioned tools has been further evaluated with learners to determine the most effective mode of feedback delivery, comparing AI alone and AI-human collaboration. Fazlollahi et al showed in a randomized clinical trial (RCT) on 70 medical students performing a simulated brain tumor resection that AI-tutoring with human feedback resulted in superior performance outcomes and skill transfer.²⁸ An overwhelming 96% of the medical students in this study preferred learning with feedback from an AI in addition to an expert instructor. Another RCT by Giglio et al reported similar outcomes of students in the AI-augmented real person feedback group outperforming the AI-tutor group with better surgical skill transfer.³¹ However, unlike Fazlollahi's study, which identified increased negative activating emotions and higher intrinsic cognitive load among students in the AI-human group, Giglio's findings contradicted this, observing reduced cognitive load in students receiving AI-tutor or AI-augmented human feedback.

Providing human instructors with AI-generated performance data to guide personalized feedback adds value by reducing the frequency of feedback required by the learners, indicating decreased error rate and faster learning.³² This makes skill acquisition both time and cost-effective for both instructor and learner. There is also a suggestion in the literature to incorporate AI-based feedback into existing surgical training curricula.³³

Challenges and Ethical Concerns

Although the integration of AI into SBME offers significant potential for self-directed learning, individualized feedback, and scalable training, it simultaneously introduces a range of significant challenges and ethical concerns. These include

limited AI literacy among educators and learners, concerns over data privacy and algorithmic bias, variability in research quality, the unknown long-term pedagogical implications of AI use in medical education, and both the overt and hidden costs associated with its implementation.

On one hand, limited AI literacy among faculty and students acts as a barrier to its effective use; while on the other hand, there are growing concerns about the validity and accountability of AI in SBME. Current AI models used for student evaluation in surgical simulations have not been comprehensively validated by human experts, raising concerns about potential biases introduced into the assessment, influencing their outcomes.³⁴ Studies have also highlighted the risk of AI-generated errors affecting both educational outcomes.^{14,21,35}

These risks are compounded by the limited transparency of AI algorithms and the so-called “black box” nature of AI decision-making.³⁶ “Black box” means the processes by which the AI system arrives at a given output are hidden or not easily interpretable, even to its developers. This can have important implications for trust, fairness, and accountability. In the absence of regulatory frameworks guiding the use of AI in SBME, it remains unclear who would be held responsible for such errors.³⁷

While literature suggests that AI-augmented tutoring and feedback in SBME may enhance learning, Fazlollahi et al, in their study on *Surgical Curriculum Design and Unintended Outcomes for Technical Competencies in Simulation Training*, described how AI integration in curricula can have unintended changes in certain competency domains, emphasizing the need for human expert supervision in the use of AI.³⁵ Other studies have also identified potential undesirable effects on student learning, including reduced opportunities for social interactions and the development of interpersonal and teamwork skills. One study even reported the use of metaverse inadvertently contributing to depersonalization and derealization of medicine, which could be a potential discord between SBME and patient-centered care, even though the primary goal of SBME is to enhance patient safety.^{21,37}

Another related concern is the limited understanding of the mechanisms through which students learn with AI, and its influence on different learning styles, particularly its impact on developing critical thinking. All these points point to insufficient research on AI integration into SBME to inform decision-making for educators. Even existing evidence on AI interventions for medical education is poor.^{11,14}

Students may also express concerns about the security of their personal data and may not readily accept evaluation by AI systems. At present, there are no universally established guidelines for obtaining consent from medical or nursing students for the use of AI in their teaching and learning.²¹

The advent of AI brings considerable potential to enhance accessibility to SBME for learners; however, the cost of infrastructure setup, hardware, and software to use these technologies (eg, VR headsets for using the metaverse), and training costs to develop AI competencies in staff, faculty, and students may be a barrier to its widespread adoption. Additional hidden costs associated with AI include the environmental impact, as its use in education expands.¹⁰ For example, a paper by De Vries estimates that global AI could consume 85–134 Terawatt-hour of electricity in 2027.³⁸ While Li et al report by the same year, the global water withdrawal for AI operations is expected to reach 4.2–6.6 billion cubic meters, exceeding the total annual water use of four to six Denmark or half of the U.K.³⁹

Future Directions

Based on current evidence, the real value of AI integration into SBME for teaching, learning, assessment, and feedback lies in AI-human collaboration. While supervised intelligent tutoring systems continue to be used, their accuracy and educational efficacy should be validated by human experts.

Further evidence is needed across all skill domains, including technical and non-technical competencies, and the educational pedagogies involved. The medical education scientific community should develop standardized criteria for evaluating the quality of AI-based studies. Interestingly, the authors of this review noted that our search strategy yielded fewer studies addressing AI applications in non-technical skills, such as counselling and communication, likely due to limitations in the MeSH terms used.²² Hence, in addition to establishing research quality standards, simulation scholars should develop a comprehensive taxonomy of AI applications in SBME, with the aim of making research in this emerging field more discoverable.

To keep abreast with the technology-induced changes in the medical field, medical colleges should consider evolving their curricula (incorporating physics, mathematics, and computational sciences) to graduate future “augmented doctors” with both clinical and digital skills.⁴⁰ Such curricular advances could build novel non-technical competencies in medical students to address unforeseeable AI-related problems.⁸

Simulation societies should collaborate to make regularity frameworks and guidelines for the application of AI in SBME, including warnings on ethical concerns surrounding it.

Limitations

A limitation of this review is that the search was restricted to 2 databases (PubMed and Google Scholar). Articles that were open access or available through our institution’s subscription were included in the review. However, four articles that had paid access and could not be retrieved were excluded from this review.

Conclusion

The findings of this review indicate that the most predominantly reported benefits to learners stem from AI-augmented human teaching rather than unsupervised AI systems. Although AI holds immense potential for personalized, adaptive, and accessible learning, robust evidence on its effectiveness, especially on how humans learn from AI, remains limited. This gap underscores the need for rigorous, methodologically sound research exploring the role of AI in teaching, learning, assessment, and feedback within SBME. In the interim, simulation societies are encouraged to develop frameworks and guidelines to support the responsible and ethical integration of AI into SBME, thereby ensuring safe, equitable, and evidence-informed practice as the field continues to evolve.

Glossary

- **Artificial Intelligence (AI):** “technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity, and autonomy.”⁴¹
- **Machine learning:** “the subset of artificial intelligence (AI) focused on algorithms that can learn the patterns of training data and, subsequently, make accurate inferences about new data. This pattern recognition ability enables machine learning models to make decisions or predictions without explicit, hard-coded instructions.”⁴²
- **Deep learning:** “a subset of machine learning driven by multilayered neural networks whose design is inspired by the structure of the human brain. Deep learning models power most state-of-the-art artificial intelligence (AI) today, from computer vision and generative AI to self-driving cars and robotics.”⁴³
- **Virtual reality (VR):** “the sum of the hardware and software systems that seek to perfect an all-inclusive, sensory illusion of being present in another environment.”⁴⁴
- **Augmented reality (AR):** “is taking digital or computer-generated information, whether it be images, audio, video, and touch or haptic sensations, and overlaying them in a real-time environment. Augmented Reality technically can be used to enhance all five senses, but its most common present-day use is visual.”⁴⁵
- **Mixed reality (MR):** “is a hybrid technology that combines AR and VR to provide an interactive virtual experience over the real world. It merges the real and virtual worlds to create a new environment where physical and 3D digital objects coexist and interact in real-time.”⁴⁶
- **Metaverse:** “a virtual place that allows users to engage in various activities and experiences. It is a fully realized, three-dimensional virtual world where users can explore and interact using digital avatars or representations of themselves.”⁴⁶

Disclosure

The authors report that there are no conflicts of interest in this work.

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