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Perspective

Technology-enhanced learning in medical education in the age of artificial intelligence

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Abstract: This paper explores the transformative role of artificial intelligence (AI) in medical education, emphasizing its role as a pedagogical tool for technology-enhanced learning. This highlights AI's potential to enhance the learning process in various inquiry-based learning strategies and support Competency-Based Medical Education (CBME) by generating high-quality assessment items with automated and personalized feedback, analyzing data from both human supervisors and AI, and helping predict the future professional behavior of the current trainees. It also addresses the inherent challenges and limitations of using AI in student assessment, calling for guidelines to ensure its valid and ethical use. Furthermore, the integration of AI into virtual patient (VP) technology to offer experiences in patient encounters significantly enhances interactivity and realism by overcoming limitations in conventional VPs. Although incorporating chatbots into VPs is promising, further research is warranted to enhance their generalizability across various clinical scenarios. The paper also discusses the preferences of Generation Z learners and suggests a conceptual framework on how to integrate AI into teaching and supporting their learning, aligning with the needs of today's students by utilizing the adaptive capabilities of AI. Overall, this paper highlights areas of medical education where AI can play pivotal roles to overcome educational challenges and offers perspectives on future developments where AI can play a transformative role in medical education. It also calls for future research to advance the theory and practice of utilizing AI tools to innovate educational practices tailored to the needs of today's students and to understand the long-term impacts of AI-driven learning environments.

Keywords: artificial intelligence; medical education; technology-enhanced learning; virtual patients; Generation Z students

1. Introduction

Technology-enhanced learning (TEL) covers all uses of digital technology to support and mediate educational activities [1]. Over time, these educational technologies have evolved with emerging technologies, including web-based technologies, mobile devices and apps, computers, tablets, and other digital devices [2]. Recently, increasing attention has been paid to the use of artificial intelligence (AI) in innovating education [3,4]. AI plays various roles in education, from augmenting traditional educational methods to introducing innovative practices [5], and has potential as a pedagogical innovation, not merely as a technological innovation [6]. While the use of AI in education is rapidly evolving, research on this topic is in its infancy, and practical evidence and theoretical models or frameworks that inform practice remain scarce [3]. Over several decades, research on TEL has shown that technology does not enhance learning; rather, it must focus on how and when to use it by understanding its mediating role in teaching and learning activities [1]. Therefore, a better understanding of the role of AI in education is required to use this emerging

pedagogical tool effectively.

This paper discusses the practice of using AI in teaching and learning, its potential and limitations, and its future implications in the context of medical education. Although AI is used in higher education for various purposes [3], this paper focuses on its role in medical education, given its importance in preparing future health professionals for workplaces where AI is expected to have increasingly significant impacts on patient care, medical research, and healthcare systems [7,8]. In this paper, current applications of AI are discussed in light of research on TEL in medical education, which aims to use technology to enhance learning through engaging, interactive, and learner-centered experiences. AI has been applied to various aspects of medical education, including admissions, teaching, learning, and assessment [5]. Among these various areas, this paper focuses on the use of AI to enhance teaching and learning, assessment, and engagement in patient encounters, which have presented challenges in medical education and AI is expected to play a prominent role in innovation. It also discusses the potential role of AI in providing learning experiences tailored to the needs of Generation Z students.

2. Applying AI to teaching and learning in medical education

Research indicates that AI lends itself well to integration with inquiry-based learning strategies in medical education, such as Case-Based Learning (CBL) and Problem-Based Learning (PBL) [9]. Generative AI can be used to develop realistic patient cases to be used in CBL and PBL with varying levels of complexity, and it can be directed to include specific content aligned with the learning outcomes in the curriculum [9]. Research has shown that AI can support PBL curriculum by providing automated and personalized feedback, helping students understand complex concepts and assisting facilitators with course responsibilities [10]. A study of urology interns found that the PBL group, which used ChatGPT to explore relevant clinical scenarios and learning issues and to practice history taking, showed significantly better learning outcomes compared to the traditional teaching group [11]. Another study has demonstrated that integrating AI into CBL can significantly improve the basic knowledge and clinical thinking of medical students [12]. In team-based learning, AI has been used to generate assessment items, and a study shows that items constructed for TBL using AI had good psychometric properties and quality, measuring higher-order domains [13]. These studies suggest that integrating AI into various inquiry-based learning activities can positively impact medical education by enhancing student learning and engagement.

Various TEL methods, such as blended learning, flipped classrooms, mobile learning, microlearning, gamification, and simulation, have been adopted in medical education and they have shown to enhance student learning outcomes and engagement [14]. Nonetheless, studies on the use of AI in medical education are yet limited. Some studies have investigated medical students' behaviors and perceptions of AI as a potentially effective learning tool [15,16], but research on its impact on educational outcomes is lacking and they are limited to a single stage in medical education or a specific discipline [17,18]. Further research is warranted with instructional models using AI in medical education to provide empirical evidence of its use to enhance

learning.

3. Using AI for assessment in Competency-Based Medical Education (CBME)

CMBE is a central framework for developing and implementing curricula in medical education in which assessment plays a pivotal role [19]. There is a growing emphasis on personalized, flexible curricula that accommodate diverse learning needs in CBME [19]. Consequently, personalized, flexible, formative and summative assessments are essential to make them aligned with these objectives. With advancements in AI, one can provide highly adaptive and responsive assessments and offer immediate and detailed feedback tailored to individual learners [20]. Furthermore, AI can be an effective tool in implementing CBME, which needs to manage large, longitudinal, and comprehensive assessment data that must be collected and analyzed to evaluate student competencies. Recent advances in AI can be promising in solving this problem in CBME by analyzing data from both human supervisors and AI, and helping predict the future professional behavior of the current trainees [21].

In CBME, students need to be assessed in their competencies in various domains, including knowledge, skills, and attitudes. Research has shown how AI can be applied to student assessment in such domains. Some earlier studies investigated the performance of generative AI in medical knowledge tests, such as medical licensing exams—it was proficient to pass exams with improved performance over time with the advancement of Large Language Model (LLM) technology [22–24]. Recent studies have focused on AI's capabilities in automatic item generation and setting standard parameters for student assessment [18]. AI can help create various assessment tools, such as multiple-choice questions (MCQs) and case-based assessments, to develop clinically relevant questions. Research has shown that AI assists in automated item generation more effectively and efficiently by enabling faculty to create numerous variations with varying complexity in medical conditions and scenarios presented in test questions [25,26]. Some research has demonstrated that AI-generated test items have good psychometric properties and can effectively measure higher-order domains in medical knowledge in basic medical sciences such as anatomy, physiology, and pharmacology [13,27,28], as well as in clinical sciences [29].

As medical students progress from lecture-based pre-clinical education to the clinical stage of their studies, assessments become more centered on their clinical performance. In clinical education, research has been reported on using AI to design and implement assessments for medical students' narrative comments and reflective papers in workplace-based assessments [30,31]. Research also shows that AI can assess non-cognitive domains such as clinical skills, professional behaviors, and attitudes [21,32], which are essential components for the assessment of clinical performance. However, challenges and ethical considerations must be addressed when using AI for student assessment, such as bias and AI-driven inaccuracies [20]. It is advised that experts review content validity [26,27], and given the challenges and limitations in the use of AI in student assessment, guidelines are recommended to ensure its validity and ethical use.

4. Virtual patients (VPs) and AI

In addition to promoting the acquisition of clinical knowledge and its assessment, AI can help augment and supplement patient encounters in medical education. Patient encounters are essential learning experiences for medical students to develop the clinical competencies expected of doctors. Traditionally, medical students practiced and were assessed on doctor-patient interactions using standardized patients (SPs)—those trained to play the role of patient to simulate patient encounters in clinical settings—to supplement real patient encounters in a risk-free environment. However, medical students have limited opportunities to practice patient encounters with SPs other than in high-stakes assessments because of the resource-intensive human role-playing involved in utilizing SPs. Consequently, VPs—a specific computer program that simulates real-life clinical scenarios—are being used to supplement these encounters. In VPs, learners emulate the roles of doctors in obtaining history, conducting physical exams, and making diagnostic and therapeutic decisions through interaction with them [33].

VPs have long been used to teach and assess various competencies, from clinical knowledge to clinical reasoning [34], and they are known to provide an effective means of improving student learning outcomes [33,35]. The use of VPs in clinical education can benefit student learning by supplementing patient encounters and offering more interactive clinical cases than the traditional paper-based formats. VPs are anticipated to be crucial in addressing the challenges affected by the rapidly evolving and complex landscape of medical education [36]. Various VP platforms have been developed, and the technologies applied have evolved from multimedia systems to virtual, augmented, and mixed reality. VPs were also used to replace SPs in clinical performance assessments during the COVID-19 pandemic. As social distancing rules disrupted traditional examinations, medical schools transitioned to virtual clinical performance assessments by incorporating VPs. A systematic review of virtual clinical performance examinations indicated that they were feasible and received positive feedback from stakeholders [37]. Nevertheless, conventional VPs have several limitations; specifically, doctor-patient interactions often fall short in creating an authentic and realistic setting for taking patient history through medical interviews where interactive encounters are essential [38]. Traditional VPs, developed with pre-LLM technology, offer a list of predefined questions for patient history, rather than allowing students to generate their own [39]. Hence, there has been increasing attention on using generative AI to overcome these limitations. Table 1 compares the characteristics of VPs in traditional and AI-based formats.

Table 1. Characteristics of virtual patients (VPs) in traditional and chatbot-based formats.

Category	Traditional VPs [39,40]	Chatbot-based VPs [40–42]
Type of question for history taking	Closed-ended	Open-ended
Interaction style	Pre-programmed scenarios with limited branching Rule-based, manually programed responses	Dynamic, conversational interaction using natural language processing Narrative responses
Customizability	Limited customization, predefined cases	High customizability; adaptable to various scenarios
Feedback	Static feedback based on pre-defined answers	Real-time feedback with personalized responses

Recently, efforts have been made to adopt generative AI in VPs to allow medical students to practice taking patients' histories by interacting with chatbots. Research has demonstrated that chatbots generate plausible answers in most cases and provide automated feedback effectively [41,42]. AI-powered VPs can be widely adopted, providing VPs that are more scalable, global, and inexpensive than conventional VPs [40]. However, these studies are limited to a few cases, using relatively small sample sizes. Moreover, while chatbots have shown promise in specific clinical cases, their generalizability across various clinical scenarios remains less explored [43]. Future research is warranted for more comprehensive studies to evaluate the effectiveness and applicability of chatbots in VPs in different medical contexts.

5. AI and Generation Z

The literature suggests that Generation Z students have unique styles and preferences regarding how they perceive and engage in learning, differentiating them from their predecessors. Research indicates that today's students prefer personalized learning and interactive, engaging materials, which call for learning environments that resonate with Generation Z's preferences [44]. Therefore, there is a need to adapt educational practices to meet the needs of this generation when integrating AI to enhance learning [45]. **Table 2** illustrates how AI can be used in the education of Generation Z students according to their learning styles and preferences.

Table 2. Potential roles of AI in education tailored to Generation Z's learning styles and preferences.

Aspect	Generation Z's Learning Styles/Preferences*	AI's Roles
Personalized Learning	Prefer personalized and flexible learning environments [46]	AI provides adaptive learning experiences tailored to individual student needs, preferences, and learning paces [3]
Multimedia Resources	Prefer to incorporate technology and multimedia content, especially videos [44]	AI creates and curates high-quality educational videos and interactive content [18]
Information Credibility	Struggle with information literacy and credibility of sources [47]	AI provides tools to evaluate and recommend credible resources, aiding students in navigating vast online information sources [48]
Engagement and Interaction	Favor interactive and engaging learning materials [44]	AI technologies (chatbots, virtual tutors) enhance interactivity in learning management systems and provide AI-assisted formative assessment, immediate feedback and support tailored to individual learners [3,45]

* Adapted from a study on learning preferences and styles of Generation Z medical students by Kim [44].

Generation Z students prefer personalized and flexible learning environments [46]. AI helps provide adaptive learning experiences tailored to individual student needs, preferences, and learning paces [3,49]. They also strongly prefer multimedia resources, particularly videos [44], and AI can create and curate high-quality educational videos and interactive content [18]. Generation Z often struggles with information literacy and the credibility of sources [47]; AI provides tools to evaluate and recommend credible resources, aiding students in navigating vast online information sources [48]. Additionally, Generation Z favors interactive and engaging learning materials [44]. AI technologies such as chatbots and virtual tutors enhance interactivity in learning management systems by providing AI-assisted formative assessment, immediate feedback and support tailored to individual learners [3,45].

Despite the potential of AI to provide education tailored to the needs of

Generation Z students, there is still a lack of research that illustrates its empirical evidence. A systematic literature review of studies on Generation Z students by Chardonnens [45] indicates that the integration of AI technologies is beneficial for providing them with personalized learning paths and real-time feedback, supporting self-regulated learning. This integration aligns well with the characteristics of Generation Z students, but over-reliance on it poses risks to the development of self-regulatory skills and metacognitive strategies. In particular, Chardonnens [45] notes the lack of research on the impact of using AI on this generation's long-term development of self-regulated learning and learning outcomes. As Generation Z students call for changes in educational practices, combined with the emerging roles of AI, future research is warranted on how to use AI tools to meet the specific needs of this generation, building upon theoretical models or frameworks on technology integration. For this purpose, one can adapt technology integration models, such as PICRAT [50], which stands for Passive, Interactive, Creative and Replacement, Amplification, Transformation, to effectively integrate AI tools into teaching and learning. The PICRAT model provides guiding principles for instructional strategies focusing on how technology can transform educational practices to make students more engaged and creative learners. Future studies are warranted to enhance our understanding of how to leverage AI tools in a way that enhances students' learning experiences and teaching practices suited for the needs of Generation Z students, especially by utilizing adaptive capabilities of AI.

6. Conclusion

As the use of AI in education is rapidly becoming more pervasive and ubiquitous, a better understanding of its use as an effective pedagogical tool is necessary. This paper highlights the transformative role of AI in medical education, addressing its potential and limitations in current applications. Research indicates that AI can assist the learning process effectively when integrated with various inquiry-based learning strategies. AI technologies facilitate student assessment competency-based medical education in the development of adaptive assessment tools by integrating adaptive assessment tools. AI can enrich student engagement in virtual patients by simulating authentic and interactive real-world clinical scenarios, aiding the cultivation of clinical competencies for patient encounters. Moreover, AI can innovate educational strategies that promote personalized and interactive learning experiences tailored to Generation Z's learning needs.

Despite these promising developments, challenges and concerns must be addressed to use AI effectively in education. Although research indicates that AI can produce high-standard assessment items, challenges and ethical issues remain in the use of AI for student assessment, which warrants guidelines to ensure its valid and ethical use. Furthermore, although the incorporation of chatbots into VPs has shown promise in specific clinical cases, their generalizability across various clinical scenarios remains less explored. Therefore, more comprehensive studies are necessary to evaluate the effectiveness and applicability of chatbots in VPs.

Moreover, this paper discusses how AI can play pivotal roles in innovating educational practices tailored to the needs of Generation Z students. It is suggested

that research particularly focus on advancing our understanding of how to utilize AI tools to innovate educational practices tailored to the needs of today's students. Future research is warranted to inform the theory and practice of integrating AI into education so that it is used as a transformative tool, as described in the PICRAT model [50], rather than merely replacing existing technological tools. Additionally, investigating the long-term impacts of AI-driven learning environments on student performance and engagement is warranted to fill the existing gaps in the literature that offers empirical evidence on the effective use of AI within this rapidly evolving technological landscape. Although AI presents considerable opportunities to enhance medical education, research on its impact on educational outcomes remains sparse. By bridging the gap between AI advancements and TEL research, future studies can offer insights that optimize the use of AI technology to enhance learning.

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