

Enhancing Knowledge Integration and Self-Directed Learning in Undergraduate Medical Education Through an AI-Based Multimodal Platform

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Objective: To evaluate the efficacy of the Sun Yat-sen Intelligent Education Platform—an AI-powered, multimodal learning system—in bridging the gap between preclinical and clinical knowledge and enhancing learning outcomes among undergraduate medical students.

Methods: A mixed-methods, prospective, randomized controlled trial was conducted with 80 fourth-year medical students at Sun Yat-sen University. Participants were randomly assigned to either an intervention group (n = 40), which used the AI platform alongside traditional teaching, or a control group (n = 40), which received standard instruction only. The study spanned six weeks, culminating in an Objective Structured Clinical Examination (OSCE). The primary outcome was the OSCE composite score. Secondary outcomes included subdomain scores (history taking, differential diagnosis, treatment planning) and student-reported satisfaction via a validated anonymous survey using 5-point Likert scales and open-ended questions assessing usability, educational value, and perceived integration of knowledge.

Results: The intervention group achieved significantly higher OSCE total scores than the control group (85.7 ± 5.8 vs. 78.3 ± 7.1; $p < 0.001$). Superior performance was observed in systematic history taking ($p = 0.008$), comprehensiveness of differential diagnosis ($p < 0.001$), and evidence-based treatment justification ($p = 0.002$). Over 90% of students reported that the platform effectively linked foundational and clinical knowledge, with high ratings for usability and educational support.

Conclusion: These findings suggest that the AI-based multimodal platform, The Sun Yat-sen Intelligent Education Platform, may support knowledge integration and self-directed learning in undergraduate medical education, though further validation in larger, multi-institutional settings is warranted.

Keywords: AI-based learning platform, undergraduation, medical education, multimodal resources, interventional study

Introduction

In the era of rapid advancements in artificial intelligence (AI), medical education faces both transformative opportunities and a persistent challenge: the significant gap between preclinical knowledge—such as anatomy, physiology, pathology, and pharmacology—and its clinical application.^{1–3} This disconnect stems largely from inherent limitations in current teaching models.

First, this gap arises from the temporal and spatial separation of preclinical and clinical training.⁴ The preclinical phase is discipline-based and campus-centered, focusing on foundational sciences,^{5,6} while the clinical phase takes place in hospitals and emphasizes case-based, real-time problem solving.^{7,8} This physical and chronological divide hinders students' ability to integrate theoretical knowledge with practical experience.⁹

Secondly, the conventional linear approach to knowledge dissemination widens this gap.¹⁰ Most curricula deliver content unidirectionally and sequentially, chapter by chapter. Yet clinical decision-making is inherently complex,

networked, and non-linear.¹¹ For example, assessing a patient with chest pain requires simultaneous integration of knowledge across cardiovascular anatomy, electrophysiology, coronary pathology, and pharmacology—a skill poorly supported by current teaching methods.

Emerging AI technologies offer new solutions by enabling interactive, explorable, and traceable virtual clinical learning environments. Intelligent teaching systems and personalized learning leverage artificial intelligence to adaptively tailor educational content,^{12,13} while large language models (LLMs) function as virtual tutors that enhance diagnostic reasoning abilities, thereby facilitating individualized learning experiences.¹⁴ Virtual patient simulations and immersive training utilize generative AI to produce dynamic virtual patients and highly realistic surgical simulations, enabling medical students to practice clinical skills within a risk-free environment.^{12,15} Furthermore, automated assessment and feedback systems employ AI to objectively evaluate student performance, deliver personalized feedback, and expedite the identification of research topics in medical studies. These platforms support integrative clinical reasoning through multidisciplinary knowledge graphs, on-demand access to connected information, and secure spaces for autonomous practice.³ This study integrates the “Sun Yat-sen Intelligent Education Platform” into undergraduate medical education to foster a shift from “linear memorization” to “networked retrieval”. The platform lies in its knowledge graph-based architecture, which dynamically enables bidirectional navigation—pushing relevant foundational concepts backward from clinical cases and introducing forward-looking clinical scenarios from basic science nodes—to scaffold continuous knowledge integration. This study therefore aimed to evaluate the impact of an AI-based multimodal learning platform on knowledge integration and self-directed learning behaviors among undergraduate medical students during their transition to clinical training.

Methods

Technical Design

The “Sun Yat-sen Intelligent Education Platform” (<https://sysu.xuetangx.com/ai-workspace/pro-ai-result-display/15382>) is a web-based application built on a three-tier technical architecture, as shown in Figure 1.

Model Layer: This layer establishes a foundational capability framework designed to facilitate collaboration among multimodal and large-scale models, characterized by high inclusivity and scalability. By integrating prominent large models, including Deepseek R1, GPT-4o, Zhipu AI, and Doubao, it enables intelligent routing, concurrent traffic management, adaptive computing resource monitoring, and context-sensitive switching to maintain efficient and stable system performance. Through dynamic scheduling and cooperative reasoning across models, the layer supports advanced learning processes and continuous refinement of core algorithms within the engine layer—such as knowledge graph construction and student profiling—thereby providing a robust artificial intelligence infrastructure for higher-level applications.

Engine Layer: This layer includes key algorithms such as a multidisciplinary knowledge graph engine, a multimodal parsing engine, and a student profiling engine. The knowledge graph engine enables “networked invocation” by linking preclinical disciplines—like anatomy, physiology, biochemistry, pathology, and pharmacology—with clinical fields including internal medicine, surgery, gynecology, and pediatrics, covering diseases, symptoms, diagnostics, and treatments.

Application Layer (Figure 2): This layer provides a 24/7 AI-powered study companion that supports natural language interactions with virtual patients, doctors, or interviewers. Students can make “data requests” (eg, “Retrieve liver function report”) or “knowledge requests” (eg, “Show a 3D model of the gallbladder triangle”). The platform responds instantly with relevant multimodal content and textual explanations, guiding learners through interdisciplinary clinical reasoning.

Study Design and Randomization

This study was conducted from October 15th, 2025, to December 31st, 2025, at Sun Yat-sen Memorial Hospital, Sun Yat-sen University, Guangzhou, China. A post hoc power analysis was conducted based on the observed effect size in OSCE scores (Cohen’s $d = 0.82$). With a total sample of 60 participants (30 per group), the study achieved approximately 85% power at a two-sided alpha level of 0.05 to detect this difference.

Platform Architecture Design

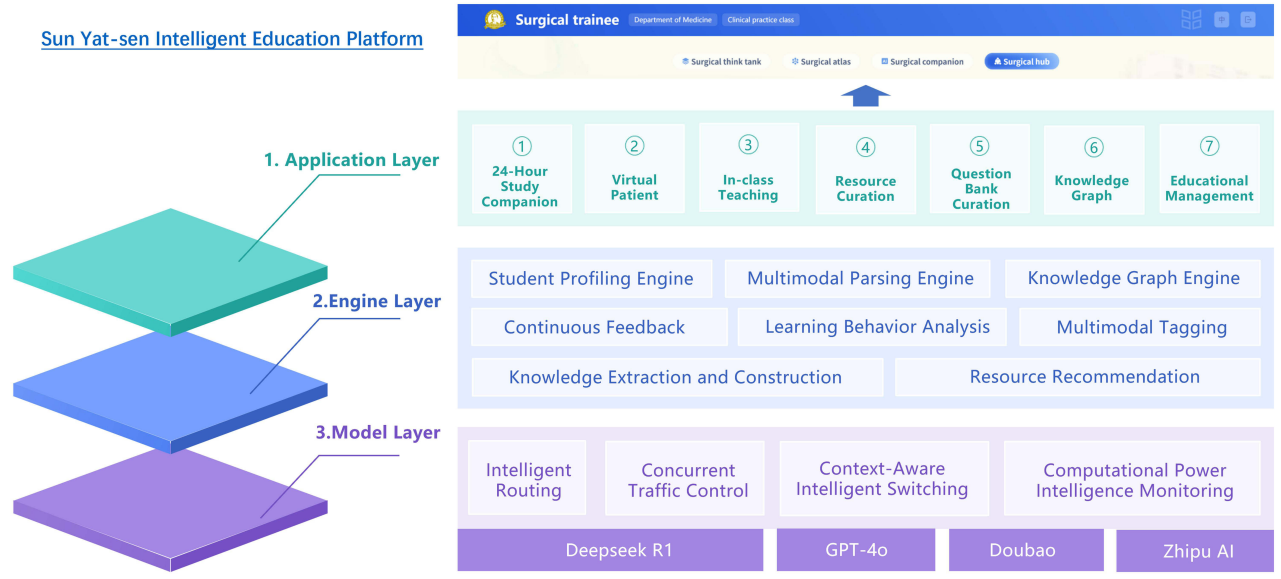


Figure 1 Sun Yat-sen Intelligent Education Platform Architecture Design. The platform adopts a hierarchical three-layer architecture designed for multimodal intelligent education: Application Layer, Engine Layer and Model Layer.

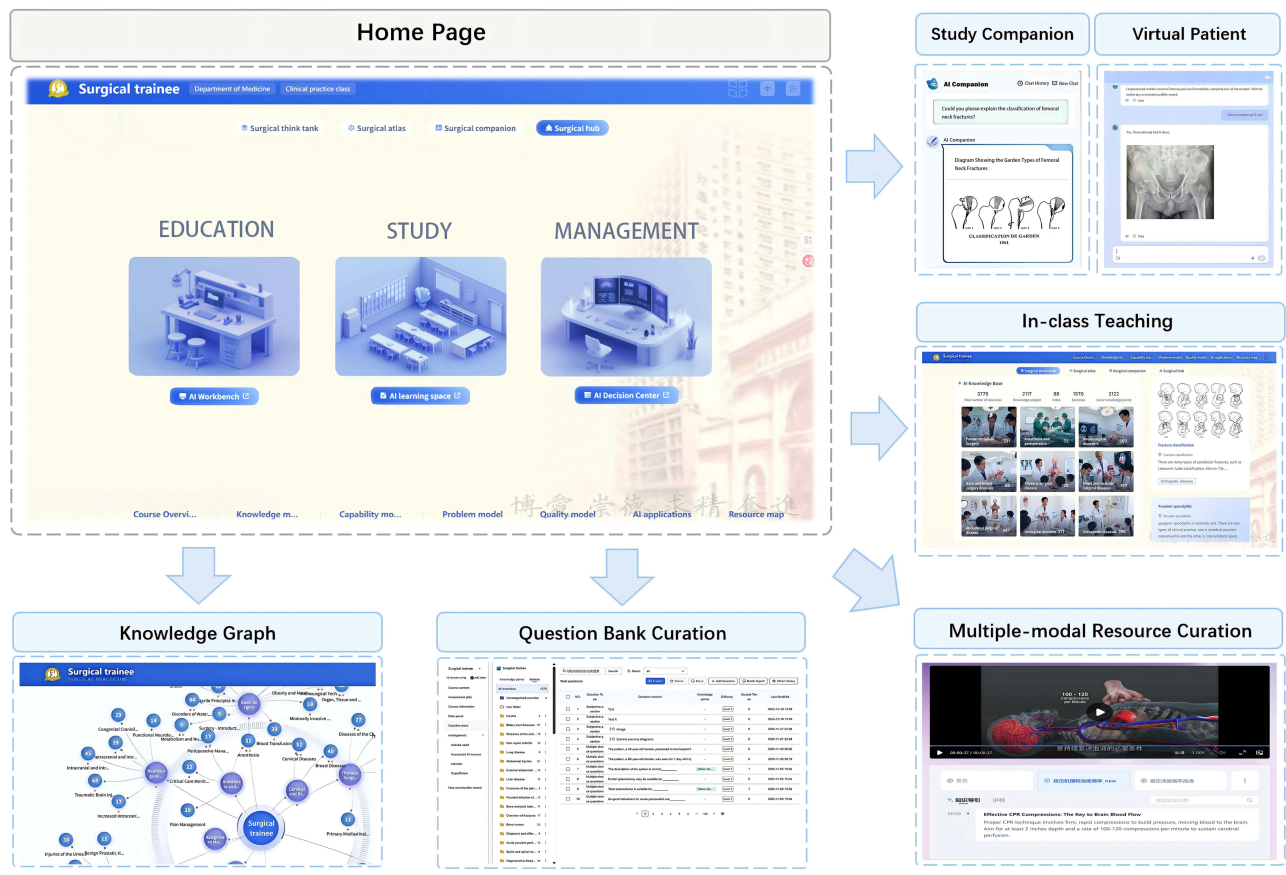


Figure 2 Application Layer setting. The user interface of the Sun Yat-sen Intelligent Education Platform provides multi-module integration for surgical training.

Eighty fourth-year clinical medicine students who had completed preclinical coursework were randomly assigned to either the experimental group or the control group.

Experimental Group (n = 40): Students in the intervention group received blended instruction combining traditional teaching (standard lectures and practical training with real patient cases in hospital wards) and the Sun Yat-sen Intelligent Education Platform. Over six weeks, they completed interactive modules on at least five comprehensive clinical cases via the platform, with usage logs showing a mean total engagement time of approximately 180 minutes per student. All participants attended a standardized 30-minute orientation session led by a trained instructor to ensure consistent understanding of platform navigation and task expectations. Although platform use was unsupervised and designed for self-directed learning, all students accessed identical multimodal content, virtual patient scenarios, and AI-generated feedback to maintain standardization across the group.

Control Group (n = 40): Students received only the traditional teaching methods described above, without access to the digital platform.

Participants were randomly assigned to either the intervention or control group using computer-generated block randomization with a block size of 4. Allocation concealment was maintained by having an independent researcher—who was not involved in participant recruitment or outcome assessment—prepare sequentially numbered, sealed, opaque envelopes containing group assignments.

Design of the OSCE Assessment

Six weeks after the intervention, all participants completed a standardized Objective Structured Clinical Examination (OSCE) following a strict protocol. The exam included 12 stations, each lasting 8 minutes, with 2-minute breaks in between. Scoring was based on expert-validated rubrics, with a total of 100 points across five domains: systematic history taking (20), standardized physical examination (20), comprehensive differential diagnosis (25), evidence-based diagnostic and treatment planning (25), and communication and humanistic care (10).

The assessment evaluated key competencies such as medical documentation, emergency procedures, doctor-patient communication, ethical decision-making, and interpretation of imaging and lab results. Each station was scored independently by three trained examiners, and the final score was the average of their ratings.

All examiners participated in a standardized training session to calibrate scoring using detailed rubrics and sample performances. Inter-rater reliability was assessed during the pilot phase for stations requiring subjective evaluation; intraclass correlation coefficients (ICCs) ranged from 0.82 to 0.91, confirming high consistency among raters.

Outcome Assessment

All OSCE stations were assessed by the same pool of trained examiners, who rotated across stations according to a pre-established schedule to ensure balanced coverage. Crucially, these examiners were blinded to participants' group assignments throughout the assessment process.

Survey Design

After the OSCE assessment, participants were invited to complete an anonymous online survey (see [Figure 3](#)) to evaluate the platform's usability, educational effectiveness, and user experience. The survey instrument was developed based on established literature, pilot-tested for clarity and face validity with a separate cohort of 10 students, and achieved a 100% response rate among the intervention group participants. It included Likert scale items (1–5) and open-ended questions to collect both quantitative and qualitative data.

Ethics

This study received ethical exemption from the Medical Education Research Ethics Committee of Sun Yat-sen Memorial Hospital (Approval No.: SYSEC2-BA-059), in accordance with institutional guidelines for low-risk educational research using anonymized data. All procedures were conducted in accordance with the Declaration of Helsinki. All participants were informed of the study's educational purpose, and participation in assessments and surveys was voluntary.

Section	Question
Platform Interaction	1. How would you rate the usability of the “Sun Yat-sen Intelligent Education Platform” website? (1 = Very Poor, 5 = Excellent) 2. How would you rate the quality of the medical content in the scenarios you participated in? (1 = Very Poor, 5 = Excellent)
Core Functional Value	3. How would you rate the platform’s feature of “on-demand provision of multimodal data” (e.g., lab reports, 3D anatomical models, surgical videos)? (1 = Very Poor, 5 = Excellent) 4. How would you rate the platform’s ability to “support networked retrieval of preclinical-clinical knowledge” (e.g., instantly explaining the pathophysiological mechanisms underlying symptoms)? (1 = Very Poor, 5 = Excellent) 5. Which aspects of the platform were most helpful to your learning? (Select all that apply) - <input type="checkbox"/> On-demand access to data (e.g., lab tests, imaging) - <input type="checkbox"/> Support for self-directed learning (practice anytime, anywhere) - <input type="checkbox"/> Realistic patient interaction - <input type="checkbox"/> Instant retrieval and integration of basic medical knowledge - <input type="checkbox"/> Detailed feedback reports - <input type="checkbox"/> Diversity of cases
Perceived Benefits	6. How would you rate the feedback provided after each scenario? (1 = Very Poor, 5 = Excellent) 7. Do you believe the “Sun Yat-sen Intelligent Education Platform” addresses a gap in current medical training? If yes, please explain how.
Limitations	8. Did you encounter any confusing or clinically unrealistic scenarios or elements in the platform? 9. If you answered “yes” to the previous question, please specify. 10. What improvements would you suggest for the platform?
Overall Evaluation	11. How would you rate the overall effectiveness of the “Sun Yat-sen Intelligent Education Platform” as a learning tool? (1 = Very Poor, 5 = Excellent) 12. How likely are you to recommend the “Sun Yat-sen Intelligent Education Platform” to others? (1 = Very Unlikely, 5 = Very Likely) 13. Please provide any additional comments or insights about the “Sun Yat-sen Intelligent Education Platform.”

Figure 3 5-point Likert scale satisfaction questionnaire. The survey covers platform interaction, core functional value, perceived benefits, limitations, and overall evaluation.

Statistical Analysis

The normality of continuous variables was assessed using the Shapiro–Wilk test. For variables that met the assumption of normality and homogeneity of variance, independent-samples t-tests were used; otherwise, non-parametric Mann–Whitney *U*-tests were applied. To account for multiple comparisons across secondary outcomes (n = 4), we applied the Benjamini–Hochberg procedure to control the false discovery rate at q = 0.05. The primary OSCE outcome was analyzed without adjustment, as it was pre-specified as the sole primary endpoint.

Results

Comparison of OSCE Assessment Scores

The OSCE outcomes demonstrated that the experimental cohort exhibited significantly greater overall clinical competence compared to the control cohort, with mean total scores of 85.7 ± 5.8 and 78.3 ± 7.1 , respectively ($p < 0.001$). Analysis of subdomains (Table 1) indicated substantial benefits for the experimental group in areas related to knowledge integration and clinical reasoning, including “Systematic History Taking” (17.8 ± 1.5 versus 16.2 ± 2.1 , $p = 0.008$), “Comprehensiveness of Differential Diagnosis” (22.5 ± 1.8 versus 18.9 ± 2.6 , $p < 0.001$), and “Evidence-Based Basis for Diagnosis and Treatment Plans” (22.1 ± 2.0 versus 19.5 ± 2.8 , $p = 0.002$). These results suggest that AI-assisted learning significantly enhances students’ capacity to synthesize foundational medical knowledge with clinical application. Conversely, no statistically significant differences were observed in the domains of “Standardization of Physical Examination” or “Communication and Humanistic Care” ($p > 0.05$), indicating a limited effect of technological interventions on competencies requiring direct interpersonal engagement.

Efficacy of the Platform as an Educational Instrument

Participants demonstrated strong approval of the platform’s primary features (Table 2). Specifically, 92% (37 out of 40) of students identified the “instant retrieval and integration of basic medical knowledge” as the most advantageous aspect; 90% (36 out of 40) valued the “on-demand provision of multimodal data”; and 88% (35 out of 40) recognized its facilitation of “self-directed learning” as beneficial. Additionally, as shown in Table 2, the platform’s usability and the quality of its medical content received high evaluations, with mean scores of 4.75 (95% CI: 4.60–4.90) and 4.72 (95% CI: 4.57–4.87), respectively, measured on a five-point Likert scale. As detailed in Table 2, the perceived quality of tailored feedback provided after each simulated scenario also achieved a favorable mean score of 4.68 (95% CI: 4.53–4.83).

Table 1 OSCE Subdomain Scores

OSCE Subdomain (Maximum Score)	Intervention Group (n = 40)	Control Group (n = 40)	p-value
Systematic History Taking (20 points)	17.8 ± 1.5	16.2 ± 2.1	0.008
Standardization of Physical Examination (20 points)	16.5 ± 1.9	16.4 ± 2.0	> 0.05
Comprehensiveness of Differential Diagnosis (25 points)	22.5 ± 1.8	18.9 ± 2.6	< 0.001
Evidence-Based Basis for Diagnosis and Treatment Plans (25 points)	22.1 ± 2.0	19.5 ± 2.8	0.002
Communication and Humanistic Care (10 points)	6.9 ± 1.1	6.8 ± 1.2	> 0.05
Total OSCE Score (100 points)	85.7 ± 5.8	78.3 ± 7.1	< 0.001

Table 2 Students’ Ratings of Sun Yat-Sen Intelligent Education Platform (N = 40)

Questions	Scores				
	1	2	3	4	5
(A) How would you rate the ease of use of the website?	0	0	0	10	27
(B) How would you rate the medical content in the scenarios you played?	0	0	0	11	26
(C) How would you rate the feedback received Dafter each scenario?	0	0	3	16	18
(D) How would you rate OSCE-GPT in comparison to traditional learning methods (eg, flipped classroom lectures, patient presentations)?	0	0	4	24	9
(E) How did the feedback received after each scenario compare to feedback received in traditional learning outlets (eg, flipped classroom lectures, patient presentations)?	1	0	7	18	11
(F) How would you rate the OSCE-GPT as a learning tool?	0	0	0	14	23
(G) How likely would you recommend OSCE-GPT to others?	0	0	1	6	30

Distinctive Value of the Platform

All participants ($n = 40$) concurred that the “Sun Yat-sen Intelligent Education Platform” effectively addresses a critical deficiency in contemporary medical training. Qualitative responses underscored two primary advantages:

Firstly, the platform facilitates the integration of knowledge. One student remarked,

Previously, when encountering a patient with ascites, my understanding was limited to ‘cirrhosis’ without comprehending underlying mechanisms such as portal hypertension or hypoalbuminemia. Now, I can promptly access a systematically organized overview of the entire knowledge framework.

Secondly, the platform promotes autonomous learning. Another participant observed,

I am able to utilize brief intervals to repeatedly practice patient interviews and clinical decision-making, exploring all potential differential diagnoses—an opportunity seldom available in actual clinical environments.

By providing timely and comprehensive information within a secure simulated environment, the platform helps enhance the depth and flexibility of medical education.

Limitations of the Platform

A minority of users (7 out of 40) identified certain limitations impacting their learning experience. One participant noted that AI-generated patient responses concerning rare diseases appeared scripted. Another suggested enhancements to the 3D models, recommending the incorporation of advanced interactive functionalities, such as the ability to dissect and examine deeper anatomical structures.

Comparison with Alternative Instructional Approaches and Holistic Assessment

Participants were invited to assess the “Sun Yat-sen Intelligent Education Platform” in comparison to conventional teaching approaches. The platform received high ratings for its capacity to facilitate knowledge integration, with a mean score of 4.20 (95% Confidence Interval: 4.00 to 4.40), demonstrating statistical significance ($p < 0.001$). The overall acceptance of the platform as an educational tool was rated at 4.65 (95% CI: 4.48 to 4.82) on a 5-point scale. Additionally, the likelihood of students recommending the platform to peers was rated at 4.80 (95% CI: 4.65 to 4.95) out of 5.

Discussion

The current investigation reveals that the “Sun Yat-sen Intelligent Education Platform” markedly improves the overall clinical competencies of medical students, particularly excelling in areas that demand integrative synthesis of knowledge. This enhancement is primarily ascribed to the platform’s utilization of artificial intelligence technologies,¹⁶ which adeptly address intrinsic limitations present in traditional medical education.^{17,18} Conventional pedagogical methods have often been hindered by disciplinary fragmentation, leading to the formation of “knowledge silos” that predispose learners to approach complex clinical cases from a narrow, unidimensional perspective, thereby restricting the cultivation of systematic diagnostic reasoning. The platform mitigates this challenge by reconstructing learners’ cognitive schemas through the development of a dynamic, multidisciplinary knowledge graph that integrates both basic and clinical medical sciences. Unlike a static information repository, this knowledge graph operates as an intelligent semantic network interlinking symptoms, clinical signs, pathophysiological processes, and pharmacological mechanisms. Results from the Objective Structured Clinical Examination (OSCE) indicate that students employing the platform significantly surpassed their peers in the “comprehensiveness of differential diagnosis” criterion ($p < 0.001$). This outcome implies that platform users are capable of systematically generating multiple diagnostic hypotheses from initial chief complaints by traversing associative knowledge pathways. Consequently, this methodology effectively simulates the holistic and multilayered cognitive processes characteristic of expert clinicians, thereby establishing a solid cognitive foundation for clinical skill development.^{7,8,19}

Notably, the platform incorporates an “on-demand mesh calling” mechanism to enable contextualized, just-in-time learning. During simulated clinical encounters, students may query pertinent information or data at any point using natural language, prompting the system to instantaneously deliver multimodal resources linked to the knowledge graph—

such as three-dimensional anatomical models, laboratory findings, and pathological animations. For example, when a student asks, “Why does jaundice occur?” the platform not only explicates the underlying pathophysiological mechanisms but simultaneously presents hepatobiliary anatomy and metabolic pathways, thereby concretizing abstract theoretical concepts within specific clinical contexts. This approach inherently serves as immersive clinical reasoning training. As one participant remarked, “It allows you to lay out the entire knowledge network at a glance”. This knowledge construction, driven by authentic (simulated) clinical demands, significantly enhances students’ competencies in areas including the “evidence basis for treatment plans” ($p = 0.002$) and the “systematic nature of history taking” ($p = 0.008$), effectively bridging the gap between foundational theory and clinical practice.

It is essential to emphasize that the platform did not produce significant advancements in the area of “communication and humanistic care”. This finding highlights a crucial consideration: the cultivation of sophisticated humanistic qualities—such as emotional communication, empathy, and ethical judgment—relies predominantly on authentic interpersonal interactions and emotional experiences,²⁰ which current virtual technologies have yet to fully replicate. Therefore, the primary role of the “Sun Yat-sen Intelligent Education Platform” is not to replace bedside teaching or standardized patient (SP) training but to serve as a robust cognitive framework that addresses fundamental challenges in knowledge integration and clinical reasoning education. As such, it functions as a complementary and synergistic element within a blended learning model alongside traditional pedagogical methods. While maintaining the indispensable importance of genuine interpersonal engagement, the platform leverages intelligent technology to overcome conventional educational constraints related to knowledge synthesis and personalized training, thereby providing a scalable technological solution for the education of medical professionals in the modern era.

While current AI platforms focus mainly on cognitive and technical skills, future iterations incorporating sentiment analysis and emotion recognition could provide nuanced feedback on learners’ empathy, tone, and nonverbal cues in simulated patient interactions. However, such tools should complement—not replace—authentic interpersonal experiences, which are irreplaceable for cultivating compassion, ethical reasoning, and professional identity. The goal is a synergistic model where AI supports reflective practice while preserving the centrality of human connection in clinical care.

Limitations

Although the study was conducted at a single institution, which theoretically raises the possibility of information contamination between groups, several measures were implemented to minimize this risk. Participants in the intervention and control groups with minimal scheduled interaction during the study period. Furthermore, all outcome assessments were performed using standardized instruments by assessors blinded to group allocation. Nevertheless, we cannot entirely rule out informal communication among participants, which represents a limitation of our study design.

A limitation of our study design is the inability to blind participants to their group assignment, which may have introduced performance bias. However, we mitigated this risk by ensuring that all outcome measures were evaluated by assessors who remained blinded to group allocation, and by using standardized, criterion-referenced scoring rubrics across all stations.

Furthermore, the relatively short duration of the intervention and the absence of follow-up assessments limit our ability to draw conclusions about the retention of skills or the long-term impact of the platform on clinical competence.

Thirdly, the lack of detailed baseline comparability data and limited granularity in platform usage metrics preclude definitive conclusions about the exact magnitude of the intervention’s effect. Future studies should incorporate individual-level randomization, comprehensive baseline assessments, and fine-grained learning analytics to better isolate the contribution of AI-enhanced case exposure to clinical performance gains.

Recommendations

Based on our findings, we offer the following recommendations:

For Researchers: Conduct longitudinal studies on knowledge/skill retention from AI platforms and explore advanced affective computing to enhance humanistic care training.

For Educators: Use the Sun Yat-sen Intelligent Education Platform as a blended-learning tool to prepare students for clinical rotations, freeing bedside time for communication, empathy, and hands-on skills.

For Policymakers: Establish clear guidelines for their ethical use, data privacy, and curriculum integration to scale up medical education effectively.

Conclusion

The artificial intelligence–driven multimodal resource interaction platform may offer a flexible and interactive approach to support the transition from preclinical to clinical education by facilitating multimodal resource use and networked knowledge retrieval. While the platform appears aligned with contemporary educational paradigms and may help address certain limitations of traditional instruction—such as challenges in resource integration and individualized training—further validation in larger, multi-institutional settings is warranted to better understand its impact on the development of future physicians’ competencies in meeting the complex demands of modern healthcare.

Abbreviations

OSCE, Objective Structured Clinical Examination; AI, Artificial Intelligence; SP, Standardized Patient.

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Disclosure

The authors report no conflicts of interest in this work.

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