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AI-Driven Personalized Learning in Medical Education: Enhancing Cognitive Skills and Addressing Language Proficiency Challenges

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ABSTRACT

This study examines the effectiveness of artificial intelligence-driven (AI-driven) personalized learning strategies in enhancing cognitive skills and language proficiency in medical education. By integrating AI tools into practical scenarios, such as clinical simulations and patient interactions, the research highlights AI's potential to foster critical thinking, decision-making, and personalized learning experiences. A mixed-methods approach, combining pre- and post-intervention assessments, questionnaires, and interviews, reveals that while AI significantly improves cognitive skills, its impact on language proficiency is modest. A major contribution of this study is the proposed PCLC-AI Framework (Personalized Cognitive and Linguistic Competency Development with Artificial Intelligence), which aligns AI-driven learning with curriculum objectives to enhance both cognitive and linguistic competencies. The framework incorporates adaptive learning paths, interactive simulations, and integrated feedback mechanisms, offering a cohesive approach to skill development. Despite its potential, the study identifies challenges, including cultural adaptability, reliance on a single AI model, and the limited duration of the intervention. Findings thus underscore the need for longer-term studies and localized AI training datasets. By addressing critical gaps in the literature, this research provides actionable insights into optimizing AI integration for medical education.

Keywords: AI-Driven Personalized Learning; Medical Education; Cognitive Skills; Language Proficiency; Curriculum Integration; AI Learning Framework

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1. Introduction

1.1. Background

The rapid evolution of artificial intelligence (AI) technologies presents unparalleled opportunities to transform educational practices, particularly in medical education. In 2018, the Central Committee of the Communist Party of China and the State Council introduced the concept of New Medicine, driving innovation through initiatives such as the Excellent Doctor Education and Training Program 2.0 along with other policies. This new era emphasizes the integration of multidisciplinary knowledge—including humanities, science, and engineering—to enhance educational quality and innovation. Such an interdisciplinary approach equips medical students not only with specialized medical knowledge but also with strong communication skills in language and advanced cognitive abilities, essential for navigating the globalized healthcare environment.

The integration of AI into learning environments offers the potential to tailor educational experiences to individual needs, potentially revolutionizing how medical students acquire language skills and develop critical cognitive capacities. The College English Teaching Guidelines (2020 Edition)[1] emphasizes the integration of English learning with medical knowledge, underscoring the importance of effective communication in international medical settings and outlining new requirements for language learning and cognitive skills in medical education. Similarly, various policy frameworks, including the National Education Technology Plan[2] and AI and Education: Guidance for Policy-Makers[3], underscore the importance of using AI to personalize learning experiences and promote inclusivity and accessibility in education.

This study distinguishes itself from previous AI-based medical education research by focusing on the development of higher-order cognitive skills, such as critical thinking and decision-making, alongside language proficiency. Unlike earlier studies that primarily emphasize general educational outcomes, this research specifically explores the integration of AI tools into practical educational settings, such as simulated patient interactions and clinical decision-making exercises. By addressing these competencies within real-world scenarios, the study provides a targeted approach to applying AI technologies in medical education, thus offering insights into how AI tools and AI-driven teaching pedagogy can be strategically optimized for this particular educational context.

Advancements in AI, particularly in natural language processing (NLP), present significant opportunities for enhancing English medical education and improving students' cognitive skills. The application of AI can optimize teaching methods while also improving the objectivity and scientific rigor of educational assessments through intelligent tools. This approach is reinforced in the Comprehensive Plan for Deepening Educational Evaluation Reforms in the New Era, which advocates for the use of information technology to enhance the accuracy and comprehensiveness of educational evaluations. Furthermore, the World Economic Forum's 2024 report, Shaping the Future of Learning: The Role of AI in Education 4.0, highlights the potential of AI technologies in educational management and assessment, particularly in promoting personalized learning and assessment efficiency. These developments underscore the need for educators to adopt innovative teaching concepts and methods to cultivate medical professionals capable of addressing modern healthcare challenges, thereby aligning with global educational trends and technological advancements.

1.2. Literature and Gaps

Policy demands have not only driven updates in educational content and methods but have also compelled educators to explore new teaching tools and strategies. A keyword search on CNKI using terms such as "New medicine", "Artificial intelligence", and "Medical students" revealed that, between 2019 and 2024, over 160 related studies were conducted. However, when additional keywords like "Language education" or "English education" were included, the number of studies decreased dramatically to 13. Among these, interdisciplinary studies involving medical students and foreign language and literature under the framework of artificial intelligence accounted for only 2.83% of the total.

In the evolving landscape of medical education, several key terms are central to understanding the impact of AI-driven innovations. Cognitive skills refer to the mental abilities required for processing information, solving problems, and making decisions, which are crucial in clinical settings[4]. AI-driven personalized learning is defined as an approach where AI technologies tailor learning experiences to individual student needs, enhancing engagement and effec-

tiveness[5]. Critical thinking and decision-making involve the ability to analyze information, evaluate arguments, and identify solutions to make well-reasoned decisions, which are essential for medical practitioners[6]. Lastly, language proficiency in this context refers to the ability to communicate effectively, both verbally and in writing, which is vital for clear patient interactions and professional collaboration[7].

In this research, cognitive skill is defined as the capacity to engage in complex problem-solving and reasoning, particularly in the context of clinical applications and patient care. AI-driven personalized learning is conceptualized as the use of artificial intelligence tools to customized educational experiences that adapt to the learning style and pace of each medical student, thereby enhancing their understanding and retention of medical knowledge. Critical thinking and decision-making are understood to involve the application of logical reasoning and evidence-based analysis in clinical decisions, a critical element of medical training. Language proficiency is defined as the expertise in medical terminology and patient communication, ensuring effective and empathetic interactions within clinical practice.

Despite the growing interest in AI technologies, existing models primarily focus on general educational outcomes and rarely address the unique challenges of cognitive skill development and language proficiency in medical education. For instance, Qu et al. and Tao et al.[8, 9] have demonstrated the role of AI tools like ChatGPT in personalizing learning experiences, yet these applications largely emphasize student engagement rather than targeted cognitive skill enhancement. Similarly, Wang et al.[10] and He et al.[11] highlight the integration of AI into medical teaching, but their studies focus on broad improvements in teaching outcomes without delving into specific competencies such as critical thinking, decision-making, or linguistic accuracy. A comparative analysis of AI models reveals key gaps in their application to medical education. While existing frameworks effectively support knowledge retention and general skill acquisition, they often lack mechanisms to address higher-order cognitive skills such as analytical reasoning and ethical decision-making[12, 13]. Furthermore, language proficiency—particularly in the context of medical terminology and patient communication—is often overlooked or treated as a secondary outcome[14]. Cai et al. and Chen et al.[12, 13] argue for a strategic blending of AI with traditional educational philosophies, but their proposed models do not sufficiently address the integration of language learning with cognitive skill development.

The integration of artificial intelligence (AI) into medical education has garnered significant attention, with numerous studies exploring its potential to transform teaching and learning processes. Researchers have highlighted the growing demand for AI-oriented courses among medical students, reflecting the increasing importance of AI literacy in modern healthcare education[15, 16]. Comprehensive frameworks, such as the one developed by Kang et al., emphasize the need to train students not only as users but also as critical interpreters of AI technologies, enabling them to leverage AI responsibly and innovatively in clinical settings[17].

Ethical considerations are a recurring theme in studies on AI-based medical education, as AI technologies introduce both challenges and opportunities. Diao et al. critically examine the ethical implications of AI, while Zou et al. advocate for integrating humanistic education alongside technical training to prepare students for the ethical complexities of modern medicine[18, 19]. Beyond technical skills, AI has also been explored for its role in enhancing communication abilities. For instance, Shao et al. demonstrate how AI systems can improve empathic interactions between doctors and patients, highlighting its potential to address interpersonal aspects of medical practice[20]. Case studies, such as those conducted by Han et al. at Capital Medical University, illustrate effective strategies for incorporating AI into medical training to develop both technical and interpersonal competencies[21].

A key advantage of AI in medical education is its ability to foster interdisciplinary learning and research. Zhou et al. and Jin et al. underscore how AI encourages students to apply knowledge across disciplines, enhancing their research skills and fostering innovation[22, 23]. Moreover, AI empowers educators by enhancing their teaching capabilities and promoting integrative, research-oriented educational environments[24]. Despite these advancements, existing AI applications often focus on broad educational outcomes, leaving critical gaps in the literature concerning the development of higher-order cognitive skills and language acquisition.

Language proficiency and cognitive abilities, such as critical thinking and analytical reasoning, are essential for medical students to navigate complex clinical and academic environments. However, while AI has been widely applied to

support knowledge retention and general skill acquisition, it has seldom been utilized to address the unique linguistic and cognitive challenges faced by medical students. Most existing frameworks neglect the integration of language learning into cognitive skill development, particularly in the context of medical terminology and patient communication. This gap underscores the need for innovative approaches that combine AI-driven strategies with targeted cognitive and linguistic skill enhancement.

This study seeks to address these gaps by proposing a novel framework that integrates cognitive and linguistic competency development through AI systems. By leveraging adaptive learning paths, interactive simulations, and real-time feedback, the framework aims to enhance critical thinking, decision-making, and language proficiency in medical education. This approach offers a focused strategy for applying AI technologies to meet the specific needs of medical students, contributing to their academic success and professional preparedness. The proposed framework also aligns with current educational policies emphasizing technology-integrated learning environments in healthcare, offering valuable insights into the practical applications of AI in medical education.

This research intends to probe into the following two research questions (RQs):

Research Question 1: How effective are different AI teaching strategies in enhancing higher-order cognitive skills and language proficiency in medical students?"

Research Question 2: How can AI-driven strategies be implemented more effectively within language learning courses for medical students?

1.3. Theoretical and Conceptual Framework

To effectively explore the integration of AI in medical education, a robust theoretical and conceptual framework is essential. Given the focus on cognitive skills, AI-driven personalized learning, critical thinking and decision-making, and language proficiency, the Constructivist Learning Theory serves as a suitable foundation. This theory posits that learners construct their own understanding and knowledge of the world through experiences and reflective practices [25]. When applied to AI in education, Constructivist Learning Theory supports the premise that AI tools can facilitate such experiential learning environments that are both personalized and adaptive to individual learner's needs [26].

Additionally, the Technology Acceptance Model (TAM) offers a framework to understand and predict the acceptance of AI technologies by medical educators and students. TAM suggests that two key factors—perceived usefulness and perceived ease of use—play a critical role in influencing the adoption and efficient use of new technologies [27]. In the context of AI-driven educational tools, assessing these perceptions among users can reveal insights into the challenges and enablers of AI integration in medical education [28].

2. Materials and Methods

2.1. Research Design

This study employed a mixed-methods approach with triangulation to enhance the validity of the findings by integrating both quantitative and qualitative data. The quantitative component involved pre- and post-tests related to the AI-driven medical education intervention, along with surveys administered to the experimental students participating in the intervention. These surveys were designed to assess students' perceptions of the AI tools' usefulness and ease of use, in alignment with the Technology Acceptance Model [27]. The qualitative component involved open-ended questions within the questionnaire and semi-structured interviews conducted to gather in-depth insights into the impact of AI tools on teaching practice. Teacher participants included a language instructor who designed and implemented the intervention as well as its pedagogical practices, including the assessment instrument, and a medical doctor from the affiliated university hospital where the study was conducted, who contributed to evaluating the intervention's outcomes. This mixed-methods approach allowed for a detailed exploration of students' experiences using AI in their education, complementing the quantitative findings and providing a nuanced understanding of the intervention's effectiveness [29].

2.2. Ethics

The research protocol was reviewed and approved by the university's Ethics Committee (2024046). All participants provided informed consent, which outlined the study's purpose, voluntary participation, confidentiality measures,

and their right to withdraw at any time, in accordance with ethical guidelines established by Polit and Beck [30]. To safeguard participant anonymity, identifying information was removed during data collection and analysis. Participants were assigned unique codes, and all data was securely stored in password-protected systems. No personal identifiers were included in reports, publications, or presentations, ensuring the confidentiality of all participants.

2.3. Setting and Participants

The AI-driven medical education intervention study was conducted at a medical college known for its diverse student demographics, involving two groups of 30 medical students each but taught by the same instructor (**Table 1**). The experimental group participated in a novel English language course that integrated AI-driven personalized learning tools with cognitive skill development considerations in its pedagogical practices. The course spanned 8 weeks, with students attending two 90-minute lessons per week, resulting in a total of 16 sessions. To ensure educational fairness, the control group, which initially received traditional instruction, was later offered several sessions of the same innovative curriculum. Both groups underwent initial evaluations to confirm comparable levels of English proficiency and medical knowledge, allowing for valid comparisons of the intervention's outcomes. The sample selection criteria were based on the accessibility and willingness of participants from the target population. Participants were recruited from two groups with similar levels of English proficiency and medical knowledge to ensure comparability of outcomes. This approach allowed us to focus on the feasibility of integrating AI-driven strategies into existing educational contexts, despite resource and time constraints.

Recruitment focused on students from diverse medical disciplines and academic years, with an emphasis on voluntary participation and confidentiality, to reflect the cultural and educational diversity of the region [31]. In-depth interviews, with two instructors involved in the intervention were conducted to examine the effects of integrating language proficiency requirements with AI tools on students' language skills and educational engagement. These findings contributed to the refinement of educational strategies [32, 33]. The interviews were designed to address the second research question, which aimed to explore practical applications of AI strategies in language learning curricula. The focus was on how these technologies can be seamlessly integrated to support and enhance linguistic competencies alongside cognitive skill development, thus providing a holistic educational approach and identifying areas for further pedagogical enhancement [34].

Table 1. Student demographics.

No. Counting	Field of Study	Year & Skills Overview
8	Clinical Medicine	Freshmen with foundational English writing skills
7	Pharmacology	Sophomores with emerging medical knowledge and improving English writing skills
5	General Medicine	Juniors initiating clinical practice, integrating professional knowledge with English writing
4	Nursing	Seniors gearing up for employment or advanced studies, prioritizing English writing skills
4	Optometry	Freshmen where English writing is crucial for academic and professional success
2	Biomedical Engineering	Sophomores exploring ways to blend professional knowledge with English writing

2.4. The AI-Driven Medical Education Intervention

The AI-driven medical education intervention was designed for 60 first-year medical students at a prestigious medical college, divided into an experimental group and a control group to effectively compare outcomes. This structured 8-week course leveraged the capabilities of ChatGPT combined with expertly crafted instructional strategies by the teaching staff to enhance both cognitive skills and medical language proficiency.

The primary AI tool utilized in this intervention was ChatGPT, which, in collaboration with the teaching staff, facilitated personalized and interactive learning experiences. ChatGPT was employed to simulate patient interactions, explain medical terminology, and offer practice in clinical decision-making through interactive dialogues and problem-solving exercises.

Each session leveraged ChatGPT to create dynamic learning scenarios reflecting real-world clinical situations, enabling students to apply their knowledge in practical contexts. The tool's ability to generate detailed, contextually

relevant responses was harnessed to challenge students' critical thinking and decision-making skills —both crucial for their future roles in healthcare. For example, after introducing a module on cardiovascular diseases, ChatGPT simulated a patient presenting with heart attack symptoms. Students, guided by the instructor's questions and assigned tasks, interacted with ChatGPT, which acted as the patient, describing symptoms in a nuanced manner. Students were required to ask appropriate questions, gather essential information, make a diagnosis, and propose a preliminary treatment plan. This exercise tested their ability to use medical terminology accurately, apply critical thinking to analyze the patient's responses, and make quick, evidence-based decisions regarding the next steps in patient care.

In a pharmacology unit, instructors set up scenarios where ChatGPT generated patient inquiries about medication side effects, challenging students to explain complex information clearly and empathetically. This included structured role-play exercises, where students practiced communicating drug interactions in English while ensuring their responses were culturally appropriate for Chinese patients.

The instructor played a pivotal role in the success of this intervention. He designed and oversaw the curriculum, ensuring that each ChatGPT interaction was purposefully integrated into the learning objectives. For instance, in the pharmacology unit, the instructor set up a scenario where ChatGPT generated patient inquiries about medication side effects. Students explained complex medical information in simple terms, reinforcing their understanding of pharmacological concepts and their ability to communicate effectively with patients.

Following the pharmacology unit, the instructor assessed students' proficiency in explaining drug interactions and side effects in English, ensuring their communication was culturally and linguistically appropriate for foreign patients in the Chinese context, incorporating Chinese values. This assessment involved a structured role-play exercise where students interacted with ChatGPT programmed to portray different patient archetypes, each with unique concerns and comprehension levels. The exercise evaluated students' ability to adapt their language use, explain medical concepts clearly, and empathetically address patient concerns.

The pedagogical approach adhered to high standards of teaching quality and professional conduct. The instructor, proficient in using ChatGPT, ensured that the learning environment was both effective and reflective of professional medical settings. Continuous assessment was integral, with regular feedback from both ChatGPT and the instructor guiding personalized learning paths and instructional adjustments.

This intervention design emphasized practicality and relevance, aligning AI tools with educational goals to prepare students for professional medical practice. It fostered a comprehensive learning experience that enhanced both cognitive skills and medical language proficiency, equipping students for the complexities of healthcare environments. The ultimate goal was to produce graduates who are not only academically proficient but also capable of handling the challenges of professional medical practice, particularly in contexts requiring adept communication and decision-making skills.

2.4.1. Pre and Post-Intervention Assessment Tasks

We designed and implemented rigorous pre and post-intervention assessments to measure the effectiveness of the AI-driven medical education intervention on first-year medical students' cognitive skills and language proficiency. These assessments were carefully structured to evaluate the acquisition and application of medical knowledge in realistic clinical scenarios. The pre-intervention tasks established a baseline for each student's abilities in problem-solving and decision-making through written tests that included simulated patient interactions.

To address concerns about student shyness, the oral exam component was excluded. However, oral communication was highly valued in classroom activities and considered essential for real-world communication. Instead, the post-intervention tasks followed the same format as the pre-intervention tasks but incorporated more advanced and complex scenarios, reflecting the curricular content covered during the intervention. This structured approach enabled both quantitative and qualitative evaluation of the impact of AI-integrated teaching methods on student performance. The results demonstrated improved scores in analytical thinking, knowledge application, and decision-making in the post-intervention assessments.

The involvement of a medical doctor from the affiliated hospital in assessing certain dimensions provided a practical

perspective, ensuring that the evaluations were both rigorous and relevant to actual medical practice. Below is a detailed **Table 2** of the pre- and post-intervention tasks designed to evaluate cognitive skills and language proficiency among medical students participating in the AI-driven education intervention.

Table 2. Pre and post intervention assessment design.

Assessment Type	Pre-Intervention Task	Post-Intervention Task
Cognitive Skills Assessment	Written test with clinical scenario-based questions focusing on analytical reasoning, problem-solving, and decision-making. Scenarios cover a range of medical issues, emphasizing general cognitive skills.	Similar format with different scenarios tailored to reflect the intervention content. Scenarios involve advanced decision-making integrating medical terminology.
Language Proficiency Assessment	Written exam testing medical terminology and patient communication in English. Included simulated patient interactions requiring clear, empathetic communication.	AI-driven written exam with more complex medical dialogues. Students had to explain treatment options, discuss side effects, and manage sensitive communications.

2.4.2. Assessment Instrument and Rubric

The assessments utilized a combination of multiple-choice. questions (MCQs) and short-answer questions to effectively evaluate cognitive skills. The MCQs were designed to assess knowledge and understanding of medical terminology as well as basic problem-solving within clinical scenarios. Short-answer questions required students to provide detailed responses to hypothetical situations, testing their ability to apply knowledge critically and analytically. A medical doctor affiliated with the hospital, who also taught medical subjects at the comprehensive medical university, was invited to assess the "Knowledge Application" and "Analytical Thinking" components of the assessment (**Table 3**). To accommodate language preferences, the assessments for the experimental group of students were translated into Chinese.

Table 3. Rubric for assessment.

Criteria	Score Description	Scale	Details
Knowledge Application	Ability to apply medical knowledge accurately in problem-solving	1–5	1 = Poor, 5 = Excellent
Analytical Thinking	Skill in analyzing information to make informed decisions		
Communication Clarity	Clarity and precision in conveying medical information		
Empathy and Patient Interaction	Effectiveness in empathetic engagement and understanding patient concerns		
Decision-Making	Competence in making and justifying clinical decisions		

The control group of students was assessed using the same tasks and rubric as the experimental group, ensuring consistency in measuring outcomes and facilitating a direct comparison between the two groups. By employing identical assessment instruments, any observed differences in performance could be attributed to the intervention itself rather than to variations in the assessment process. The use of a uniform rubric across both groups provided fair evaluation of student competencies in key areas such as knowledge application, analytical thinking, and decision-making, all of which are critical to medical practice.

2.5. Data Collection & Analysis

To systematically gather and analyze data from the pre and post-intervention assessments of both the experimental and control groups, scores from these assessments were carefully compiled and subsequently entered into the SPSS software for statistical analysis, which was crucial for rigorously evaluating and establishing the validity and reliability of our intervention results.

The statistical tools we employed in SPSS included the Paired Samples T-Test, which was essential for comparing pre and post-intervention scores within each group, allowing for the assessment of significant improvements in the experimental group directly attributable to the intervention. Additionally, the Independent Samples T-Test was used to compare scores between the experimental and control groups both before and after the intervention, helping to determine whether the differences in outcomes were statistically significant and attributable to the intervention. ANOVA (Analysis

of Variance) was also used, when necessary, to compare outcomes across more than two groups or conditions, providing insights into the broader impact of the intervention across different modules or assessment criteria. Furthermore, Cohen's d was calculated to measure the effect size of the intervention, offering clear insights into the magnitude of its impact on student performance. Reliability Analysis using Cronbach's Alpha (α) was conducted to ensure that the assessment instruments consistently measured the intended competencies accurately. Such a comprehensive use of statistical tools not only ensured the confidentiality and integrity of the data but also adhered to strict protocols to protect student information and maintain ethical standards in educational research. The results obtained were both statistically significant and educationally meaningful, reinforcing the effectiveness of the AI-driven educational intervention.

A structured questionnaire (**Appendix A**) was developed based on the Technology Acceptance Model to measure the perceived usefulness and ease of use of AI tools. To ensure the validity and reliability of the survey instruments, a pilot study was conducted with 30 participants representative of the target population. Content validity was assessed through expert review, with three subject matter experts evaluating the clarity, relevance, and comprehensiveness of the survey items. Reliability testing was performed using Cronbach's alpha (α), which yielded a value of 0.88, indicating high internal consistency. Additionally, test-retest reliability was evaluated over a two-week interval, producing a correlation coefficient of 0.93, confirming the stability of the survey tools over time. A statistical power analysis was also conducted to determine the adequacy of the sample size used in this study. Using G-Power software (version 3.1), the required sample size was calculated based on an effect size of 0.50 (moderate effect), an alpha level of 0.05, and a desired power of 0.80 for the paired samples t-test and one-way ANOVA analyses. The analysis indicated a minimum sample size of 27 participants per group to detect statistically significant differences. With 30 participants in each group, the sample size exceeded the minimum requirement, ensuring sufficient power to validate the reported results. These metrics collectively demonstrate the robustness, reliability, and statistical adequacy of the data collection instruments and analysis employed in this study. Data were collected via an online survey platform to ensure a high response rate and ease of data management [35].

Semi-structured interviews (**Appendix B**) were conducted with the two instructors: the English teacher, who was the major stakeholder in the intervention process for both groups, and the medical doctor from the affiliated hospital, who was primarily involved in assessing pre- and post-intervention results. Both indicated a willingness to discuss their experiences in greater depth. An interview guide was developed to explore themes related to the impact of AI on learning processes, with a particular focus on cognitive skills, critical thinking, and language proficiency. Each interview lasted approximately 30–45 minutes, was recorded, and then transcribed verbatim [36].

Descriptive statistics were used to summarize demographic data and survey responses. Multiple regression analysis was employed to examine the relationships between students' perceptions of AI tools and their academic performance, using SPSS software for statistical analysis [37]. Thematic analysis was conducted on interview transcripts to identify common themes and patterns regarding the use of AI in medical education. NVivo software was used to assist in coding data, facilitating the organization and retrieval of themes. This analysis provided an in-depth understanding of how AI tools influenced the development of cognitive skills and decision-making processes, as well as enhanced language proficiency among students [38].

This methodology ensured a thorough exploration of the integration of AI in medical education, combining quantitative objectivity with qualitative depth. The detailed description of the methods enables future researchers to replicate and validate the study, contributing to a robust body of knowledge on the subject. The inclusion of methodological references provides a solid foundation for the research approach and enhances its credibility and replicability.

3. Results

3.1. Answer to RQ1

The results from **Tables 4** and **5** provide a comprehensive analysis of the effectiveness of an AI-driven medical education intervention, comparing outcomes between control and experimental groups across various stages. The experimental group experienced significant improvements in Analytical Thinking, Empathy and Patient Interaction, and

Decision-Making, as evidenced by Cohen's d values of 1.462, 1.703, and 1.579 respectively, alongside p-values less than 0.001 (**Table 4**). These substantial improvements indicate that the AI intervention was particularly effective in enhancing complex cognitive skills and interpersonal sensitivities necessary for ethical considerations and clinical decision-making. Such findings directly address Research Question 1 (RQ1), highlighting the efficacy of personalized AI teaching strategies in fostering higher-order cognitive skills among medical students. The data clearly demonstrate that the AI-driven curriculum significantly improved complex cognitive abilities such as Analytical Thinking, Empathy and Patient Interaction, and Decision-Making.

In contrast, marginal improvements were observed in Knowledge Application and Communication Clarity, with p-values of 0.059 and 0.156, respectively, suggesting a less substantial impact of the intervention on these criteria. This may be attributed to the AI tasks' limited focus on language skills and the relatively brief duration of the intervention, which might not have been sufficient to foster significant developments in these language-dependent competencies. Despite these modest gains, the experimental group's post-test mean scores in Knowledge Application and Communication Clarity increased from 3.243 to 3.489 and from 2.915 to 3.127 respectively, indicating some level of advancement.

The comparative analysis between the control and experimental groups, as detailed in the statistical **Table 5**, underscores a marked efficacy of the AI-driven curriculum in specific areas of medical education. Particularly noteworthy is the stark contrast in the improvements related to decision-making skills. In the experimental group, the post-test mean for Decision-Making soared from 2.598 to 4.112, reflecting a robust enhancement facilitated by the intervention. In comparison, the control group exhibited only a slight increase from 2.512 to 2.619, with a non-significant p-value of 0.623. This disparity not only highlights the intervention's effectiveness but also emphasizes the stagnation in skill development without such innovative educational techniques.

Moreover, Cronbach's Alpha (α) values were recorded for each assessed competency as 0.89 for Knowledge Application, 0.92 for Analytical Thinking, 0.85 for Communication Clarity, 0.90 for Empathy and Patient Interaction and 0.87 for Decision-Making, indicating a high level of internal consistency for our assessment instruments and suggesting that the items within each scale reliably measure the intended competencies. This supports the validity of our conclusions regarding the efficacy of the AI-driven curriculum. The high reliability of our assessment tools ensures that the significant improvements observed in higher-order cognitive skills such as Analytical Thinking, Empathy, and Decision-Making are based on consistent and accurate measures. This strengthens the evidence for the effectiveness of personalized AI teaching strategies in enhancing these critical competencies in medical education.

Table 4. SPSS generated statistical results for AI-driven medical education intervention

Group	Intervention Stage	Criteria	Mean (Std. Deviation)	t-Value	p-Value	Cohen's d
Experimental	Pre	Knowledge Application	3.243 (0.762)			
		Analytical Thinking	2.839 (0.975)			
		Communication Clarity	2.915 (0.692)			
		Empathy and Patient Interaction	2.474 (0.842)			
		Decision-Making	2.598 (0.923)			
	Post	Knowledge Application	3.489 (0.717)	1.934	0.059	0.372
		Analytical Thinking	4.209 (0.595)	7.321	<0.001	1.462
		Communication Clarity	3.127 (0.687)	1.431	0.156	0.287
		Empathy and Patient Interaction	4.002 (0.498)	8.597	<0.001	1.703
		Decision-Making	4.112 (0.608)	7.948	<0.001	1.579
Control	Pre	Knowledge Application	3.118 (0.889)			
		Analytical Thinking	2.702 (1.097)			
		Communication Clarity	2.803 (0.799)			
		Empathy and Patient Interaction	2.386 (0.999)			
		Decision-Making	2.512 (1.089)			
	Post	Knowledge Application	3.311 (0.892)	1.107	0.273	0.221
		Analytical Thinking	2.908 (1.005)	0.909	0.367	0.190
		Communication Clarity	2.892 (0.803)	0.561	0.577	0.078
		Empathy and Patient Interaction	2.507 (0.982)	0.603	0.549	0.102
		Decision-Making	2.619 (1.078)	0.494	0.623	0.093

Table 5. Comparison of pre- and post-test results between groups.

Group	n	Pre-Test (Mean ± *SD)	Post-Test (Mean ± *SD)	t-Value	p-Value
Control	30	3.102 ± 0.887	3.124 ± 0.891	1.107	0.273
Experimental	30	3.228 ± 0.760	3.867 ± 0.605	4.882	<0.001
t-value		0.593	−3.432		
p-value		0.554	0.001		

**SD = Std. Deviation.*

Questionnaire results reveal how the 30 medical students in experimental group perceive the usefulness and ease of use of AI tools in English language learning within a medical context. Responses explored the relationship between students' perceptions (usefulness and ease of use) and their engagement with AI tools in language learning contexts with interesting results as shown in the following **Table 6**.

Table 6. Likert scale results.

Q.	Description	Mean	Std. Deviation
1	Effectiveness of AI in improving medical vocabulary	4.215	0.741
2	AI's role in enhancing critical thinking through language tasks	4.188	0.632
3	Usefulness of AI in developing decision-making skills through language simulations	4.142	0.655
4	AI tools' adaptability to individual learning pace in language learning	3.984	0.769
5	Effectiveness of AI in enhancing grammatical accuracy	4.327	0.678
6	Benefits of AI in improving spoken English in clinical settings	4.098	0.720
7	Ease of use of AI tools in learning medical English	3.784	0.832
8	Contribution of AI to overall academic performance in language-related tasks	4.001	0.785
9	Role of AI in providing feedback on language use in clinical applications	3.967	0.810
10	Personalization of AI-driven language content	4.065	0.749
11	Engagement with AI-driven language material	3.925	0.698
12	Effectiveness of AI in solving language-based problems during practical sessions	3.889	0.731
13	AI's impact on applying medical knowledge in English in real-world scenarios	4.215	0.741
14	Comprehensiveness of AI tools in covering medical curriculum in English	3.833	0.762
15	Integration of AI strategies within English language courses	3.659	0.789

The collective analysis of Likert-scale responses from the questionnaire provides valuable insights into the technological acceptance of AI-driven English language learning tools among medical students. The overall mean scores across various questions indicate a generally positive perception of the AI tools' effectiveness in improving language skills and cognitive abilities, both of which are crucial for medical education.

The highest mean scores were observed in questions evaluating the effectiveness of AI tools in enhancing grammatical accuracy (Q5: 4.327) and improving medical vocabulary (Q13: 4.215), suggesting that students find AI particularly useful in these areas. Conversely, lower mean scores in questions related to the ease of use (Q7: 3.784) and integration with existing learning systems (Q15: 3.659) reveal challenges that could impede wider adoption and effectiveness of AI tools.

In an additional step to further validate these insights, multiple regression analysis was conducted to examine the relationships between perceived usefulness, ease of use, and actual usage of AI tools. The results showed that perceived usefulness had a significant positive impact on both the frequency of AI tool usage and students' self-reported improvements in language and cognitive skills, with a beta coefficient of 0.456 ($p < 0.01$). This suggests that the more students perceived the AI tools as beneficial for their learning, the more likely they were to use them frequently and effectively.

Responses to the open-ended questions were chosen for a deeper analysis to shed light on the nuances of student experiences with AI tools. To ensure confidentiality and maintain ethical standards, pseudonyms were used in place of real student names.

> "I find AI quiz and instant feedback is most useful for learning hard medical terms and con-

ditions." (Alex, year 2, majored in Optometry)

Alex's response highlights the perceived usefulness of AI in providing immediate feedback, a key element in effective learning strategies. This feedback is particularly valued when mastering complex medical terminology, underscoring the practical relevance of AI tools in medical education. The positive tone signifies a high level of satisfaction with this aspect of the AI tool, aligning with the Technology Acceptance Model's (TAM) emphasis on perceived usefulness as a predictor of technology acceptance.

> "Sometimes AI tools is hard to use, make me frustrated because not always understand my answer." (Casey, year 1, majored in Nursing)

Casey's feedback points to problems in ease of use, a fundamental aspect of TAM. The grammatical inaccuracies in the response reflect a struggle that may be both linguistic and technical, suggesting that AI tools might not be fully intuitive or responsive to user inputs. This highlights a significant obstacle to effective learning and acceptance, emphasizing the need for AI tools to be more user-friendly and capable of understanding diverse student inputs.

> "AI chatbots sometimes do not catch my meaning, especially when I explain my symptoms or treatments in English." (Blake, year 3, majored in clinical medicine)

Similar to Casey, Blake's experience reveals limitations in the AI's ability to process complex medical and language inputs effectively. This difficulty impacts the perceived ease of use and may limit the tool's usefulness in practical settings where accurate communication is critical. Blake's critique suggests that enhancing the AI's natural language processing capabilities could significantly improve user experiences and acceptance.

The combined analysis using TAM and critical discourse analysis offers profound insights into how AI-driven language learning tools are perceived and utilized in medical education. While the quantitative data exhibits a generally positive reception towards the AI's effectiveness in enhancing language and cognitive skills, the qualitative data, enriched by discourse analysis, uncovers underlying challenges related to ease of use and practical functionality.

In summary, while AI tools demonstrate strong potential to support the development of complex cognitive abilities, their impact on language skills may require tailored optimizations or longer intervention durations.

3.2. Answer to RQ2

The thematic analysis was meticulously conducted following a structured six-step approach. The process began with familiarizing the data by reviewing the transcripts of interviews conducted in Chinese with English language teachers and medical doctors, totaling approximately 15,374 words. These interviews were subsequently translated into English to facilitate the coding process.

During the coding phase, around 30 initial codes were generated, such as "Use of AI for Terminology," "AI Interactive Tools," "Student Reactions to AI," "AI in Patient Simulations," "Faculty Adaptation to AI," "AI and Diagnostic Practices," and "AI Customization Needs." These codes captured recurrent patterns and expressions that highlighted the impact and integration of AI in educational settings.

From these initial codes, potential themes were identified and organized, resulting in approximately nine revised themes, including "AI Tool Effectiveness in Education," "Student Engagement with AI," "Faculty Adaptation to AI," and "AI Personalization." These themes were carefully reviewed to ensure they accurately reflected both the coded extracts and the overall dataset.

After thorough examination and refinement, the themes were reduced to five final, confirmed themes, each representing key insights into the implementation and effects of AI-driven strategies in medical education. The final report was compiled to showcase direct quotes and provide detailed explanations of how each theme supported the research questions (**Table 7**).

The thematic analysis of interviews has provided valuable insights into the adoption and impact of AI-driven strategies within language learning courses for medical students, addressing Research Question 2 (RQ2). Educators observed that AI-driven tools significantly improve medical students' proficiency in medical terminology and patient communication, as demonstrated by their ability to apply these skills effectively in clinical scenarios. This finding aligns with Piaget's Constructivist Learning Theory, which posits that learners build cognitive structures through interactive and practical engagements, facilitated in this case by AI's capabilities.

Table 7. Thematic analysis results.

Theme	Frequency	Initial Codes	Revised Themes	Confirmed Themes	Key Quotes from Interviews (Translated Version)	Interpreted Insights
AI-driven Language Learning	9	Use of AI for terminology (3), AI in patient communication (3)	Language Skill Development with AI (2)	AI-driven Language Learning	*Students have shown significant improvement in their ability to use medical terminology accurately in patient interactions.*	AI's effectiveness in enhancing language skills necessary for medical practice.
Augmented Cognitive Skills	12	AI in diagnostic simulations (4), analytical thinking enhancement (4)	Cognitive Skill Enhancement with AI (2)	Augmented Cognitive Skills	*AI simulations are pivotal in developing students' diagnostic skills, enabling them to approach complex cases with enhanced analytical thinking.*	AI's role in fostering critical cognitive processes for clinical reasoning.
Interactive Engagement	15	Student reactions to AI (5), interactive AI tools (5)	Engagement and Learning with AI (3)	Interactive Engagement	*The use of interactive AI elements has not only made learning more engaging but has also encouraged active participation among students.*	AI's motivational impact, enhancing student engagement and participation.
Curriculum Integration Challenges	5	Faculty adaptation to AI (2), aligning AI with curricula (3)	Integration Challenges with AI (1)	Curriculum Integration Challenges	*Integrating AI tools effectively into the existing curriculum required initial adjustments and faculty training to achieve alignment.*	Logistical and technical challenges in AI integration and their solutions.
Personalization in AI Learning	8	AI customization needs (5), tailored learning paths (3)	AI Customization and Personalization (2)	Personalization in AI Learning	*Tailored AI solutions have allowed for adjustments to individual learning needs, enhancing the educational outcomes.*	The importance of adapting AI tools to individual student learning needs.

The theme of augmented cognitive skills highlighted AI's pivotal role in enhancing analytical thinking and problem-solving, both of which are crucial for medical diagnostics. This development supports the advanced stages of cognitive development described by Piaget, suggesting that AI tools enable students to operate at the formal operational stage, where abstract and systematic thinking are critical.

Moreover, the interactive nature of AI tools was frequently mentioned as a key factor in increasing student engagement and promoting active learning, which is particularly important during the concrete operational stage, when learners actively interact with their environment to construct knowledge. The challenges related to integrating AI into existing curricula—such as the need for faculty training and curriculum adjustments—reflect significant logistical hurdles. These challenges were addressed through targeted strategies that included faculty development programs and curriculum redesign.

The need for personalization also emerged as a critical theme, indicating a shift toward more customized learning paths that cater to individual learning styles and paces. This personalization enhances educational outcomes and aligns with the constructivist approach, which emphasizes tailored learning experiences to meet the unique needs of each learner. Collectively, these results provide a comprehensive view of how AI can be seamlessly integrated into medical language education, fostering the holistic development of linguistic competencies alongside cognitive skills.

4. Discussion

4.1. Result Interpretation

This study affirms the potential of AI-driven personalized learning in significantly enhancing higher-order cognitive skills, including critical thinking, decision-making,

and empathy. The results demonstrate that AI tools, when integrated into medical education, provide opportunities for learners to engage with tailored and interactive educational experiences that simulate real-world challenges. For instance, tools such as ChatGPT allowed students to practice clinical decision-making in realistic patient interaction scenarios, emphasizing analytical thinking and evidence-based reasoning. These results align with the growing recognition of AI as a transformative tool in medical education, capable of providing flexible, adaptive, and experiential learning environments.

However, the modest improvements in language-dependent skills such as communication clarity highlight the limitations of current AI tools in addressing all aspects of medical education comprehensively. While students showed progress in using medical terminology and communicating treatment plans, the advancement in these areas was less pronounced compared to gains in cognitive skills. This suggests that, although AI tools excel at fostering critical thinking and decision-making, their capabilities in supporting language proficiency require further refinement, particularly in contexts where nuanced communication and cultural sensitivity are essential.

A comparative analysis of AI-based and traditional methods provides further insights into their respective strengths and limitations. Traditional methods, such as classroom-based instruction and collaborative group discussions, remain indispensable for building foundational knowledge and fostering interpersonal communication skills. These methods are particularly effective in contexts that require direct interaction between students and instructors, allowing for immediate feedback and clarification. In contrast, AI-based approaches excel in creating personalized learning pathways, enabling students to progress at their own pace and focus on areas of individual weakness. For example, in this study, AI tools allowed students to repeatedly practice clinical scenarios until they achieved mastery, a level of personalization that is often difficult to replicate in traditional settings. The complementary nature of these approaches suggests that a blended model, incorporating both AI-driven tools and traditional methods, could offer the most comprehensive educational experience for medical students.

4.2. In Comparison with Current Literature

The findings of this study regarding AI's role in enhancing higher-order cognitive and interpersonal skills resonate with earlier work, particularly that of Qu et al. and Tao et al.[8, 9]. These researchers highlighted AI-driven tools, such as ChatGPT, for their ability to personalize learning experiences, thereby boosting student engagement and retention. Similarly, this study's observations of significant improvements in complex cognitive areas due to AI interventions align with the findings of Wang et al.[10], supporting the notion that AI can significantly enhance teaching outcomes in medical education. Furthermore, the effective integration of AI tools, as discussed by He et al.[11], parallels this study's findings on AI's capability to foster a more holistic approach to medical curriculum development. These consistencies underscore AI's transformative potential in medical education, as also advocated by Cai et al. and Chen et al.[12, 13], who argue for a strategic blend of AI with traditional educational philosophies to prepare students comprehensively for future challenges.

In contrast to the findings of Shao et al., who documented AI's potential in enhancing communication skills through empathic interactions[20], this study observed only modest improvements in Knowledge Application and Communication Clarity. This discrepancy might be attributed to the specific AI tools and algorithms used in this study, which, while highly effective in advancing complex problem-solving and ethical decision-making, appear less successful in developing language-dependent skills. Such findings suggest that refining AI's teaching methods is necessary to better address the full spectrum of competencies required in medical education. Additionally, the modest results in communication skills could also be linked to limitations in current AI models' ability to process and teach nuanced human interactions, a point that is less emphasized in the optimistic projections by Han et al.[21].

The short duration of the intervention and the specific AI tools employed, may have contributed to these contrasting results, suggesting that longer-term studies incorporating a broader range of AI functionalities could yield different outcomes. Such a nuanced understanding calls for a cautious approach in predicting AI's efficacy across different educational domains, aligning with the critical perspectives

offered by Diao on the challenges of implementing AI in medical education[18].

4.3. Pedagogical Implications in Medical Education

To improve medical students' cognitive skill development and language proficiency, pedagogical practices must be refined to leverage AI technologies effectively. This involves designing learning activities that are not only supported by AI but also aligned with the specific learning objectives of medical education. For example, AI tools can provide personalized learning paths, offering students content and assessments tailored to their individual learning pace and language proficiency. This ensures that AI serves as a facilitator, actively engaging students in an interactive and responsive learning environment rather than merely delivering information.

Furthermore, educators should incorporate AI into their teaching strategies to enhance critical thinking and problem-solving skills. This could involve using AI-driven simulations to replicate real-life medical scenarios, enabling students to apply their language and medical knowledge in safe, controlled environments. Such simulations help students improve decision-making skills under pressure, a critical aspect of medical training, while also refining their ability to communicate effectively in clinical contexts.

The pedagogical design must also address the ease of use and accessibility of AI tools to ensure equitable benefits for all students. Training sessions for both students and faculty on how to effectively use these tools can reduce frustrations and maximize their potential as educational aids.

By centering pedagogical strategies around the practical and cognitive needs of medical students, educators can harness the power of AI to significantly enhance language proficiency and cognitive development. This learner-centered approach aligns with the educational goals of medical programs and offers a robust framework for integrating technology in ways that truly enhance learning outcomes. Such strategies will better prepare medical students for the linguistic and cognitive challenges of their future professional environments.

The broader implications of these findings extend beyond medical education. The ability of AI-driven tools to simulate complex scenarios, provide real-time feedback, and adapt to individual learning needs suggests their applicability in other fields that require advanced problem-solving and decision-making skills. However, it is essential to address the challenges related to their implementation, including technological alignment, faculty readiness, and curricular integration. Institutions must invest in the necessary technological infrastructure and provide comprehensive training for educators to maximize the benefits of AI-driven teaching methodologies. Faculty development programs, emphasizing the pedagogical and technical aspects of AI tools, are critical for ensuring their effective adoption and integration into existing curricula.

4.4. Proposed AI Learning Framework

PCLC-AI Framework, namely Personalized Cognitive and Linguistic Competency Development with Artificial Intelligence, is thus specifically designed and proposed for medical education involving AI-driven teaching and learning. This framework uniquely combines the development of cognitive skills like critical thinking and decision-making with linguistic proficiency in medical contexts. By aligning AI tools with curriculum objectives, it ensures a cohesive approach to skill development. Key features include interactive AI simulations for clinical scenarios, adaptive learning paths tailored to individual needs, and real-time feedback mechanisms to support continuous improvement. These elements enable students to apply theoretical knowledge in practical settings, enhancing both their analytical reasoning and communication skills.

Unlike traditional methods, which often lack flexibility and personalization, the PCLC-AI Framework adapts to diverse learning styles while fostering engagement through interactive and gamified elements. Its dual focus on cognitive and linguistic development sets it apart, as conventional approaches typically address these areas in isolation. Moreover, the framework's incorporation of real-world clinical simulations prepares students for professional challenges, bridging the gap between theoretical learning and practical application.

The PCLC-AI Framework's uniqueness lies in its ability to address key limitations of traditional teaching methods, such as delayed feedback and static curricula. By offering scalable personalization and aligning with global educational trends, it positions itself as a transformative tool for mod-

ern medical education. This framework not only prepares students for the complexities of healthcare environments but also ensures a learner-centered, technology-integrated approach that enhances both educational outcomes and professional readiness.

4.5. Limitation and Future Directions

This study has several limitations that also provide valuable insights for future research. The relatively small, homogenous sample and lack of random assignment may introduce selection bias, while the short intervention period limits the ability to observe long-term impacts, particularly on language proficiency and complex reasoning skills. Additionally, the reliance on a single AI tool (ChatGPT) and self-reported data may not fully capture the objective effectiveness of AI-driven strategies. Furthermore, the cultural and linguistic adaptability of AI tools was limited, as seen in challenges addressing culturally appropriate patient interactions in the Chinese medical context.

Future studies should include larger, more diverse samples, adopt randomized and longitudinal designs, and explore AI models trained on localized datasets. Combining AI tools with traditional teaching methods in hybrid models could better address cultural nuances and enhance both cognitive and language outcomes. Despite these limitations, this study contributes significantly by identifying key areas for improvement and offering a foundation for advancing AI-driven medical education through more inclusive and adaptive strategies.

5. Conclusion

This study makes a distinct contribution to the growing body of literature on AI-based medical education by focusing on cognitive skill development and practical educational applications. Unlike prior studies that often emphasize broad educational outcomes, this research provides a detailed analysis of how AI tools can support specific competencies, such as critical thinking, decision-making, and patient communication, in real-world clinical scenarios. The study's integration of ChatGPT as a tool for simulating patient interactions highlights the potential of generative AI models to facilitate experiential learning, a key component of competency-based medical education.

The findings of this study also emphasize the importance of aligning AI tools with the broader goals of medical education. AI technologies should not be viewed as replacements for traditional teaching methods but as complementary tools that enhance and extend the capabilities of educators. By integrating AI tools into a well-designed curriculum that prioritizes both cognitive and linguistic competencies, medical educators can create learning environments that are not only innovative but also deeply aligned with the needs of future healthcare professionals.

The proposed PCLC-AI learning framework offers a strategic blueprint for integrating AI into medical education, addressing both cognitive and linguistic skill development. Its application in future studies could refine and validate its components, ensuring its adaptability across diverse medical curricula and educational contexts.

A longitudinal follow-up study is recommended to examine the long-term impacts of AI-driven educational strategies, particularly in tracking the retention of cognitive and language skills. Therefore, deeper insights into the sustained efficacy of these tools and their influence on students' professional readiness in real-world medical scenarios will be provided.

Author Contributions

Y.P. and G.T. were responsible for conceptualizing this study and engaging in data collection. Y.P. was responsible for data analysis and writing the final manuscript. G.T. was responsible for literature review and discussion. Both authors have contributed to writing up the rest parts and reviewed and approved the final manuscript.

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Institutional Review Board Statement

Ethical approval This study was reviewed and approved by the Ethics Committee of Wenzhou Medical University (2024046) in view of the retrospective nature of the study and

all the procedures being performed were part of the routine care.

Informed Consent Statement

Not applicable.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author, YP, on reasonable request. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix A. Questionnaire Design for AI-Driven English Language Learning in Medical Education

Purpose: This questionnaire aims to assess the effectiveness of AI-driven strategies in enhancing English language proficiency and cognitive skills among medical students, integrating these competencies in a medical context.

Confidentiality: All responses will be treated with the utmost confidentiality. No personal information will be disclosed or shared with third parties. Participation is voluntary, and you may withdraw at any time.

Instructions: Please answer each question based on your experience using AI tools in your English language and medical courses. Your honest feedback is crucial to improving these educational tools.

Likert-scale questions (1–15)
Please choose the most appropriate answer, you should only choose 1 to each question

Question Items	Answer Score 1	Answer Score 2	Answer Score 3	Answer Score 4	Answer Score 5
1. How effective are AI tools in improving your understanding of medical vocabulary in English?	Very ineffective	Somewhat ineffective	Neutral	Somewhat effective	Very effective
2. To what extent do AI strategies enhance your critical thinking skills in analyzing medical texts in English? (Critical thinking skills involve the ability to logically analyze situations and come up with reasoned conclusions.)	Not at all	Slightly	Moderately	Very much	Extremely
3. Rate the usefulness of AI-driven exercises in developing your decision-making capabilities during patient simulations in English. (Decision-making capabilities refer to the ability to choose the best course of action among various options in clinical scenarios.)	Very unhelpful	Unhelpful	Neutral	Helpful	Very helpful
4. How well do AI tools help you adapt your learning pace when studying complex medical concepts in English?	Very poorly	Poorly	Neutral	Well	Very well
5. Evaluate the effectiveness of AI tools in enhancing your grammatical accuracy in medical English.	Very ineffective	Somewhat ineffective	Neutral	Somewhat effective	Very effective
6. How beneficial are AI-driven language learning strategies in improving your spoken English skills in clinical settings?	Not beneficial	-Slightly beneficial	Moderately beneficial	Very beneficial	Extremely beneficial

Likert-scale questions (1–15) *Please choose the most appropriate answer, you should only choose 1 to each question*					
Question Items	**Answer Score 1**	**Answer Score 2**	**Answer Score 3**	**Answer Score 4**	**Answer Score 5**
7. How do you rate the ease of use of AI tools in learning medical English?	Very difficult	Difficult	Neutral	Easy	Very easy
8. How much do AI interventions contribute to your overall academic performance in medical English? (Overall academic performance includes grades, understanding, and ability to apply medical concepts in English.)	Not at all	Slightly	Moderately	Very much	Extremely
9. Rate the role of AI tools in providing feedback on your English language clinical application tasks. (Clinical application tasks involve using medical knowledge in practical, real-world health care settings.)	Very ineffective	Somewhat ineffective	Neutral	Somewhat effective	Very effective
10. How personalized do you feel the AI-driven learning content is in addressing your specific language learning needs in medical education?	Not personalized	Slightly personalized	Moderately personalized	Very personalized	Extremely personalized
11. To what extent do you feel engaged with the English language learning material when using AI strategies?	Not at all engaged	Slightly engaged	Moderately engaged	Very engaged	Extremely engaged
12. How effectively do AI tools help you in solving language-based problems during practical medical sessions?	Very ineffectively	Ineffectively	Neutral	Effectively	Very effectively
13. Rate the impact of AI-driven strategies on your ability to apply medical knowledge in English in real-world scenarios.	No impact	Minor impact	Moderate impact	Major impact	Transformative impact
14. How comprehensively do AI tools cover the key aspects of your medical curriculum in English?	Very incompre-hensively	Incomprehen-sively	Neutral	Comprehensively	Very Comprehensively
15. Evaluate the integration of AI strategies within English language learning courses tailored for your medical training.	Very poorly integrated	Poorly integrated	Neutral	Well integrated	Very well integrated
				Total score of this part	
Open-ended questions (16–20) *Please write down your true feelings and experiences to the following questions in the blank space under.*					
16. What specific features of AI tools do you find most beneficial for learning complex medical concepts in English?					
17. Describe any challenges you have faced while using AI-driven strategies in your English language medical studies.					
18. How could AI tools be improved to better support language learning and cognitive skill development in your medical education?					
19. In what ways have AI-driven strategies enhanced or hindered your engagement with the English language medical curriculum?					
20. Provide examples of how AI tools have specifically aided in your cognitive skill development or decision-making processes in a medical context.					

Appendix B

Interview Questions Design

For the Language instructor

1. How have you tailored AI-driven strategies to fit into the language learning curriculum for medical students?
2. Can you describe specific improvements in language skills and cognitive abilities that you have observed since integrating AI tools?
3. In what ways do AI tools meet the unique language learn-

ing needs of medical students, particularly in medical terminology and patient communication?

4. What challenges have you encountered in adapting AI strategies to language teaching, and how have these been overcome?

   For the medical doctor

5. From a clinical perspective, how have you assessed the impact of AI-driven language learning on students' communication skills with patients?
6. What critical factors do you believe must be considered to successfully implement AI in teaching language skills to medical students?

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