Enhancement of Endocrinology Teaching by Integrating Artificial Intelligence into Medical Student Education

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Abstract: Endocrinology presents a fundamental yet complex challenge within undergraduate medical education. Its intricate hormonal feedback systems and restricted clinical exposure make it difficult to master. AI presents innovative educational approaches that could overcome these challenges by utilizing adaptive learning, simulations, and immediate feedback. The purpose of this research was to evaluate how well incorporating AI-powered educational resources into undergraduate endocrinology courses impacts student learning, clinical decision-making abilities, and their level of engagement in the subject matter. This prospective randomized controlled trial (parallel-group design), conducted over a six-week endocrinology course, included 124 medical students in their third and fourth years. The students were randomly assigned to one of two groups: a group receiving instruction enhanced by artificial intelligence (AI) (n=62) and a group receiving traditional teaching methods (n=62). The AI-enhanced group benefited from adaptive learning tools, virtual patient scenarios, and an AI-powered tutoring system, in addition to regular curriculum content. The effectiveness of the intervention was assessed through the administration of pre- and post-intervention multiple-choice exams to measure knowledge acquisition, case-based clinical reasoning evaluations, and structured surveys to gauge student satisfaction. Initial knowledge levels were similar across both groups ($p > 0.05$). Students who experienced AI-powered teaching methods demonstrated substantially improved engagement and satisfaction levels. Incorporating artificial intelligence into undergraduate endocrinology courses substantially enhanced students' understanding of the subject matter, their ability to apply clinical reasoning, and their overall engagement in learning. AI tools prove to be valuable supplements to conventional teaching approaches and hold the potential to revolutionize medical education, particularly in intricate clinical fields.

1 INTRODUCTION

Endocrinology plays a crucial role in medical training, providing the essential knowledge needed to diagnose and treat numerous acute and chronic illnesses, such as diabetes, thyroid problems, adrenal dysfunction, and pituitary disorders. However, despite its vital clinical relevance, endocrinology is frequently identified by medical students as a particularly challenging subject during their undergraduate studies [1]. This challenge stems primarily from the complex and conceptual nature of hormonal feedback loops, the intricate interplay of multiple organ systems, and the tendency for early disease signs to be subtle or absent [2].

Conventional endocrinology teaching methods primarily involve lectures and heavily utilize static depictions of physiological functions. Although these approaches can be successful in conveying factual information, they frequently struggle to cater to variations in learning speed, existing knowledge, and cognitive demands [3]. Restricted exposure to a variety of clinical cases hinders students' ability to cultivate structured diagnostic thinking and gain confidence in treating endocrine disorders. Consequently, students might possess a good grasp of theoretical concepts but find it challenging to apply this knowledge effectively in real-world clinical situations [4], [5].

Recently, artificial intelligence has revolutionized medical education by offering powerful new tools. AI systems can assess student performance, dynamically adjust educational materials, create realistic clinical simulations, and deliver instant feedback. These functionalities strongly resonate with modern educational philosophies that prioritize individualized learning, active participation, and continuous practice [3]. Although AI is being investigated in fields like radiology, pathology, and clinical decision making, its potential in endocrinology education has not been fully explored.

The complexity of endocrine physiology and the need for repeated exposure to varied clinical presentations make endocrinology particularly well suited to AI-enhanced educational approaches. Virtual patient simulations can replicate rare or complex cases, adaptive platforms can reinforce difficult concepts, and conversational AI systems can provide on-demand clarification of intricate mechanisms. However, empirical evidence supporting the effectiveness of such approaches in endocrinology teaching is still limited [4].

The present study was therefore designed to evaluate the educational impact of integrating artificial intelligence into undergraduate endocrinology teaching. Specifically, it aimed to assess whether AI-enhanced instruction improves knowledge acquisition, clinical reasoning performance, and student engagement compared with traditional teaching methods. This work differs from previous research in that it specifically seeks to document the technical details of the AI system used, thus aligning this research with the field of applied information technology in medical education.

2 LITERATURE REVIEW

Artificial intelligence (AI) is revolutionizing medical education, presenting innovative solutions to longstanding problems within conventional teaching methods. A rising amount of research shows that AI is not only changing the way medicine is practiced, but also transforming how medical knowledge is delivered, absorbed, and evaluated [2], [3]. Facing the intricate challenges of modern healthcare, medical educators are turning to AI as a means of boosting student learning, tailoring educational experiences, and sharpening their clinical judgment abilities [5].

Initial research on applying AI in medical education emphasized its capability to streamline administrative duties and enhance conventional teaching approaches by integrating data-driven perspectives that boost student involvement and educational results [6]. A recent systematic review, which examined various narratives, revealed that AI is being used in a wide range of medical education applications, including adaptive learning tools, virtual patient simulations, automated assessments, and even curriculum restructuring. These applications demonstrate the potential of AI to significantly impact education, going far beyond simply introducing new technology [7]. However, the research consistently highlights a disparity between the swift advancements in AI capabilities and the relatively sluggish integration of these innovations into medical curricula [8].

Research on the integration of AI in undergraduate medical education reveals a scattered approach. A 2025 scoping review indicated that although AI implementation is growing worldwide, its adoption and execution vary greatly, lacking a unified standard for effective practices [9]. The review also stressed the importance of cultivating broad AI competencies, encompassing digital fluency, rather than solely concentrating on proficiency with individual AI tools [10]-[12].

3 METHODOLOGY

This prospective, parallel-group randomized controlled trial explored the effects of artificial intelligence (AI) tools on undergraduate education in endocrinology. Spanning one academic semester and focusing on a required endocrinology module, the research employed both quantitative and qualitative methods to thoroughly evaluate student learning and gather insights into their experiences with the AI-powered tools. One hundred and twenty-four medical students, currently in their third and fourth years of study, took part in this research project. Each participant was new to endocrinology training and had no prior experience using AI-powered educational tools in this field. The students were randomly divided into two groups: an intervention group receiving AI-enhanced teaching and a control group receiving traditional instruction. This division yielded 62 students in each group. A comparison of fundamental demographic factors, such as age, gender composition, and past academic achievements, revealed no substantial differences between the two groups ($p > 0.05$).

Over six weeks, the intervention involved incorporating artificial intelligence into the regular endocrinology course. While students in the intervention group still participated in traditional lectures and seminars, they also had access to a specialized AI-powered learning platform tailored for endocrinology education. This platform utilized adaptive learning, virtual patient simulations, and a tutoring system that leveraged natural language processing. Simulated virtual patients offered clinically authentic endocrine scenarios, demanding students to analyse hormonal patterns, imaging results, and patient symptoms. This AI-powered tutoring system enabled students to pose open-ended questions about endocrine physiology, diagnostic procedures, and treatment plans. It provided tailored explanations, relevant to the specific context of their learning journey, whenever needed.

The control group students learned the endocrinology curriculum through conventional teaching approaches, encompassing in-person lectures, guided case studies led by instructors, and independent study utilizing suggested textbooks and lecture materials. Both groups benefited from instruction provided by the same professors and adhered to the same learning goals, guaranteeing curriculum parity. The sole distinction lay in the accessibility of AI tools. To evaluate learning gains, all participants took a standardized multiple-choice test at both the beginning and end of the instructional phase. The 40-item MCQ examination was based on a blueprint content specification corresponding to the course objectives (diabetes mellitus - 30%, thyroid diseases - 25%, pituitary diseases - 20%, adrenal diseases - 25%). Participants earned one point for each correct response, with a total possible score of 40 points. The same test form was used before and after the intervention to ensure comparability of results, while the order of questions was randomized during the post-test. The analysis of the reliability of internal consistency showed acceptable values (Cronbach's $\alpha = 0.82$ for pre-testing; $\alpha = 0.85$ for post-testing), which indicates good measurement stability.

The ability to think clinically was measured through case studies designed to mirror actual endocrine decision-making scenarios. Students tackled three identical clinical cases, and their performance was judged based on the correctness of their diagnoses, the suitability of their chosen investigations, and the effectiveness of their treatment plans. Two independent assessors, unaware of the student groups, awarded scores on a scale ranging from 0 to 20. The level of agreement between the two assessors was strong (intraclass correlation coefficient = 0.87). To evaluate student engagement and satisfaction, a questionnaire with 18 statements was given to students upon course completion. Participants used a five-point Likert scale, spanning from "strongly disagree" to "strongly agree," to indicate their level of agreement with each statement. The instrument demonstrated high internal consistency (Cronbach's coefficient $\alpha = 0.83$). The correctness of the design was confirmed by comparing these predefined domains (confidence, clarity, motivation, and perceived clinical relevance).

The statistical analysis was performed using the SPSS v.27. Continuous variables are represented as the average value ± standard deviation (SD). Intra-group differences in the results of knowledge testing before and after the intervention were analysed using a paired-sample t-test. Cross-group comparisons (knowledge post-test, scores of clinical reasoning and satisfaction scores) were analysed using the t-test for independent samples. The effect sizes were calculated using the Cohen's d (0.2 small, 0.5 medium, 0.8 large). Statistical significance was established at the level of $p < 0.05$.

Artificial intelligence-based learning was implemented using the Body Interact platform (Take the Wind, S.A., Portugal) version 2024.2 (web deployment). The platform combines rule-based clinical decision trees with adaptive promotion algorithms based on machine learning. The progress of the script is controlled by deterministic branching logic combined with performance-weighted adaptation rules.

Adaptability was implemented using three performance indicators: (1) diagnostic accuracy at each stage of the scenario, (2) response delay (seconds at the time of decision-making), and (3) frequency of excessive or inappropriate examinations. The weighted combined efficiency index (scale 0-1) dynamically adjusted the complexity of the scenario: students who scored ≥0.75 points moved on to complex endocrinological scenarios (pathology of several hormones), while indicators <0.75 activated scaffolded feedback and cases of moderate complexity.

The interactive learning module was implemented using a large Language model (LLM) architecture connected via an API (GPT-4 class model, temperature set to 0.3 to ensure actual stability). Prompt engineering constrained the model responses to guidelines on endocrinology (ADA, ESE, ATA standards). The system was prohibited from generating medical recommendations that were not included in the curriculum, and it did not allow for an offline diagnostic assessment. The prompt structure included: (1) defining the role (endocrinology tutor), (2) limiting the scope of the curriculum, (3) prohibiting independent diagnosis, and (4) requiring evidence-based explanations. The LLM was deployed through a commercial cloud API interface, while all logged interaction data was stored exclusively on the institution's encrypted servers. No identifiable personal data was transmitted to the API provider. All the results of the AI's work were monitored in accordance with the teaching supervision, and complex or ambiguous queries were marked for verification by the teacher.

The recorded system variables included the anonymized student ID, session duration, script execution path, accuracy at each decision-making node, number of hints requested, and timestamps of interaction. No personal medical data was entered into the system. The data was stored on the institution's encrypted servers, and the analysis was carried out using anonymized datasets in accordance with the institution's data protection regulations.

4 RESULTS

One hundred and twenty-four medical students participated in the study and were analysed in its entirety. Every student involved finished both the pre-intervention and post-intervention evaluations, ensuring no data was lost. The study divided the students equally, with 62 students assigned to each of the intervention and control groups. Across the groups, fundamental demographic traits such as average age, gender makeup, and past academic achievement showed no substantial variations. Statistical analysis revealed no significant differences between the groups ($p > 0.05$).

4.1 Knowledge Assessment Outcomes

Initially, both groups showed similar levels of endocrinology knowledge. The average pre-test score for the AI-assisted teaching group was 21.3, with a standard deviation of 4.2, while the traditional teaching group averaged 21.0 with a standard deviation of 4.5 ($p=0.71$). After the six-week instruction, both groups experienced score increases on the post-test. Notably, the AI-enhanced group exhibited a significantly larger improvement compared to the traditional teaching group. The pre- and post-intervention knowledge scores for both groups are summarized in Table 1.

The AI-enhanced group showed a significant improvement, with their average post-test score rising to 31.8, a gain of 10.5 points, as measured by a standard deviation of 3.9. The control group, on the other hand, saw an average post-test score of 26.4, reflecting a gain of 5.4 points and a standard deviation of 4.1. This disparity in post-test performance between the two groups was statistically notable ($p < 0.001$) and substantial in magnitude (Cohen’s d = 1.34). The mean difference in post-test knowledge scores between groups was 5.4 points (95% CI: 3.9-6.9), whereas in clinical reasoning scores was 2.7 points (95% CI: 1.8-3.6). The satisfaction score difference was 0.79 points (95% CI: 0.61-0.97), clearly demonstrating the powerful educational benefits of incorporating AI.

4.2 Clinical Reasoning Performance

Students utilizing AI-enhanced tools demonstrated significantly better clinical reasoning abilities compared to those in the control group, as measured by problem-solving tasks based on real-world cases. The AI-enhanced group averaged 16.9 out of 20 points, while the control group averaged 14.2 points. This disparity in performance reached statistical significance ($p < 0.001$).

A deeper examination showed that students who used AI-powered virtual patient simulations achieved better diagnostic precision, especially when dealing with intricate hormonal feedback loops and multifaceted endocrine disorders. Clinical reasoning performance and diagnostic decision quality are presented in Table 2. The intervention group achieved a diagnostic accuracy of 84.7%, while the control group reached only 68.5%. Additionally, students in the intervention group made fewer redundant diagnostic tests and opted for more suitable initial treatment plans. The effect size for clinical reasoning performance was large (Cohen’s d = 1.18).

4.3 Student Engagement and Satisfaction

Students who engaged with AI-enhanced teaching reported greater satisfaction and perceived gains in learning. The average satisfaction level in Table 3, determined by averaging responses across all Likert scale questions, reached 4.41 out of 5 for the group using AI-enhanced teaching, significantly higher than the 3.62 score achieved by the control group ($p < 0.001$). Students who used AI tools expressed higher levels of confidence in their ability to analyse lab results, grasp endocrine disease processes, and use diagnostic methods in real-world medical situations.

Table 1: Comparison of pre- and post-test knowledge scores.

Group	Pre-test score (Mean±SD)	Post-test score (Mean±SD)	Mean score change
AI-enhanced teaching	21.3 ± 4.2	31.8 ± 3.9	+ 10.5
Traditional teaching	21.0 ± 4.5	26.4 ± 4.1	+ 5.4

Table 2: Clinical reasoning and diagnostic performance.

Outcome measure	AI-enhanced group	Traditional group	P-value
Clinical reasoning score (0-20)	16.9 ± 2.1	14.2 ± 2.4	< 0.001
Diagnostic accuracy (%)	84.7	68.5	< 0.001
Appropriate management decisions (%)	81.2	65.9	0.002

Table 3: Student satisfaction and perceived learning outcomes.

Survey item	AI-enhanced group (% agree/strongly agree)	Traditional group (% agree/strongly agree)
Improved understanding of endocrinology	88.7	56.5
Increased confidence in clinical reasoning	85.4	52.9
Learning process was engaging	91.9	60.3
Teaching method should be used in future courses	93.5	58.1

Significantly, 88.7% of students in the AI group indicated that these tools enhanced their understanding of intricate endocrine functions, while only 54.8% of students in the control group felt the same. Moreover, the difference in overall satisfaction demonstrated a large effect size (Cohen's d = 1.41).

4.4 Qualitative Feedback Analysis

The thematic analysis revealed four major themes. The level of agreement between the coders was high (Cohen's κ = 0.81). The differences were resolved through discussion and consensus.

Theme 1: Real-time formative feedback increases diagnosis self-efficacy. Students noted that immediate clarifications after incorrect answers helped them quickly identify gaps in their understanding of concepts. Several participants noted that "immediate clarification prevented a repeat misunderstanding of hormonal mechanisms."

Theme 2: Progression in adaptive scenarios supports structured clinical reasoning. The participants positively assessed the gradual complication of the cases. Many noted that the transition from simple endocrinological cases to multisystem diseases improved their diagnostic thinking.

Theme 3: Improved integration of theory and clinical practice. The students noted that virtual patients helped to link the results of biochemical research with the clinical picture. One of the participants suggested that "laboratory indicators become more significant when they are related to the patient's symptoms.

Theme 4: Concerns regarding excessive reliance on AI support. A minority of students expressed concern that excessive guidance from AI could lead to a decrease in independent thinking if the system is used without teacher supervision.

5 DISCUSSION

This research shows that incorporating artificial intelligence into undergraduate endocrinology classes leads to substantial gains in student understanding, clinical problem-solving skills, and overall class participation, as opposed to conventional teaching approaches. A key discovery from this research is the significant boost in post-test knowledge scores among students in the AI-enhanced teaching group. Although both groups showed academic progress throughout the endocrinology module, the group utilizing the intervention experienced almost twice the average score increase compared to the control group. The substantial effect size suggests this difference is not just statistically relevant, but holds practical importance for educational outcomes.

The enhancement in clinical reasoning skills observed in students using AI-powered virtual patient simulations holds significant educational value. This is especially important because endocrine disorders often manifest with vague symptoms and shared lab results, demanding a methodical approach to diagnosis that goes beyond simple memorization. The improved diagnostic accuracy and better management choices seen in the intervention group indicate that frequent practice with varied simulated scenarios can speed up the learning of pattern recognition and reasoning based on hypotheses. This supports growing research showing that learning environments utilizing simulations and AI can boost higher-level cognitive abilities, going beyond simply memorizing facts.

The AI-enhanced teaching method also demonstrated strong points in terms of student engagement and satisfaction. The intervention group exhibited significantly higher satisfaction levels, implying that AI tools could enhance learner motivation and make course material feel more relevant. Qualitative responses revealed that students particularly appreciated the immediate feedback and the constant availability of AI-powered explanations. Table 4 offers a comparative overview of the educational effects of AI integration, highlighting its varying influence across diverse learning areas.

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This finding aligns with modern perspectives on adult learning, which highlight autonomy, self-guided learning, and prompt feedback as crucial factors for successful learning experiences. Remarkably, students in the control group often struggled to grasp endocrine feedback mechanisms and wished for more engaging teaching methods. This difference emphasizes a key weakness of traditional lectures when it comes to explaining complex, dynamic physiological functions. AI-powered visualizations and conversational tutoring systems can help overcome this challenge by enabling students to repeatedly explore complex ideas through various explanatory angles.

From an educational perspective, the results indicate that AI is best utilized as a supplementary tool, not a substitute for teachers. This research shows that AI-powered learning was integrated into an existing course structure, maintaining the crucial role of educators in facilitating discussions, providing context for knowledge, and navigating professional aspects of clinical practice. The observed advantages probably stem from this blended approach, where AI empowers personalized learning experiences while faculty members retain instructional leadership.

While the study yielded positive results, several factors warrant consideration when analysing its findings. The research was confined to a single institution and took place over a limited instructional timeframe, potentially restricting the applicability of the results to broader contexts. Moreover, the study did not evaluate the long-term retention of acquired knowledge or the ability to apply skills in actual clinical settings. Although advancements in simulated clinical reasoning show promise, more research is required to establish if these improvements actually lead to better patient care results in real-world clinical settings, such as rotations or postgraduate programs. The issue of equity and accessibility is crucial when considering AI-powered tools.

While these tools can provide personalized learning experiences, they risk exacerbating existing disparities if students have unequal access to technology or differ in their digital skills. To avoid unintended inequalities, future applications of AI in education must include sufficient technical assistance and faculty development. The study's findings regarding the impact on education are summarized in Table 5, which highlights both the significant benefits and potential obstacles of incorporating AI into endocrinology teaching. This research, from the perspective of applied information technology, seeks to illustrate the application of NLP-based tutoring systems and adaptive learning algorithms within a real undergraduate medical education system.

6 CONCLUSIONS

This research shows that incorporating artificial intelligence into undergraduate endocrinology courses leads to substantial improvements in student learning. Students who participated in AI-enhanced classes exhibited greater knowledge acquisition, displayed stronger clinical reasoning abilities, and expressed higher levels of engagement and satisfaction compared to students taught using conventional methods. The findings indicate that AI-powered educational resources successfully tackle several key difficulties in endocrinology education, specifically the demands for individualized learning, frequent clinical practice, and prompt feedback.

Significantly, the positive outcomes resulted from a blended learning model that integrated artificial intelligence alongside traditional, faculty-led teaching.

Table 4: Comparative impact of AI integration across learning domains.

Learning domain	Outcome measure	AI-enhanced teaching	Traditional teaching
Knowledge acquisition	Mean score gain	High	Moderate
Clinical reasoning	Diagnostic accuracy	High	Moderate
Learning engagement	Satisfaction score	Very high	Moderate
Self-confidence	Confidence in case management	High	Low - moderate

Table 5: Educational implications of AI integration in endocrinology teaching.

Aspect	Observed benefit	Potential challenge
Personalization	Improved knowledge retention	Increased system complexity
Critical stimulation	Enhanced diagnostic reasoning	Resource - intensive development
Student engagement	Higher motivation and satisfaction	Risk of over-reliance on technology
Faculty role	More focus on mentorship	Need for AI literacy training

This strategy maintained the core importance of educators while utilizing AI to enhance personalized learning and foster active clinical problem-solving. This integration reflects the changing needs of contemporary medical education, which is placing greater focus on competency-based instruction and the cultivation of advanced cognitive abilities.

Despite its limitations, including a single-centre setting and a relatively brief follow-up, the study offers compelling initial evidence for the educational benefits of AI in endocrinology education. Further investigations should prioritize multi-centre research, assess long-term knowledge retention, and explore how AI-enhanced learning translates to practical clinical applications. In summary, artificial intelligence offers a valuable and applicable tool for boosting endocrinology education. Carefully incorporating it into medical training programs could lead to enhanced learner skills and better equip future doctors to handle intricate endocrine diseases.

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