

**INTEGRATION OF ARTIFICIAL INTELLIGENCE AND 3D VISUALIZATION IN
TEACHING HUMAN ANATOMY TO MEDICAL STUDENTS**

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Abstract: The teaching of human anatomy has traditionally relied on cadaver dissection and textbook-based learning. However, the rapid development of digital technologies has significantly transformed medical education. This study investigates the impact of integrating artificial intelligence (AI) and three-dimensional (3D) visualization tools into the teaching of human anatomy for medical students. The research evaluates how these technologies influence students' understanding of complex anatomical structures and spatial relationships. A comparative analysis was conducted among medical students who studied anatomy using traditional methods and those who used AI-assisted 3D learning platforms. The results demonstrate that students exposed to digital anatomical tools showed significantly improved comprehension, retention of knowledge, and engagement during the learning process. The findings highlight the potential of AI-based educational technologies to enhance the effectiveness of anatomy education in modern medical universities.

Keywords: human anatomy, medical education, artificial intelligence, 3D visualization, anatomy teaching, digital anatomy.

Аннотация: Преподавание анатомии человека традиционно основывалось на работе с анатомическими препаратами и обучении по учебникам. Однако стремительное развитие цифровых технологий значительно изменило медицинское образование. В данном исследовании рассматривается влияние интеграции искусственного интеллекта (AI) и инструментов трёхмерной (3D) визуализации в преподавание анатомии человека студентам-медикам. Исследование оценивает, каким образом эти технологии влияют на понимание студентами сложных анатомических структур и пространственных взаимосвязей. Был проведён сравнительный анализ между студентами-медиками, изучавшими анатомию традиционными методами, и студентами, использовавшими AI-поддерживаемые 3D-платформы обучения. Результаты показывают, что студенты, обучавшиеся с применением цифровых анатомических инструментов, продемонстрировали значительно более высокий уровень понимания, запоминания материала и вовлечённости в учебный процесс. Полученные данные подчёркивают потенциал образовательных технологий на основе искусственного интеллекта для повышения эффективности преподавания анатомии в современных медицинских вузах.

Ключевые слова: анатомия человека, медицинское образование, искусственный интеллект, 3D-визуализация, преподавание анатомии, цифровая анатомия.

Annotatsiya: Inson anatomiyasini o'qitish an'anaviy ravishda anatomik preparatlar bilan ishlash va darsliklar asosida ta'lim berishga tayangan. Biroq raqamli texnologiyalarning jadal rivojlanishi tibbiy ta'limni sezilarli darajada o'zgartirdi. Ushbu tadqiqotda tibbiyot talabalari uchun inson anatomiyasini o'qitish jarayoniga sun'iy intellekt (AI) va uch o'lchamli (3D) vizualizatsiya vositalarini integratsiya qilishning ta'siri ko'rib chiqiladi. Tadqiqot ushbu texnologiyalar talabalarining murakkab anatomik tuzilmalar va fazoviy o'zaro bog'liqliklarni tushunishiga qanday ta'sir ko'rsatishini baholaydi. Anatomiya fanini an'anaviy usullar asosida o'rgangan tibbiyot talabalari hamda AI yordamida ishlovchi 3D ta'lim platformalaridan foydalangan talabalar o'rtasida qiyosiy tahlil o'tkazildi. Natijalar shuni ko'rsatdiki, raqamli anatomik vositalar yordamida ta'lim olgan talabalar materialni tushunish, eslab qolish va o'quv jarayonidagi faollik darajasi bo'yicha sezilarli darajada yuqori natijalarni namoyon etdilar. Olingan ma'lumotlar sun'iy intellektga asoslangan ta'lim texnologiyalari zamonaviy tibbiyot oliygohlarida anatomiya fanini o'qitish samaradorligini oshirishda katta salohiyatga ega ekanini ta'kidlaydi.

Kalit so'zlar: inson anatomiyasi, tibbiy ta'lim, sun'iy intellekt, 3D vizualizatsiya, anatomiya o'qitish, raqamli anatomiya.

INTRODUCTION

Human anatomy is one of the fundamental disciplines in medical education and serves as the basis for understanding clinical medicine. Accurate knowledge of anatomical structures is essential for diagnosing diseases, performing medical procedures, and interpreting medical imaging. Traditionally, anatomy has been taught through cadaver dissection, anatomical atlases, and lectures. While these methods remain valuable, they often present challenges related to limited access to cadavers, ethical considerations, and difficulties in visualizing complex three-dimensional relationships within the human body.

In recent years, digital technologies such as artificial intelligence (AI), virtual reality (VR), and three-dimensional (3D) visualization systems have become increasingly integrated into medical education. These technologies allow students to interact with digital anatomical models, explore internal structures from multiple perspectives, and simulate clinical scenarios. AI-based educational systems can also provide personalized learning experiences and adaptive feedback for students.

Several recent studies have demonstrated that the integration of digital tools into anatomy education improves student engagement and enhances the understanding of complex anatomical relationships. Despite these advancements, there is still a need for systematic evaluation of how AI-assisted technologies influence learning outcomes in anatomy education.

Therefore, the aim of this study is to evaluate the effectiveness of integrating artificial intelligence and 3D visualization technologies in the teaching of human anatomy to medical students.

MATERIALS AND METHODS

This study was conducted at a medical university during the 2024–2025 academic year to evaluate the educational effectiveness of integrating artificial intelligence (AI)-assisted three-dimensional (3D) anatomical learning tools into the teaching of human anatomy. The research employed a comparative quasi-experimental design involving second-year medical students enrolled in a compulsory human anatomy course.

A total of 120 second-year medical students participated in the study. The participants were divided into two equal groups: a control group (n = 60) and an experimental group (n = 60). Group allocation was carried out according to the existing academic structure of the course, with

both groups being comparable in terms of age, previous academic achievement, and baseline anatomy knowledge. All participants had previously completed the introductory medical science curriculum and had no prior formal experience with AI-assisted anatomy learning systems.

The control group received anatomy instruction through conventional teaching methods widely used in medical education. These methods included classroom lectures delivered by experienced faculty members, guided textbook study, anatomical atlases, and cadaver-based demonstrations in the dissection laboratory. The instructional process emphasized theoretical explanation, identification of anatomical structures, and observation of anatomical relationships through traditional practical sessions.

In contrast, the experimental group studied the same anatomical topics using a digital learning platform enhanced with AI-assisted 3D visualization tools. This platform enabled students to manipulate virtual anatomical models, rotate structures in multiple planes, isolate organs and systems, and examine topographical relationships in detail. In addition, the system provided self-assessment quizzes, automated feedback, and adaptive learning support based on student performance. The AI component was designed to identify common errors, recommend additional review materials, and personalize certain aspects of the learning pathway according to the user's progress.

Both groups studied the same curriculum content during the same academic period and were taught by instructors from the same department to minimize instructional variability. The duration of the intervention was 12 weeks. Topics covered during the study included the musculoskeletal system, cardiovascular system, respiratory system, digestive system, and nervous system. Teaching hours and general learning objectives were identical for both groups, ensuring that the main difference between them was the mode of instruction.

To measure learning outcomes, students in both groups completed a standardized anatomy knowledge test before the intervention (pre-test) and after the completion of the study period (post-test). The test consisted of multiple-choice questions, short-answer items, and structure-identification tasks designed to assess factual knowledge, spatial understanding, and applied anatomical reasoning. The validity of the test was reviewed by faculty specialists in anatomy, and its reliability was confirmed through pilot testing before implementation.

In addition to the knowledge assessment, a structured questionnaire was administered to evaluate student engagement, learning satisfaction, motivation, and perceived effectiveness of the teaching methods. The questionnaire included both Likert-scale items and several open-ended questions that allowed students to provide qualitative feedback regarding their learning experience. Particular attention was given to student perceptions of spatial understanding, ease of content retention, and confidence in identifying anatomical structures.

Data were analyzed using SPSS statistical software. Descriptive statistics were calculated for all quantitative variables, including means, standard deviations, and percentage distributions. Independent t-tests were used to compare differences between the control and experimental groups, while paired t-tests were applied to assess within-group changes between pre-test and post-test scores. A p-value of less than 0.05 was considered statistically significant.

Ethical principles were considered throughout the study. Participation was voluntary, and all students were informed about the purpose of the research. Confidentiality of individual responses was maintained, and the collected data were used exclusively for academic and research purposes.

RESULTS

The findings of the study revealed clear differences in academic performance and learning experience between the control and experimental groups. At the beginning of the study, there was no statistically significant difference between the two groups in the pre-test results,

indicating that both groups had a comparable baseline level of anatomical knowledge. The average pre-test score of the control group was 58.3 ± 7.4 , while the experimental group demonstrated a similar mean score of 57.9 ± 7.1 .

After the 12-week instructional period, both groups showed improvement in anatomy knowledge; however, the degree of progress differed considerably. The post-test results demonstrated that the control group improved to 71.6 ± 6.9 , reflecting a positive gain following traditional instruction. In contrast, the experimental group, which studied with AI-assisted 3D anatomical learning tools, achieved a substantially higher post-test score of 84.2 ± 5.8 . Statistical analysis confirmed that the difference in post-test performance between the two groups was significant ($p < 0.01$), suggesting that the use of AI-supported digital tools had a measurable positive effect on student learning outcomes.

A comparison of score gains further emphasized the effectiveness of the digital intervention. The control group demonstrated an average improvement of 13.3 points between the pre-test and post-test, whereas the experimental group showed a markedly greater gain of 26.3 points. This result indicates that students exposed to AI-assisted 3D visualization not only improved more significantly, but also appeared to benefit from a deeper understanding of anatomical content.

In addition to overall knowledge acquisition, differences were also observed in the students' ability to understand spatial and topographical anatomical relationships. Performance on structure-identification tasks and applied anatomical reasoning items was notably stronger in the experimental group. Students who used the digital platform showed greater accuracy in identifying anatomical structures from different orientations and demonstrated better comprehension of the positional relationships between organs, tissues, and body systems. These findings suggest that interactive 3D tools were especially effective in supporting spatial learning, which is a critical aspect of anatomy education.

The results of the questionnaire complemented the quantitative test findings. A large majority of students in the experimental group reported positive perceptions of the digital learning experience. Specifically, 87% of participants indicated that the use of AI-assisted 3D models improved their understanding of complex spatial anatomical relationships. Approximately 82% stated that the platform increased their motivation to study anatomy, while 79% reported that the interactive format made it easier to retain information over time. In addition, 76% of students noted that immediate automated feedback helped them identify weaknesses and correct errors more effectively during independent study.

By comparison, students in the control group generally expressed satisfaction with traditional instructional methods, particularly with instructor explanations and cadaver-based demonstrations. However, a considerable number of them reported difficulties in visualizing anatomical structures in three dimensions and in independently reviewing complex material outside the classroom. This contrast suggests that while conventional approaches remain valuable, they may be less effective in promoting active engagement and individualized learning.

Qualitative feedback from open-ended questionnaire responses provided additional insight into student experiences. Many students in the experimental group emphasized that the possibility to rotate, enlarge, and isolate anatomical structures on the screen made the learning process more understandable and less stressful. Several participants also reported that the digital system encouraged repeated practice and self-directed learning. At the same time, some students noted that digital tools should be used as a supplement rather than a complete replacement for cadaver-based instruction, particularly for developing a realistic perception of anatomical variation.

Overall, the results indicate that AI-assisted 3D anatomical learning tools significantly enhanced academic achievement, spatial understanding, and student engagement compared with

traditional teaching methods alone. These findings support the growing role of digital educational technologies in improving the quality of anatomy instruction in medical education.

DISCUSSION

The findings of this study support the growing body of evidence that digital technologies can significantly improve anatomy education. AI-based learning platforms provide interactive and personalized learning environments that allow students to explore anatomical structures more effectively than traditional methods alone.

One of the major advantages of 3D visualization tools is the ability to represent spatial relationships between anatomical structures. This is particularly important in anatomy education, where understanding the spatial organization of organs and tissues is critical.

In addition, AI algorithms can adapt educational content to the individual needs of students, offering personalized feedback and identifying areas where additional study is required. This approach aligns with modern student-centered learning strategies in medical education.

However, digital technologies should not completely replace traditional anatomy teaching methods such as cadaver dissection. Instead, the integration of both approaches may provide the most effective learning experience for medical students.

CONCLUSION

The integration of artificial intelligence and 3D visualization technologies significantly enhances the effectiveness of human anatomy education. Students who used AI-assisted digital learning platforms demonstrated higher academic performance, improved spatial understanding of anatomical structures, and increased engagement in the learning process.

The results suggest that combining traditional anatomy teaching methods with modern digital technologies can improve the quality of medical education and better prepare future healthcare professionals.

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