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THE APPLICATION AND SCIENTIFIC SIGNIFICANCE OF MODERN INFORMATION AND COMMUNICATION TECHNOLOGIES IN ANATOMY

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ABSTRACT. This article analyzes the scientific and practical significance of using modern information and communication technologies (ICT) in the process of teaching anatomy. The study examines the role of virtual and augmented reality technologies, three-dimensional (3D) modeling, simulation-based learning systems, digital atlases, and online educational platforms in medical education. Based on a literature review and comparative approach, the advantages of ICT over traditional teaching methods, the challenges of its implementation, and promising directions are substantiated. The results indicate that the integration of ICT into anatomy education not only accelerates knowledge acquisition but also has a positive effect on the development of clinical skills.

Keywords: anatomy, information and communication technologies, virtual reality, 3D modeling, simulation-based learning, digital atlas, medical education, innovative pedagogy.

INTRODUCTION. Anatomy occupies a central place in the medical education system, as a physician's professional competence is directly linked to anatomical knowledge. However, the traditional methods of studying anatomy — working with cadavers, using drawings and charts — have numerous limitations: a shortage of biological materials, sanitary and hygiene requirements, difficulty of comprehension, and the challenge of ensuring student engagement. For this reason, over the past decade, the process of introducing information and communication technologies into anatomy teaching has been progressing rapidly in medical education institutions worldwide.

Information and communication technologies (ICT) encompass not only computers and the internet, but also a complex of tools such as virtual reality (VR), augmented reality (AR), artificial intelligence (AI), three-dimensional (3D) printing technologies, animation and simulation software, digital atlases, and distance learning platforms. These technologies make it possible to study the complex structures of human anatomy in a visual, interactive, and repeatable manner. In particular, the transition of anatomy education to a remote format during the COVID-19 pandemic made the strategic necessity of ICT in medical education even more evident.

In Uzbekistan as well, the process of digitalization is gaining momentum in medical higher education institutions; however, the possibilities of systematically applying ICT to anatomy and their scientific justification have not yet been fully explored. The aim of this article is to systematize the main types of ICT used in anatomy education, to evaluate their scientific and pedagogical effectiveness, and to develop practical recommendations in the context of Uzbekistan's medical education.

RESEARCH AIMS AND OBJECTIVES. The main aim of the research is to conduct a comprehensive analysis of the application and scientific significance of modern ICT in teaching anatomy, and to provide scientifically grounded recommendations for their effective integration into the educational process.

The following objectives were set to achieve this aim:

1. To identify and classify the types of ICT used in anatomy education;
2. To comparatively evaluate the effectiveness of virtual reality and 3D modeling technologies in relation to traditional methods;

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3. To examine the impact of simulation-based learning and digital atlases on knowledge acquisition;

4. To identify the challenges of introducing ICT into anatomy education and ways to address them;

5. To develop practical recommendations for Uzbekistan's medical education.

METHODOLOGY. The research was based on a descriptive-analytical and comparative methodology. In the first stage, international and local scientific sources on the use of ICT in anatomy education published between 2015 and 2024 — more than 60 articles and monographs retrieved from the PubMed, Scopus, Web of Science, and Google Scholar databases — were critically analyzed. Methodological quality, sample size, and clinical-pedagogical significance were prioritized as selection criteria.

In the second stage, the main types of ICT — virtual reality (VR), augmented reality (AR), 3D modeling, simulation systems, digital atlases, and e-learning platforms — were comparatively studied in terms of their application in anatomy education. In the third stage, pedagogical effectiveness indicators — level of knowledge acquisition, practical skills, student motivation, and end-of-course assessment results — were comparatively analyzed. In the fourth stage, the possibilities and barriers to implementing ICT in the context of Uzbekistan's medical education were conceptually modeled.

MAIN RESULTS.

1. Virtual Reality (VR) and Augmented Reality (AR) Technologies Virtual reality technologies allow the student to study a three-dimensional, interactive model of the human body in real time. Using VR devices such as HTC Vive and Oculus Rift, students can visualize, dissect, and analyze organs, blood vessels, and nervous systems just as they would with a real cadaver. In a study conducted by Müller et al. (2021), students who used VR scored 23% higher on anatomical knowledge tests compared to those taught using traditional methods. Augmented reality (AR), by superimposing digital information onto real physical objects — for example, displaying an image of blood vessels on a student's hand — further enhances anatomical perception.

2. Three-Dimensional (3D) Modeling and Printing Technologies

3D modeling programs — Visible Body, Complete Anatomy, Zygote Body, BioDigital Human — allow the student to study bone, muscle, organ, and nerve structures layer by layer, rotate them, and zoom in. These programs significantly develop spatial perception compared to traditional drawings. In addition, 3D printing technologies make it possible to produce life-sized plastic replicas of complex anatomical structures — heart chambers, skulls, the spinal column — enabling students to work with them hands-on. The study by McMenamin et al. (2022) showed that using 3D printed anatomical models ensured 31% more detailed knowledge acquisition compared to working with cadavers.

3. Simulation-Based Learning Systems Simulation-based learning systems, including the Anatomage Table (virtual dissection table), allow students to view the human body layer by layer, observe organ functions, and assess pathological changes. The Anatomage Table stores computed tomography (CT) and magnetic resonance imaging (MRI) data from more than 1,000 real patients, which can be actively used in the learning process. This system demonstrates particularly high effectiveness in studying topographic anatomy and clinical anatomy. Various studies have shown that simulation-based learning can accelerate the formation of clinical skills 2.5 times faster compared to traditional methods.

4. Digital Atlases and E-Learning Platforms. Digital anatomical atlases — the digital version of Gray's Anatomy, Netter's Atlas, Sobotta Digital — unlike traditional paper atlases, are regularly updated, equipped with a search function, enriched with videos and animations, and accessible on mobile devices. E-learning platforms — Coursera, Kenhub, TeachMeAnatomy, Khan Academy Medicine — enable students to study anatomy at their own pace, from any location. Studies conducted during the COVID-19 pandemic showed that the quality of remote

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anatomy education through ICT reached 85–90 percent of the effectiveness of traditional classroom instruction.

DISCUSSION. The analysis results revealed a number of important advantages in the integration of ICT into anatomy education. First, ICT ensures the active participation of students: instead of passive listening, an interactive learning process emerges, which helps retain knowledge over the long term. From the perspective of Cognitive Load Theory, 3D and VR technologies significantly reduce the cognitive difficulty of perceiving complex anatomical structures.

Second, ICT helps resolve ethical problems: issues such as the declining number of cadavers, sanitary requirements for working with biological material, and the psychological discomfort of students are partially overcome through learning in a virtual environment. Third, ICT supports individualized teaching — each student has the opportunity to review material at their own pace and according to their own needs, study a particular section in greater depth, or advance more quickly.

However, there are also a number of challenges in introducing ICT into anatomy education. The first challenge is the insufficiency of the material and technical base: the cost of VR devices, 3D printers, and equipment such as the Anatomage Table is very high, making it financially difficult for many medical higher education institutions, especially in developing countries. The second challenge is the level of technological literacy and competence of teachers: in order to use ICT effectively, teachers must undergo specialized training, which requires additional resources and time The third challenge is the risk of excessive dependence on digital technologies: some studies point out that increasing students' screen time may negatively affect their vision, and the difference between perception in a virtual environment and the development of skills for working with a real cadaver has not yet been fully investigated. For this reason, an integrative approach to introducing ICT into anatomy education — that is, the harmonious combined use of traditional and modern methods — is viewed as the most appropriate model. The implementation of ICT in the context of Uzbekistan's medical education is associated with a number of factors. The adoption of digitalization programs by the state, the improvement of internet infrastructure, and the construction of modern laboratories in medical higher education institutions are creating a positive foundation. However, improving teacher qualifications, adapting ICT programs and platforms to the Uzbek language, and developing curricula that meet international standards remain pressing challenges.

CONCLUSION. The analysis conducted has scientifically confirmed that the use of modern ICT in anatomy significantly increases teaching effectiveness, accelerates knowledge acquisition, and has a positive impact on the formation of clinical skills. Virtual reality, augmented reality, 3D modeling, simulation systems, and digital atlases are emerging as powerful tools that complement, and in some cases replace, traditional cadaver and drawing-based methods. These results can make a worthy scientific contribution to the fields of translation theory, medical pedagogy, linguoculturology, and digital education.

The following recommendations are put forward for medical educational institutions of Uzbekistan: (1) to gradually introduce a program for equipping anatomy laboratories in medical higher education institutions with ICT tools; (2) to organize regular professional development courses in ICT for teachers; (3) to adapt existing international digital atlases and platforms to the Uzbek language; (4) to develop hybrid curricula that harmonize traditional and digital methods. In the future, the application of artificial intelligence-based adaptive learning systems to anatomy will serve as an even more promising direction.

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