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EVOLUTION OF TEACHING AND LEARNING THROUGH TECHNOLOGY

ВЛИЯНИЕ ТЕХНОЛОГИЙ НА РАЗВИТИЕ ОБРАЗОВАНИЯ

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Digital technologies integration into clinical training of medical students: tools and methodological solutions

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Abstract. *Problem statement*. The dissonance between the pace of technological advancement in clinical practice and the relative stasis of traditional medical pedagogy represents a critical challenge. The classical model, built upon lectures, textbook-centric learning and practical sessions, reveals significant limitations in preparing graduates for a digitally healthcare system. While these methods have historically formed the basis of medical training, they are increasingly insufficient for cultivating the dynamic, complex competencies – data-driven decision-making, virtual patient interaction, digital applications. *Methodology*. For the formation of subject competencies priority should be given to teaching using the Digital Medical Educational Environment, which must include modern technologies: interactive anatomical atlases, augmented and virtual reality technologies, platforms or applications for working with extensive databases of real clinical cases, AI-powered expert systems that guide students through differential diagnosis, various medical devices and others. *Results.* The authors prove that the classical model of medical education with its primary reliance on lecture-based instruction and time-bound practical sessions is increasingly inappropriate for cultivating the dynamic skill set required in the modern digital clinic. To bridge this growing competency gap the intentional design and implementation of a comprehensive Digital Medical Educational Environment is offered. This environment should function not as an auxiliary layer but as the fundamental "digital skeleton" of the entire educational process. The authors explore the pedagogical imperatives, architectural principles and systematic classification of digital tools required to build an integrated Digital Medical Educational Environment capable of systematically fostering clinical thinking and preparing future physicians for the complexities of 21st-century medicine. *Conclusion.* The gradual and discipline-specific integration of digital tools – from

interactive atlases and simulators to specialized clinical applications – into a unified Digital Medical Educational Environment provides the foundation for training medical students in both basic and specialized departments at medical schools. This environment offers unlimited opportunities for access to modern clinical knowledge during their studies in basic and specialized departments and during their internships, practical training and future career.

Keywords: digital tools, digital medical educational environment, informatization of education, interactive atlases, virtual reality, simulators, expert systems, clinical department, medical university

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Интеграция цифровых образовательных технологий в клиническую подготовку студентов-медиков: инструментарий и методические решения

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Аннотация. *Постановка проблемы*. Несоответствие между темпами технологического прогресса в клинической практике и относительной статичностью традиционной медицинской педагогики представляет серьезную проблему. Классическая модель, основанная на лекциях, практических занятиях, обучении по учебникам, демонстрирует существенные ограничения в подготовке выпускников к работе в цифровой системе здравоохранения. Хотя эти методы исторически составляли основу медицинского образования, они все чаще оказываются недостаточными для формирования динамичных сложных компетенций, таких как принятие решений на основе медицинских данных, виртуальное взаимодействие с пациентами и работа с цифровыми приложениями. *Методология.* Для формирования предметных компетенций студентов приоритет следует отдавать обучению с использованием цифровой медицинской образовательной среды, которая должна включать современные технологии: интерактивные анатомические атласы с дополненной и виртуальной реальностью, платформы или приложения для работы с обширными базами данных реальных клинических случаев, экспертные системы на основе искусственного интеллекта, помогающие студентам в дифференциальной диагностике, различные медицинские приборы и др. *Результаты.* Авторы доказывают, что классическая модель медицинского образования, в первую очередь опирающаяся на лекционный формат обучения и ограниченные по времени практические занятия, становится все менее подходящей для развития динамичного набора навыков, необходимых в современной цифровой клинике. Для преодоления этого растущего дефицита компетенций предлагается целенаправленное проектирование и внедрение комплексной цифровой медицинской образовательной среды, которая должна функционировать не как вспомо-

гательный слой, а как фундаментальный «цифровой скелет» всего образовательного процесса. Исследуются педагогические императивы, архитектурные принципы и систематическая классификация цифровых инструментов, необходимых для создания интегрированной цифровой медицинской образовательной среды, способной систематически развивать клиническое мышление и готовить будущих врачей к сложностям медицины XXI в. *Заключение.* Постепенная и целенаправленная интеграция цифровых инструментов – от интерактивных атласов и симуляторов до специализированных клинических приложений – в единую цифровую медицинскую образовательную среду обеспечивает основу для обучения студентов-медиков как на базовых, так и на клинических кафедрах медицинских вузов. Такая среда предоставляет неограниченные возможности студентам для доступа к современным клиническим знаниям во время обучения на базовых и профильных кафедрах, а также в процессе прохождения учебной и производственной практики и в будущей профессиональной деятельности.

Ключевые слова: цифровые инструменты, цифровая медицинская образовательная среда, информатизация образования, интерактивные атласы, виртуальная реальность, симуляторы, экспертные системы, клиническая кафедра, медицинский университет

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Problem statement. The dissonance between the pace of technological advancement in clinical practice and the relative stasis of traditional medical pedagogy represents a critical challenge. The classical model, built upon lectures, textbook-centric learning, and practical sessions reveals significant limitations in preparing graduates for a digitally healthcare system. While these methods have historically formed the basis of medical training, they are increasingly insufficient for cultivating the dynamic, complex competencies – data-driven decision-making, virtual patient interaction, digital applications.

The chaotic use of information technologies in the educational process does not lead to increase learning efficiency. The solution to this challenge is a creation of a *digital medical environment*, which used not just as an addition, but as a kind of "digital skeleton" of all the entire educational process. Such an environment must be used from the first year of education of students till a graduation, including educational practice and practice in medical institutions [1–4].

For a medical university, such a digital environment is a multicomponent system that combines simulation equipment, expert systems, electronic databases of clinical cases, telemedicine platforms, learning management systems and special digital tools in one system. The analysis of the effectiveness of the integration of these components and their impact on the formation of clinical thinking of future doctors is the central task of modern didactics of higher medical education. Here the centrality of medical ethics and deontology should be concerned: digital tools

must be designed to foster empathy, ethical discernment and patient-centered communication, ensuring that technological proficiency does not come at the expense of humanistic care.

Of course, the Digital Medical Educational Environment must obliterate the boundaries between the university campus and different clinical establishments (hospitals, outpatient clinics), ensuring continuity of learning and mentorship across physical spaces. Moreover, students and future doctors can use the Digital Medical Educational Environment at practice and during educational process. As a result, the using of the Digital Environment focuses on lifelong learning: the platform must instill the habits and provide the tools for continuous professional development, preparing graduates for a career of constant knowledge renewal and adaptation to future technologies.

Methodology. The construction of the Digital Medical Educational Environment requires a systematic approach grounded in the principle of pedagogical expediency rather than technological fashion. The key criterion for selecting any digital tool is its demonstrable efficacy in solving specific tasks of clinical specialist training. This moves the discourse from a simple inventory of available technologies to the deliberate design of an integrated system where each element is logically and purposefully woven into the process of professional development.

For the formation of robust *subject competencies*, priority should be given to teaching using specialized software, such as: interactive anatomical atlases with augmented and virtual reality (AR/VR) layers, platforms or applications for working with extensive databases of real clinical cases, AI-powered expert systems that guide students through differential diagnosis, various medical devices and others.

For the development of *practical and psychomotor skills of medical students* the integration of hardware and software systems is critical, including high-fidelity virtual and haptic surgical simulators, telemedicine platforms for supervised remote patient interactions, student performance monitoring systems that provide structured, automated error reports for deliberate practice.

Results and discussion. This research examined the digital tools utilized in the educational process at a medical university. This analysis proved the necessity for developing and using an integrated Digital Medical Educational Environment. The analysis of academic articles and researches showed that there are several definitions of the concept of digital tools such as “pedagogical software tools”, “computer-based learning tools”, and “electronic learning resources” and ect. For the purposes of this study the encompassing term “digital tools” will be used. To rationalize their selection and integration within the Digital Medical Educational Environment a methodological classification is essential. These digital tools can be categorized by their primary function [5–8]:

- electronic instructional and manuals – electronic textbooks, electronic manuals, interactive teaching aids;
- mathematical and simulation modeling tools – high-fidelity patient simulators, virtual laboratories for physiology, pathophysiology, microbiology, anatomy classes, mathematical modeling of disease progression;

- training and assessment tools – electronic learning systems for different medical disciplines (biology, histology, pharmacology, pediatrics, gynecology, ect.), tools for knowledge monitoring and automated skills assessment platforms;
- communication and collaborative tools – digital platforms for teleconferencing, distance mentoring and collaborative problem-solving among students and teachers across different locations;
- expert and intelligent systems – integrated automated training systems, expert systems providing diagnostic and treatment support and intelligent tutoring systems used for individual student learning trajectories;
- information and reference tools – electronic encyclopedias, information research systems and medical databases.

This taxonomy underscores that the Digital Medical Educational Environment is not a monolithic platform but a multi-layered, convergent ecosystem. Its power lies not in the isolated functionality of each tool, but in their synergistic interplay within a unified pedagogical framework. Taking into account the classification of digital tools by their methodological purpose, the educational electronic resources were analyzed used within the framework of computerization of the following disciplines, according to the curriculum in a medical university: anatomy / pathological anatomy, histology, normal physiology, microbiology, immunology, pathological physiology, urology, pharmacology, therapy, neurology, topographic anatomy and operative surgery, infectious diseases, ophthalmology, otolaryngology, pediatrics, anesthesiology, psychiatry, oncology (some examples are given in Table).

The integration of digital technologies into medical education represents a paradigm shift in pedagogical approaches, particularly evident in the curriculum containing the preclinical and clinical stages of education.

The medical students from the first till the third year of education get acquainted with interactive anatomical and pathology atlases because every future physician must have a perfect understanding of all anatomical structures. In histology classes students use microscope simulators, which significantly facilitates the educational process of teachers as purchasing expensive equipment is problematic for every student. In the microbiology course students learn microorganisms, cells, viruses, bacteria and study their 3D-models using applications. In their fourth to sixth-years medical students work with surgical simulators and 3D-atlases of medical instruments in surgery classes and in neurology they study brain structures using the 3D-Brain applications. In urology courses students use specialized atlases and educational portals, in the department of internal medicine they work with therapist's reference books and study the educational portal of the Association of Pediatricians in pediatrics classes.

During the initial three years, students study foundational biomedical sciences through interactive digital tools. In anatomy and pathology classes the traditional reliance on static textbook illustrations and cadaveric dissection is supplemented and often supplanted by interactive 3D-atlases. These platforms help students make

deconstruction and layered exploration of anatomical structures, from gross organ systems down to vasculature and innervation, fostering a superior understanding of spatial relationships [9–11].

Analysis of educational electronic resources of the Internet used in clinical departments of a medical university

Discipline	Digital tool	Type	Characteristics	Downsides
Anatomy / pathological anatomy	Interactive anatomy atlas	Educational	The students use interactive anatomical atlas to work with a 3D-model of the human body	Using this atlas students study skeletal system, cardiovascular system, muscular system, nervous system. But the main downside is absence of knowledge control
	Atlas of Pathology	Information and reference	The atlas is used as an auxiliary teaching tool in classes on pathological anatomy for students and teachers	A disadvantage of the atlas is the description of pathologies is given in English, which is inconvenient for Russian students
Histology	Microscope simulator Simpop	Imitation	The program emulates a real microscope, which allows viewing high-resolution histological images at all zoom levels	The program's content is quite limited. There is no control function for sudents
	Cells and their components Cell Biology	Educational	An application for studying 3D-models of animal and plant cells. The application tests students' knowledge through interactive tasks and quizzes	The study of animal and plant cells is only a topic within the General Microbiology section of the academic discipline, so the application is not in demand among students
Normal physiology, Pathological physiology	Physiology online	Educational	An additional resource for learning different topics in classes on normal physiology	There is no control function for students
Pharmacology	Encyclopedia of Medicines	Educational	An electronic resource for studying medicinal drugs and their use	The electronic resource is used in university classes and in practice in hospitals. But there is no control function for students

Source: compiled by Kristina S. Itinson.

Histology education is enhanced through virtual microscope simulators. These applications provide high-resolution annotated digital devices which mitigate significant logistical and financial constraints. These applications provide that all students can develop critical skills in tissue identification and pathological recognition without resource limitations.

In microbiology and virology classes students transcend two-dimensional textbook images by interacting with detailed 3D-models of microorganisms, viruses, and bacterial cells. Such applications enable the visualization of structural components and in advanced simulations even model mechanisms of pathogenesis and antibiotic interaction at a molecular level [12; 13].

The transition to clinical training marks an intensification in the use of high-fidelity simulation technologies. In surgery classes students utilize procedural simulators (ranging from basic laparoscopic trainers to virtual reality platforms) to practice instrument handling, triangulation and specific surgical techniques in a risk-free environment. Concurrently, they study from 3D-atlases of surgical instruments, which detail phases and anatomical considerations for various interventions.

Neurological sciences benefit immensely from applications like 3D-Brain, which offers an interactive layered exploration of neuroanatomy. Students can isolate specific nuclei, trace neural pathways, and correlate structural damage with clinical syndromes, thereby solidifying the complex link between neuroanatomy and clinical neurology [14–16].

Specialized disciplines employ targeted digital resources. In urology classes students access specialized digital atlases and educational portals (for example, Uroweb, European Association of Urology resources) featuring case studies, video libraries of endoscopic and surgical procedures and updated clinical guidelines. The department of internal medicine integrates digital therapeutic reference platforms (e.g., UpToDate, Dynamed) into training, teaching students evidence-based decision-making and differential diagnosis construction. In pediatrics classes the curriculum is supported by authoritative educational portals from professional associations (e.g., the American Academy of Pediatrics), which provide access to growth charts, vaccination schedules, clinical algorithms, and peer-reviewed case repositories tailored to child health [17; 18].

Conclusion. The phased and discipline-specific integration of digital tools – from interactive atlases and simulators to specialized clinical application – constitutes a comprehensive Digital Medical Educational Environment for medical education. It addresses core pedagogical challenges: standardizing exposure to complex structures, providing unlimited practice opportunities and ensuring access to current clinical knowledge.

The critical task for modern medical didactics is to advance from the mere availability of digital components to a sophisticated understanding of their synergistic integration. The main goal is the effective interweaving of digital resources within a single digital medical educational environment to achieve the main goal of medical education – the formation of systematic clinical thinking in students.

The creation of the Digital Medical Educational Environment that is pedagogically based, systematically designed and seamlessly integrated allows students to move beyond traditional learning and their use of digital tools. The created Digital Medical Educational Environment should be used at medical classes, at clinical practice and in future career. The future physician will be one whose clinical reasoning has been formed within the Digital Medical Educational Environment that mirrors the complexity, dynamism and technological richness of the modern world.

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