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METHODOLOGY FOR DEVELOPING STUDENTS' BIOPHYSICAL COMPETENCE THROUGH GENERATIVE AI-ASSISTED VIRTUAL LABORATORY CASES IN TEACHING BIOLOGICAL PHYSICS

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Abstract

This article is aimed at improving the methodology of teaching Biological Physics in medical higher education institutions through generative artificial intelligence-assisted virtual laboratory cases. Biological Physics occupies an important place in the formation of future physicians' scientific worldview because it explains the physical mechanisms of biological systems, diagnostic technologies, biophysical processes in tissues, and the principles of modern medical equipment. However, many topics, including bioelectric phenomena, hemodynamics, biomechanics, optics of the eye, membrane transport, radiation biophysics, and medical imaging, are abstract and difficult for students to understand without visualization and practical modelling. The study analyzes the methodological potential of generative AI, virtual simulations, digital laboratory scenarios, and problem-based biophysical cases. On this basis, a BIOPHYS-AI methodological model was developed. The model includes problem situation analysis, AI-assisted explanation, virtual experiment, data interpretation, clinical-biophysical justification, and reflective assessment. The proposed approach contributes to the development of students' biophysical competence, scientific

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reasoning, digital literacy, and the ability to apply physical laws to medical problems. The results of the methodological analysis show that the integration of generative AI and virtual laboratory cases can increase the didactic effectiveness of Biological Physics teaching when used under teacher supervision, with academic integrity, data reliability, and ethical principles being strictly observed.

Keywords: Biological Physics, biophysical competence, generative artificial intelligence, virtual laboratory, medical education, digital simulation, clinical-biophysical case, biomechanics, bioelectricity, hemodynamics, optics of the eye, radiation biophysics, problem-based learning, digital pedagogy.

Introduction

The rapid development of digital technologies and artificial intelligence has created new requirements for the training of future medical specialists. Modern physicians are expected not only to know clinical facts but also to understand the physical basis of diagnostic and therapeutic technologies. Biological Physics provides this foundation by explaining the mechanisms of blood flow, nerve impulse transmission, membrane potentials, diffusion, thermoregulation, visual perception, ultrasound diagnostics, magnetic resonance imaging, X-ray methods, and laser technologies used in medicine.

At the same time, Biological Physics is often perceived by medical students as one of the most abstract and theoretically difficult disciplines. Students may experience difficulties in connecting mathematical formulas and physical laws with real clinical situations. For example, Poiseuille's law is frequently learned as a formula, although it is directly related to vascular resistance, arterial pressure, stenosis, and microcirculation. Similarly, the optical principles of the eye are sometimes studied separately from refraction disorders, and bioelectric phenomena are not always connected with electrocardiography, electroencephalography, and neuromuscular transmission.

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The integration of virtual laboratories, computer simulations, generative AI tools, and clinical-biophysical cases can help overcome this gap. PhET simulations and other digital laboratory platforms provide visual and interactive models for physics, chemistry, biology, and mathematics learning [1]. In medical education, virtual simulation and digital patient-based learning are increasingly used to strengthen clinical reasoning and practical decision-making [2]. Generative AI can support the creation of individualized explanations, formative questions, laboratory scenarios, and case-based assignments, but its outputs must be checked by teachers and verified through reliable scientific sources [3].

International organizations also emphasize the importance of responsible and human-centered use of AI in education and health care. UNESCO recommends that generative AI in education should be used with clear pedagogical goals, protection of human agency, and attention to academic integrity [4]. The World Health Organization notes that large multimodal models can be useful in health-related education and research, but their risks include inaccurate responses, bias, privacy concerns, and overreliance on automated outputs [5]. Therefore, the use of generative AI in Biological Physics teaching should be methodologically structured and pedagogically controlled.

The relevance of this research is determined by the need to modernize the teaching of Biological Physics in medical universities, strengthen the link between physical laws and clinical thinking, and develop students' ability to interpret digital and experimental data. The aim of this article is to develop a methodology for improving students' biophysical competence through generative AI-assisted virtual laboratory cases in teaching Biological Physics.

Methodology

The article is based on theoretical analysis, pedagogical modelling, comparative evaluation of digital tools, and the design of clinical-biophysical cases. Scientific publications on generative AI in medical education, virtual simulation, digital

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pedagogy, and physics education were reviewed. Regulatory and methodological recommendations on the responsible use of AI in education and health care were also analyzed.

The object of the study is the process of teaching Biological Physics in medical higher education institutions. The subject of the study is the methodology for using generative AI-assisted virtual laboratory cases to develop students' biophysical competence. In this article, biophysical competence is interpreted as the integrated ability of a student to understand physical laws, apply them to biological and clinical processes, work with digital simulations and experimental data, and explain medical phenomena through scientific reasoning.

The proposed methodology is organized around the BIOPHYS-AI model. The model includes six sequential stages: 1) formulation of a clinical-biophysical problem; 2) activation of prior physical knowledge; 3) AI-assisted explanation and generation of guiding questions; 4) performance of a virtual laboratory experiment; 5) interpretation of digital and graphical data; 6) reflective conclusion and medical application. Each stage is supervised by the teacher in order to prevent uncritical acceptance of AI-generated information.

Generative AI is used only as a didactic assistant. It may generate a simplified explanation of a law, propose a laboratory task, formulate a clinical situation, create comparison questions, or help students reflect on their errors. However, AI is not used as an independent source of final scientific truth. Students are required to verify AI-generated explanations with textbooks, teacher instructions, and reliable scientific materials.

Main Part

The development of biophysical competence requires the transition from reproductive learning to active modelling, experimentation, and clinical interpretation. In traditional lessons, students often memorize formulas without understanding their clinical meaning. The BIOPHYS-AI methodology changes

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the focus of learning: each physical concept is presented through a medical problem, investigated through a virtual experiment, and interpreted through a clinical-biophysical conclusion.

For example, the topic of hemodynamics can be taught through a case of arterial stenosis. Students first analyze the clinical situation, then recall the relationship between vessel radius, viscosity, pressure gradient, and blood flow. After that, they perform a virtual experiment by changing the vessel radius and observing how flow resistance increases. Generative AI may be used to formulate guiding questions, but students must independently explain why a small decrease in vessel radius causes a sharp increase in vascular resistance.

The topic of bioelectricity can be taught through a case related to membrane potential and electrocardiography. Students model ion movement across the membrane, analyze depolarization and repolarization, and connect these processes with the formation of electrical signals recorded in clinical practice. In this way, abstract physical concepts become clinically meaningful.

The topic of optics of the eye can be integrated with ophthalmology. Students analyze myopia, hyperopia, astigmatism, and presbyopia through lens models and virtual optical simulations. They calculate focal length changes and explain why different corrective lenses are used. Generative AI can provide comparative explanations, while the teacher ensures scientific accuracy.

Radiation biophysics can be taught through cases related to X-ray diagnostics, radiation dose, biological effects of ionizing radiation, and safety principles. Virtual laboratory tasks allow students to compare penetration, attenuation, shielding, and dose-dependence without exposing learners to real radiation risk.

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Table 1. Components of biophysical competence developed through the BIOPHYS-AI methodology

Component	Content	Expected student activity
Conceptual component	Understanding laws and principles of Biological Physics	Explains physical mechanisms of biological and medical phenomena
Experimental component	Ability to perform and interpret virtual laboratory tasks	Changes parameters, observes results, and analyzes graphs
Clinical-biophysical component	Application of physical laws to clinical situations	Justifies diagnostic and therapeutic processes using biophysical concepts
Digital component	Use of simulations, AI tools, and digital platforms	Works with virtual laboratories and verifies AI-generated explanations
Reflective component	Evaluation of accuracy, limitations, and learning outcomes	Identifies errors, formulates conclusions, and explains practical significance

Effectiveness of the Methodology

The expected effectiveness of the BIOPHYS-AI methodology is connected with several pedagogical mechanisms. First, virtual laboratories reduce the abstractness of Biological Physics by transforming invisible or complex processes into visual and interactive models. Second, generative AI supports individualized explanation and formative feedback, helping students understand difficult concepts at their own pace. Third, clinical-biophysical cases create a meaningful bridge between physical laws and future professional activity.

The methodology also supports active learning. Students do not passively receive information; they formulate hypotheses, perform virtual experiments, compare results, detect contradictions, and justify conclusions. Such learning activities develop analytical thinking and strengthen the ability to transfer knowledge from physics to clinical disciplines. This is especially important for medical students, because many diagnostic technologies and treatment methods are based on physical principles.

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A significant advantage of the approach is the possibility of safe experimentation. Students can model changes in blood viscosity, vessel radius, lens curvature, membrane permeability, radiation shielding, or sound wave frequency without risk to patients or laboratory equipment. As a result, learning becomes more flexible, visual, and clinically oriented.

At the same time, the methodology requires responsible organization. AI-generated answers may contain inaccuracies, oversimplifications, or unsupported statements. Therefore, teacher supervision, academic honesty, verification of sources, and critical analysis are obligatory elements of the methodology.

Practical Recommendations

In order to effectively implement generative AI-assisted virtual laboratory cases in teaching Biological Physics, the following recommendations should be taken into account:

1. Clinical orientation of each topic - every physical law should be connected with a biological or medical situation, such as blood flow, ECG, vision, ultrasound, or radiation diagnostics.
2. Use of virtual laboratories - complex processes should be visualized through simulations, models, graphs, and interactive experiments.
3. Pedagogically controlled use of generative AI - AI should be used for explanations, questions, and scenario generation, but all outputs must be checked by the teacher.
4. Development of prompt literacy - students should learn to formulate accurate, ethical, and scientifically appropriate prompts for educational tasks.
5. Verification of AI-generated content - students should compare AI explanations with textbooks, teacher materials, and reliable sources.
6. Integration with clinical subjects - Biological Physics assignments should include examples from physiology, cardiology, ophthalmology, radiology, neurology, and rehabilitation.

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7. Assessment through rubrics - students should be evaluated not only by correct answers but also by reasoning, data interpretation, and reflection.

8. Prevention of cognitive overload - multimedia, AI explanations, formulas, and clinical cases should be presented step by step and in a logically structured manner.

Conclusion

The integration of generative AI-assisted virtual laboratory cases into the teaching of Biological Physics is a promising methodological approach for medical higher education. It makes abstract physical concepts more understandable, strengthens the connection between physics and clinical practice, and develops students' biophysical competence. The proposed BIOPHYS-AI model organizes learning through problem analysis, AI-assisted explanation, virtual experimentation, data interpretation, clinical-biophysical justification, and reflective assessment.

The methodology does not replace the teacher, classical theory, or laboratory thinking. On the contrary, it strengthens their role by providing new digital and interactive tools for explanation, modelling, and assessment. When generative AI is used responsibly and under teacher supervision, it can become an effective didactic instrument for improving the quality of Biological Physics education in medical universities.

Further research should include pedagogical experiments with control and experimental groups, statistical analysis of learning outcomes, and assessment of students' motivation, digital literacy, and ability to apply biophysical concepts to clinical situations.

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