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Methodology of Interdisciplinary Integration of Physics Laboratory Classes for The Development of Professional Competencies of Medical Engineers

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ABSTRACT

This article develops the methodological foundations for organizing physics laboratory classes in the training of medical engineers not as an isolated theoretical and practical component, but as an integrative educational environment closely connected with biomechanics, bioelectricity, medical instrumentation, clinical diagnostics, informational signal analysis, radiation safety, and engineering design. The main idea of the study is that, for a medical engineer, physics is not merely a fundamental supporting discipline, but a methodological basis that explains the relationship between the operating principle of a medical device, measurement accuracy, the physical nature of signals, the mechanisms of interaction with biological media, technical safety, and clinical interpretation. Therefore, the article substantiates the necessity of designing laboratory classes on the basis of the chain "physical phenomenon – measurement method – medical device – clinical task – engineering solution," developing students' experimental, analytical, communicative, and design-related competencies within a unified system, and transferring physics laboratory work into a real clinical and technological context. As a result, the target-oriented, content-based, procedural, and assessment components of an integrative laboratory methodology appropriate for biomedical engineering programs were developed.

Keywords: Biomedical engineering, physics laboratory, interdisciplinary integration, professional competence, medical devices, biophysics, experimental teaching, engineering education, clinical context, integrative methodology.

INTRODUCTION

At the present stage of higher education development, especially in fields where engineering and healthcare intersect, the quality of graduate training is no longer assessed solely by the sum of acquired knowledge, but by such competencies as the ability to apply fundamental theory to practical problems in complex professional situations, to understand the functional relationship between a device and a biological system, to comply with safety requirements, to interpret measurement results, and to develop engineering solutions collaboratively; in Uzbekistan, the ongoing renewal of educational content on a competency-based basis, the need to adapt curricula and syllabi to modern demands, the introduction of the credit-module system, and the adoption of specific state decisions aimed at improving the quality of physics education make this issue even more methodologically relevant.

Biomedical engineering is inherently an interdisciplinary field in which physics, mathematics, electronics, programming, materials science, physiology, and clinical practice intersect; therefore, for a student in this field, an electrical signal in a circuit is not merely a physical quantity, but an indicator of cardiac activity in the form of an ECG recording; optical absorption is not simply a light phenomenon, but the basis for the functioning of a pulse oximetry sensor; and wave propagation is not only a matter of general mechanics or acoustics, but the physical foundation of ultrasound diagnostics. International sources also emphasize the particular importance of safety, precision, systems thinking, design, and communication competencies for specialists working with medical devices; ABET criteria and BMES approaches identify interdisciplinary preparation as an essential requirement for engineering programs, while the WHO recognizes personnel capacity as a key factor in the safe and effective use of medical devices.

The problem is that traditional physics laboratory classes are often limited to demonstrating a general physical law and do not sufficiently reveal its real functional role in medical technology, clinical measurement, biomaterials, diagnostic systems, or engineering design. As a result, students complete the laboratory work but do not deeply understand its professional significance. Although national pedagogical sources have pointed out the importance of interdisciplinary relations, diagnostic approaches, innovative technologies, and vocational education methodology, recent studies in medical physics and engineering education confirm the necessity of redesigning laboratory activities on an integrative and competency-based foundation.

This article was carried out within a theoretical and methodological framework. The object of the study was the process of physics laboratory classes in biomedical engineering education, while the subject of the study was the methodology for organizing this process on the basis of interdisciplinary integration. The source base consisted of 33 verified resources, including national regulatory and legal documents, Uzbek pedagogical and specialized literature, foreign monographs, articles indexed in the Scopus database, and official web resources. The criteria for selecting the sources were their actual existence, direct relevance to the topic, the extent to which they addressed educational and professional competencies, and their methodological applicability.

The study employed comparative-analytical methods, content analysis, competency mapping, didactic modeling, and structural-functional synthesis. First, it was determined which segments of physical knowledge in the professional activity of a medical engineer could be considered practically “working knowledge.” Then, for each laboratory topic, a matrix was constructed according to the scheme “fundamental content – technological application – clinical task – measurement practice – interpretation of results – engineering reflection.” After that, assessment rubrics were designed according to the criteria of experimental accuracy, data processing, device-related thinking, safety, and teamwork.

METHODS

Table 1. Integration of Physics Laboratory Topics into the Field of Biomedical Engineering

No.	Physics laboratory topic	Laboratory topic integrated into biomedical engineering
1	Determination of the linear dimensions of solid bodies using a vernier caliper and micrometer	Determination of the geometric dimensions of biomedical technical components using a vernier caliper and micrometer
2	Determination of the density of substances	Determination of the density of materials and implant models used in biomedicine
3	Determination of the density of solid bodies with regular geometric shapes. Determination of the density of solid bodies by the hydrostatic method	Determination of the density of prostheses, implants, and biomaterial models by geometric and hydrostatic methods

4	Determination of gravitational acceleration using a mathematical pendulum	Study of free oscillation parameters in systems associated with rehabilitation devices and biomechanical vibration processes
5	Study of the determination of Young's modulus of elastic bodies	Determination of the elastic properties of biomedical materials, polymers, and soft tissue models on the basis of Young's modulus
6	Study of methods for determining the coefficient of internal friction of liquids	Determination of the viscosity characteristics of biological fluids and infusion solutions
7	Determination of the specific heat capacity of solid bodies	Determination of the thermal properties and thermal stability of materials used for manufacturing medical devices
8	Measurement of low resistances and determination of the resistivity of conductors	Determination of the electrical resistance of biomedical sensors, electrodes, and conductive materials
9	Connecting capacitors and determining the capacitance of an unknown capacitor	Connection of capacitors in biomedical electronic devices and diagnostic circuits and determination of unknown capacitance

The topics of laboratory classes were integrated into the fields of biomedical engineering, and classes on these topics were conducted in a whole-class format.

RESULTS

As a result of the analysis, a methodological model consisting of four interrelated components was developed, transforming physics laboratory classes into a means of developing the professional competencies of medical engineers. The first component is the goal-oriented competency component, in which fundamental physical literacy, experimental and analytical competence, competence in working with medical devices and sensors, competence in the preliminary interpretation of clinical data, safety and ethical responsibility, as well as skills in teamwork communication and technical report writing were defined as a unified outcome. The second component is the content-integrative component, in which the sections of physics were adapted to medical technologies, namely: mechanics and hydrodynamics were linked with infusion systems, blood flow models, and biomechanics; electricity and magnetism were linked with ECG, EEG, electromyography, biosensors, and device circuits; optics was linked with endoscopy, pulse oximetry, and photometric measurements; vibrations and waves were linked with ultrasound diagnostics; and atomic and nuclear physics was closely connected with X-ray, CT, dosimetric control, and radiation safety.

The procedural component of the developed model envisages organizing laboratory work in four stages. At the first stage, students are provided with brief but purposeful pre-laboratory diagnostics and a clinical-technological context in which the importance of the laboratory work for a specific medical problem is explained. At the second stage, measurement, observation, and work with a device scheme or simulation are carried out, but the task is presented not in the form of simple algorithmic repetition, but as a problem-based assignment. At the third stage, the obtained data are processed from the point of view of physics and analyzed according to such indicators as error, reliability, signal-to-noise ratio, sensitivity, and accuracy. At the fourth stage, the result is interpreted from clinical and engineering perspectives, and students are asked reflective questions such as: “If there is a deviation in the sensor, how will it affect the clinical decision?” and “If the device calibration is incorrect, what risk may arise for patient safety?”

Based on this methodology, a number of exemplary integrative modules for physics laboratory classes were recommended. For example, in the laboratory work “Physics of Bioelectric Signals and the ECG Sensor,” electrical potentials, filtration, amplification, and the time-amplitude characteristics of signals are related to cardiac rhythm; in the laboratory work “Optical Absorption and Sensor Accuracy in Pulse Oximetry,” light absorption, photodiode sensitivity, and the calculation of the SpO_2 index are studied; in the work “Wave Propagation in Ultrasound Diagnostics,” frequency, medium resistance, and the echo principle are linked with the image formation quality of the device; the module “Hydrodynamics in Infusion Systems” analyzes the functional safety of a medical system through pressure, flow velocity, and fluid resistance; and the laboratory “Dosimetric Control and Radiation Safety” integrates the physical nature of ionizing radiation with clinical safety protocols, thereby enabling students to transform a physical law into a professional decision.

CONCLUSION

Thus, the methodology of interdisciplinary integration of physics laboratory classes for the development of the professional competencies of medical engineers elevates physical knowledge from the status of a “supporting theory” to that of a “functional tool organizing professional activity,” because precisely through this approach students learn to connect a physical phenomenon with the operating principle of a medical device, a measurement result with clinical meaning, experimental error with safety risk, and a laboratory task with an engineering decision. The methodological model developed in the article offers a holistic solution for biomedical engineering education in terms of content, procedure, and assessment, and its practical value lies in the fact that it can serve to harmonize physics laboratories in higher education institutions with modern medical technologies, biophysical systems, and clinical problems.

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