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DEVELOPING CRITICAL THINKING IN MEDICAL EDUCATION THROUGH THE TECHNOLOGIES OF BIOLOGICAL MODELLING

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Abstract
This article discusses the development and formation of critical thinking skills in medical students through the use of modern technologies, particularly biological modelling tools, in the medical education system. The role of modelling technologies in applying theoretical medical knowledge to practical situations, understanding complex biological processes, and developing scientifically-based approaches is analyzed. The author integrates this process with interactive, integrated, and analytical approaches to education, highlighting the intellectual foundations of critical thinking. Furthermore, the article examines practical examples, modelling programs used in lessons, and analyzes their effectiveness.

Keywords: Medical education, biological modelling, critical thinking, interactive technology, student engagement, scientific analysis, integrated approach.

Introduction

Critical thinking is increasingly recognized as one of the core components of modern professional competence in medical education. It encompasses not only the ability to memorize information but also to analyze, assess, make informed decisions, propose alternative solutions, and test them in practice. Especially in fields like medicine, where precision and responsibility are paramount, the critical thinking processes—such as diagnosis, treatment, and prevention—form the foundation for making accurate and timely decisions.

In today's rapidly advancing scientific and technological landscape, understanding biological and medical processes based solely on theoretical knowledge is

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insufficient. Many physiological and pathological processes in the human body manifest as complex, dynamic, and interconnected systems. To comprehend these complex systems and develop effective medical approaches, it is essential to utilize modelling technologies.

Biological modelling is a scientific approach that allows the representation of complex biological systems using mathematical, graphical, or computational models, providing the ability to predict changes within them. This technology serves not only to visually and interactively explore medical subjects but also fosters the development of critical and systematic thinking among students. During the modelling process, students independently identify the problem, create relevant models, predict potential outcomes, assess results, and draw conclusions. This plays a crucial role in shaping the culture of medical thinking.

Integrating modelling technologies into the learning process ensures the synergy of interdisciplinary medical sciences, enhances students' skills in using information and communication technologies, and fosters their ability to conduct independent research and substantiate scientific ideas. This is particularly significant for young specialists preparing for clinical thinking, as they will be able to link theoretical knowledge with practical applications by studying real clinical cases and the pathogenesis of diseases through models.

In this context, the introduction of biological modelling technologies into medical education can contribute to the formation of deeply analytical, critically thinking specialists who are capable of making informed scientific decisions. This, in turn, serves to improve the overall effectiveness of the healthcare system.

Main Body

Biological modelling is an interdisciplinary methodology that allows the analysis of complex biological processes through mathematical expressions, computational algorithms, and graphical representations. The use of modelling technologies in medical education enhances not only academic knowledge but also serves as an essential tool for shaping professional competences, especially in developing critical thinking skills.

Critical thinking is the ability to solve any scientific or practical problem in a logical, grounded, and analytical manner, based on evidence, rather than relying on traditional or intuitive approaches. For medical professionals, this skill is vital

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when making clinical decisions, conducting complex analyses of patients' conditions, and choosing the optimal path in uncertain circumstances.

The Interrelationship Between Biological Modelling and Critical Thinking

Medical-biological modelling not only visualizes information but also allows for the conceptual reconstruction of problems. In this process, students:

1. Create a conceptual model—identifying the components of a biological system and their interconnections.
2. Convert it into a mathematical expression—describing the dynamics of processes through equations.
3. Conduct simulations and experiments—testing the model under various parameters, or running virtual experiments in the classroom.
4. Analyze the results—drawing analytical and critical conclusions based on model outcomes.
5. Develop new hypotheses—proposing new questions, alternative approaches, and solutions based on the obtained results.

Each of these steps transforms the student from a passive learner into an active problem-solver, capable of independent thinking and analysis.

Several advanced pedagogical technologies are effectively used to enhance critical thinking through modelling:

- Problem-based learning: Students face real-life biological or clinical problems and must find scientifically based solutions.
- Interdisciplinary integrated teaching: Connecting biology, informatics, mathematics, physiology, and pharmacology to provide a comprehensive approach.
- Use of visual and interactive tools: Programs like MATLAB, BioUML, COPASI, and NetLogo allow students to visualize, build, test, and assess biological systems.
- Collaborative small group work: Encouraging teamwork in analysis and modelling fosters communication and social competence.

Types and Stages of Modelling

When working with students, the following types of models are used:

- Static models: Represent anatomical structures, tissue composition, and inter-organ relationships (e.g., BioDigital Human).
- Dynamic models: Illustrate biochemical processes, metabolic cycles, and hormonal regulation systems (e.g., COPASI, SimBiology).

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- Agent-based models: Used to analyze population processes, epidemics, and the effects of health policies (e.g., NetLogo).

Each model is studied according to the following didactic cycle:

1. Diagnosis: Identifying the student's prior knowledge and understanding.
2. Model construction: Expressing the biological system in a diagrammatic or mathematical model.
3. Simulation: Activating the model in a virtual environment.
4. Reflection: Analyzing results, applying critical thinking, and drawing final conclusions.
5. Transfer: Applying the knowledge and skills to real-world situations (clinical problems, disease scenarios).

Practical Experience and Results. Experimental lessons, project-based training, and interdisciplinary laboratory sessions conducted at medical universities in Uzbekistan show that students trained using biological modelling techniques perform 25–30% better on critical thinking tests. Their scientific speech, logical consistency, ability to conduct independent analysis, and hypothesis development skills have significantly improved.

For instance, students working with SimBiology on the "pharmacokinetic model of hypoglycemia" analyzed the time-dependent effects of insulin, glucose fluctuations, and the body's responses to increasing or decreasing doses, successfully developing alternative solutions for a real clinical problem.

Conclusion

The introduction of biological modelling technologies in medical education plays a vital role in renewing traditional teaching methods, transforming the learning process into an interactive, student-driven, and scientifically grounded system. These technologies offer the following key opportunities:

- Expanding cognitive and analytical capacity: Students deeply analyze complex biological systems and processes using mathematical and computational models, allowing them to identify complex problems, analyze their core elements, and compare them systematically. As a result, students' logical and analytical thinking skills significantly improve.
- Enhancing critical thinking: Through the modelling process, students learn to make independent, analytical decisions in solving real-world clinical and

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biological problems. By recognizing the potential outcomes and possible errors of different scenarios, their critical thinking capabilities improve. This, in turn, enhances their ability to make quick, accurate decisions in complex medical situations.

- Strengthening evidence-based approaches: Biological modelling technologies provide students the opportunity not only to memorize existing knowledge but also to test it through experimental trials, analyze the results, and compare them with real clinical conditions. This strengthens their ability to develop and validate hypotheses in scientific research.
- Innovating approaches to contemporary medical problems: Knowledge derived from models encourages students to propose innovative solutions to future medical challenges. They actively participate in developing new methodologies and technological approaches in areas like pharmacodynamics, pathological processes, and epidemiological analyses.

Overall, the integration of biological modelling technologies into medical education boosts student creativity, independent thinking, and scientific creativity. This process allows them to not only deepen their theoretical understanding but also apply it to real-world complex systems, providing them with the opportunity to develop strong clinical and scientific skills for the future. Thus, the methodology of critical thinking developed through modelling can become a crucial pedagogical tool for solving complex medical issues in a precise, effective, and innovative manner.

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