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MATHEMATICAL MODELING AS A POWERFUL TOOL FOR PROVIDING QUALITY OF HIGHER EDUCATION

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Abstract

This article presents the importance, necessity and essence of the use of mathematical models, which are considered a powerful tool in higher education in the specialty of biology and medicine, as a powerful tool in the research work of scientific researchers, as well as to study the features of using the methodology of mathematical modeling in the study of the activity of biological systems. As an example of mathematical modeling, an example is given of the construction of a mathematical model that represents the regulatory mechanisms of cardiac activity.

Keywords: regulatory mechanisms of cardiac activity, mathematical modeling, digital technologies, digital technologies in education, regulatorika.

Introduction

The quality of any education can be assessed by the knowledge obtained by the students. Mathematical knowledge and mathematical concepts of students in the specialty of biology and medicine, will basis for the educational result. Today, various modern approaches, modern pedagogical technologies and digital technologies are used to improve the quality of the educational process. Among these, the use of mathematical modeling methodology in the organization of effective teaching of specialized sciences is also an important factor for students in the specialty of biology and medicine. The use of mathematical models in the study of a process or object in higher education students and the formation of mathematical modeling skills is one of the ways to achieve our goal and is considered an important basis. This article presents of applying the methodology of mathematical modeling as a means of qualitative organization of teaching process in higher education.

It is known that mathematical modeling can be used as a means of studying the characteristics of physical and natural processes, determining and predicting parameters that are impossible in practice. In higher education, in particular, in the field of biology and medicine it is an important task to focus on the formation of mathematical modeling skills in students for organization of teaching of specialized courses in the field of bioengineering, bioinformatics and biotechnology. Because mathematical models are indispensable tools in the study biological objects and natural processes.

In various sources, we can see a number of scientific works on the use of mathematical modeling as an effective tool for teaching in the field of education. The paper [1] substantiates the potential of mathematical modeling in the formation of social and adaptive qualities of future specialists capable of implementing qualitative changes in the sphere of social and professional activities. The conditions for the introduction of mathematical modeling as a means of forming the social and adaptive qualities of students are identified. It is substantiated that the use of mathematical modeling contributes to the deepening of the processes of humanization and humanitarization of teaching mathematical disciplines, enhances the students' perception of mathematics as a tool for understanding the world around them, an important part of human culture. In [2], the author presented the influence of a mathematical model on the solution by students of a practical problem related to the field of professional activity, the principles and aspects of the application of mathematical modeling in the formation of students' professional competence. In [3] literature, the author reasonably stated that in the management of objects and processes, a good understanding of the mechanisms occurring in them is required, and in such cases, mathematical modeling is become as very helpful and important instrument of study. The main stages of mathematical modeling are given. In these sources, the authors provide information about the application of mathematical modeling methodology in certain directions, and this article focuses on the applying the mathematical modeling methodology that can be used in the organization of education of students in the field of cardiology.

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Main Part

Modeling, as a method of cognition, has been used for a long time and involves the study of the main patterns and features of the behavior of any processes, phenomena or other real objects using their models. The purpose of the modeling method, as a method of cognition of the surrounding reality, is to establish the basic laws and features of the functioning of a real existing object, phenomenon or process. The main task of modeling is to create an artificially created physical or abstract image of a real object and study its properties and identify different types. The essence of this method is to replace the original real-life object with its "image" or "display" and further study the model using various algorithms.

A model is an artificially created theoretical image of a real object that reflects its most important and fundamental properties and makes it possible to predict the behavior of an object based on an experiment with its model. A mathematical model is an image or display of a real object, built using mathematical relationships that establish links between the defining properties of an object (equations, inequalities).

The beginning of XIII century includes attempts to use mathematics in the formulation of any laws or patterns observed in experiments. For example, Leonardo Pisano (Fibonacci) analyzes a simple model of the rabbit population in his book about arithmetic in 1202. In the second half of the XVII century, a more serious and systematic attempt to introduce mathematics into biology was made by Galileo's student Giovanni Borelli. He proposed a geometric approach to the mechanics of the movement of animals and humans. Significant progress in the theory of modeling was made by Isaac Newton (the second half of the 17th - early 18th centuries), who widely used mathematical methods and constructions in his works. The first mathematical models of I. Newton, L. Euler, D. Bernoulli, R. Hooke and other natural scientists were the simplest relations, as a rule, in the form of linear algebraic equations. These equations interconnected the main properties of the phenomenon under study, characterizing the state or behavior of the studied object of reality [4].

By the second half of the 20th century, the rapid development of computer technologies led to the emergence of new opportunities in the field of modeling.

As a result, computer models based on mathematical models began to be created. The use of computer models has become the most important element of development as a result of the rapid and accurate implementation of numerous and complex calculation operations with the help of a computer. Calculation experiments started to be conducted with the help of computer models. With the help of computer models, it became possible to predict processes or behavior of objects in advance. As a result of the application of mathematical modeling, the possibilities of scientific research have expanded significantly

Applying the methodology of mathematical modeling. To create computer models, students are required to have a sufficient mathematical foundation. In this article, a unique approach to the issue of applying the methodology of mathematical modeling in medicine and biology is considered. As an example, let's take the issue of researching the regulatory mechanisms of the human heart. Students should understand that mathematical models play a very important role in researching the activity of such biological systems. The literature [5-8] presents mathematical modeling methods for researching the regulatorika of living systems. Using these methods, research of dynamic environments allows to predict their activity in advance. The use of such methods in the teaching of bioengineering students in specialized courses will serve as a necessary resource for improving student's knowledge of mathematical modeling, forming specialist competence, and for future scientific research activities.

The process of mathematical modeling of the considered biological object can be carried out in the following stages:

1. Let's start by clarifying what will be researched and what tools will be used for it. That is, we can clarify the research object and subject.

In our example, the object of research is regulatory mechanisms of cardiac activity, and the subject is a mathematical model. The parts that make up the activity of a biological object and the connection and mutual relations between them are studied, and if possible, a scheme representing their relations is drawn.

In the literature [5-8], presented the concept of OrAsta specific to biological systems. Based on this concept, we can construct a biological scheme of regulatory mechanisms of cardiac activity. Taking into account that the regulatory mechanisms of cardiac activity are determined by the activity of the conduction system and the propagation of the excitation wave in the heart, the biological scheme can be drawn as shown in Fig. 1.

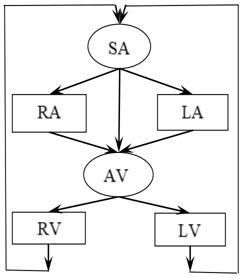

Fig.1. Biological schema of cardiac regulatorika

2. Building a mathematical model based on the biological scheme.

In our example, taking into account the delay times in the propagation of an electric impulse in the cardiac conduction system expressed in the biological scheme, the following (1) mathematical model is expressed in the form of nonlinear, complex system of functional-differential equations with delay argument.

$$\begin{cases} \dfrac{dx(t)}{dt} = \dfrac{a_1\Theta(t-h)\eta(t-h)}{(1+\sigma_1{}^2\Theta^2(t-h))(1+\sigma_2{}^2\eta^2(t-h))} - b_1x(t), \\ \dfrac{dy(t)}{dt} = a_2x(t-h) - b_2y(t), \\ \dfrac{dz(t)}{dt} = a_3x(t-h) - b_3z(t), \\ \dfrac{dv(t)}{dt} = \dfrac{a_4x(t-h)y(t-h)z(t-h)}{1+\sigma_3{}^2x^2(t-h)y^2(t-h)z^2(t-h)} - b_4v(t), \\ \dfrac{d\Theta(t)}{dt} = a_5v(t-h) - b_5\Theta(t), \\ \dfrac{d\eta(t)}{dt} = a_6v(t-h) - b_6\eta(t), \end{cases} \qquad (1)$$

$$t > h,$$

$$x(t) = \varphi_1(t),\ y(t) = \varphi_2(t),\ z(t) = \varphi_3(t),\ v(t) = \varphi_4(t),\ \Theta(t) = \varphi_5(t),\ \eta(t) = \varphi_6(t),\ t \in [0,h],$$

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where $a_i,\ b_i,\ i=1,2,...,6$ - parameters representing the rates of increase and decrease of activity of excitation in the nodes and heart parts, i.e SA node, right and left ventricles, AV node, right and left ventricles , respectively; $\sigma_i,\ i=1,\ 2,\ 3$ - excitation inhibition coefficients at SA and AV nodes; h - the delay time in the propagation of the excitation wave between the parts of the heart. The system of functional-differential equations with delays (1) represents the activity of the regulatory mechanisms of the process of propagation of the excitation wave in the heart.

3. Obtaining the solutions of the constructed mathematical model and checking the reliability of the solutions.

In our case, determining the exact solutions of the system of equations (1), the basic modes and properties derived from them is very complicated due to the nonlinearity of the considered equations and the large number of parameters and variables in it. In this case, the qualitative analysis of functional-differential equations (1), solving the system, the development and implementation of a method for obtaining numerical solutions on a computer is a complex issue. Therefore, the system of equations (1) can be simplified by using the reduction method and scaling operations [9] and lead the following form.

$$\frac{1}{h}\frac{dZ(\theta)}{d\theta}=\frac{AZ^6(\theta-1)(1+BZ^6(\theta-1))^2}{((1+BZ^6(\theta-1))^2+CZ^6(\theta-1))((1+BZ^6(\theta-1))^2+DZ^6(\theta-1))}-b_1Z(\theta),$$
$$\theta>1, \qquad (2)$$
$$Z(\theta)=\varphi(\theta),\quad \theta\in[0,1],$$

where $Z(\theta)$ - activity of cardiac conduction system; $A,\ B,\ C,\ D,\ b_1$ - nonnegative parameters.

Numerical solutions of (2) are obtained using the method of "delayed identifiers" presented in the research work [10], and a qualitative analysis of the model is performed to check the reliability of the solutions [10].

4. Carrying out calculation experiments in a mathematical model and presenting research conclusions.

As a result of calculation experiments carried out in (2), the following results were obtained (Fig. 2).

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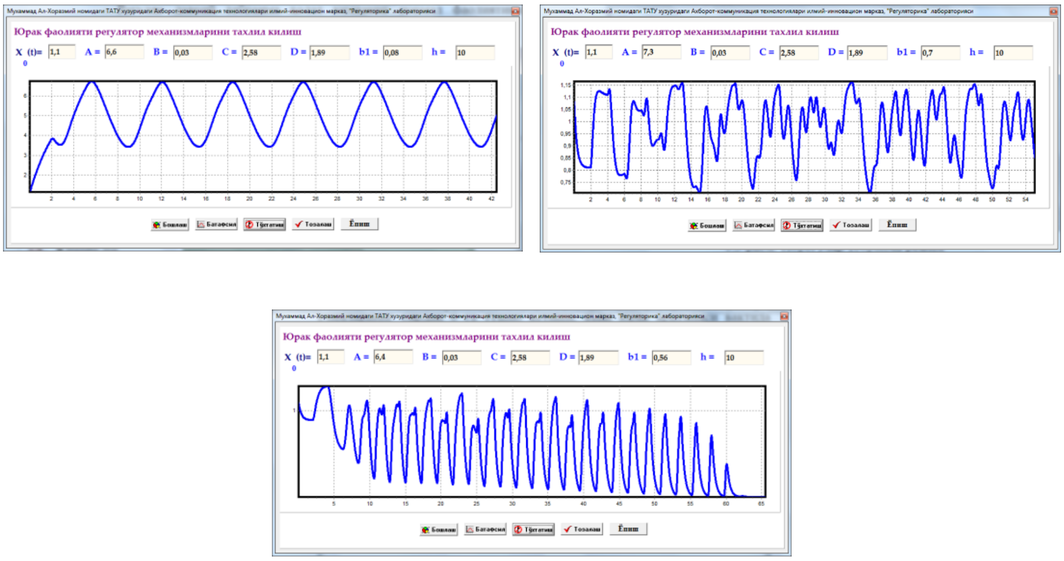

Fig.2. Modes of cardiac regulatorika (regular, irregular oscillation mode and "black hole" mode, i.e. the state of sudden cardiac death, respectively)

Summarizing the above considerations, it can be noted that the studied equation (2) has the ability to express a normal state of heart (solutions of periodic oscillations), arrhythmia (solutions with irregular oscillations) and sudden cardiac death (sometimes sudden drop solutions with irregular oscillations to 0 – “the black hole” effect). So, equation (2) can be used for study the regulatory mechanisms of cardiac activity.

Thus, this mathematical modeling methodology can be used in the research of self-control mechanism, i.e. regulatory mechanism of biological objects, living systems, dynamic environments. Mathematical models that take into account the biological characteristics of the considered system, delay arguments and biological feedback mechanisms can fully express all the regulatory mechanisms and work modes related to the research object.

Conclusion

The use of such mathematical modeling methodologies in the study of the activity of biological systems considered in the course of teaching in higher education institutions of biology and medicine serves as the main tool for researching, analyzing and predicting the activity of the biological system and will be the basis for better understanding of the regulatorika of the living systems. This mathematical modeling methodology is appropriate to be used not only in the organization of higher education, but also in the research work of young scientists and researchers.

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