Ways to Improve the Quality of Mathematical Training of Bioengineers at the University

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Abstract. The article is considered the possibility of solving the problems of low level of mathematical training of students-bioengineers. Successfully completed the higher mathematics course of study, students are faced with serious difficulties in real professional activity trying to use the existing arsenal of mathematical knowledge and skills to the bioengineering task. The author offers a solution to this problem through a bio-oriented approach to teaching mathematics to students of bioengineering specialties. The essence of this bio-orientated approach is revealed and analyzes its effectiveness on the basis of the experiment. The article deals with the problems of bioengineering, some basic mathematical concepts are presented in a biological context. The organization of the educational process in mathematics in accordance with the bio-oriented approach contributes to the formation of students-bioengineers of a high level of research mathematical skills, motivation and desire for self-education.

1. Introduction

In the modern fast-paced world, scientists face more and more complex tasks of universal importance: study of DNA, development of biomaterials, creation of bioartificial organs, population-genetic and molecular studies. Bioengineering specialists are engaged in solving these problems, which require a high level of both biological and mathematical training. Training of highly qualified bioengineering personnel is an important task of national education.

The analysis of the Concept of development of mathematical education in the Russian Federation, the Strategy of innovative development of the Russian Federation for the period up to 2020, "Development of education for 2013 – 2020" State program, the Forecast of long-term socio-economic development of the Russian Federation for the period up to 2030 allowed to formulate the main goals of teaching mathematics to students of bioengineering specialties.

First goal: formation of a mathematical knowledge and skills system necessary for further study of special disciplines, as well as their practical application.

Second goal: formation of research mathematical skills (analysis of the real problem, its translation into the language of mathematics, the choice of the optimal method of solving the problem at the abstract level, the interpretation of the results in the initial terms, the presentation of the result in the form of accurate qualitative conclusion).

Third goal: formation of students’ positive perception of mathematics, understanding the importance of acquired knowledge, personal interest.

The fourth goal: formation of the ability to self-education, readiness to acquire the necessary information and improve mathematical skills.
However, the quality of mathematical specialist training often does not meet these goals, as well as does not meet the trends and development rates of science and technology. Having learned a considerable amount of mathematical formulas, theorems and proofs, having mastered computational skills and having powerful research tools, young specialists, faced with a real workplace problem, withdraw from it. They are not able to see the mathematical essence of the process or phenomenon under consideration, to translate the bioengineered problem into a universal and accurate language of mathematics.

This problem of personnel discrepancy is connected with "conservatism of the content of education and ways of organizing training" [4, p.104]. The course presentation of higher mathematics is strictly formalized, there are no interdisciplinary relationships, the level of development of bioengineering science is not taken into account. The content of the course does not take into account the bioengineering specialization of students, there is no material showing the relationship of mathematics and biology. The standard examples and problems considered at the lessons also do not allow students to see the possibility of using mathematical tools in solving real problems of bioengineering. The isolation of mathematics knowledge, the complexity of perception of the studied material, the inability to apply it to the solution of professional problems lead to the fact that the mathematical preparation of students to be limited to the knowledge of formulas, theorems and template skills only. In addition, memorizing a significant volume of "non-working" material, solving narrow classes of problems on the calculation of derivatives and integrals, students reasonably ask: "Why do we need to learn mathematics and how it will be useful in our future profession?".

Analysis of the situation will allow to formulate the main problem of the study: low level of mathematical training of students of bioengineering specialties, which does not meet the goals of mathematical education.

Analysis of research papers on the problems of mathematical education (Evans, J, Wedege, T. [5]; Bortnik, L. I., Kaygorodov, E. V., Raenko, E. A. [2]; Kölner, O., Baumert, J., Schnabel, K. [11]; Flegg, J., Mallet, D., Lupton, M. [7] Hannula, M. S. [8]; Brown, M., Bibby, T. [3]; Fedoseyev, V. [6]; Matthews, A., Pepper, D. [15]; Onion, A.[17]; Hernandez-Martinez, P., Vos, P. [9]; Willcox, K., Bounova, G. [20]; Alpers, B. A. et al [1], Noskov, M. V., Shershneva, V. A. [16], Rellensmann, J., Schukajlow, S. [18], Maaß, J., O’Meara, N., Johnson, P., O’Donoghue, J. [14]. Loch, B., Lamborn, J. [13]), allows us to conclude about the relevance of the problem under consideration.

Research question: is it possible to improve the quality of mathematical training of bioengineering personnel by building the educational process in higher mathematics in accordance with the bio-oriented approach?

2. Bio-oriented approach
Bio-oriented approach is a methodological orientation of the educational process in higher mathematics on bioengineering specialization of students. It regulates the selection of content, methods, means and forms of training of students.

Implementation of bio-oriented approach in the educational process in higher mathematics involves:

1. Concordance with content of the course of higher mathematics, methods and educational process workflow management of bioengineering specialization of students, as well as the requirements for the level of their mathematical training. The study of the fundamental branches of higher mathematics is carried out by filling abstract concepts with biological meaning, without violating the internal logic of mathematical science.

In order to update the knowledge of students in matrix format can be represented, known from the school course of biology, the second and third laws of Mendel.

According to the second law, when hybridise of the first generation, the segregation occurs in relation to 3:1 by phenotype (a set of features) and 1:2:1 by genotype (a set of genes). Mathematically, this law can be written in matrix format:
\( M_1 = \begin{pmatrix} 3/4 \\ 1/4 \end{pmatrix} \) - matrix of the characters segregation by phenotype,

\( M_2 = \begin{pmatrix} 1/4 \\ 2/4 \\ 1/4 \end{pmatrix} \) - matrix of the characters segregation by genotype.

In accordance with the third law, when dihybrid crossing (hybrids differ in two pairs of characters) in the second generation, there is a segregation of characters in relation to 9:3:3:1 by phenotype and 4:2:2:1:1:1:1:1 by genotype.

Mathematical record of the third Mendel's law has the form:

\( M_3 = \begin{pmatrix} 9/16 \\ 3/16 \\ 3/16 \\ 4/16 \\ 2/16 \\ 2/16 \\ 2/16 \\ 1/16 \\ 1/16 \end{pmatrix} \) - matrix of the characters segregation by phenotype,

\( M_4 = \begin{pmatrix} 2/16 \\ 1/16 \\ 1/16 \\ 1/16 \end{pmatrix} \) - matrix of the characters segregation by genotype.

In the study of differential calculus, along with the traditional geometric and physical meaning of the derivative, it is advisable to consider the biological meaning of this concept.

Assume that function \( y = f(t) \) be the size of the population at a time \( t \). Over a period of time \( \Delta t \), the number of individuals will change by the value

\[ \Delta y = f(t_0 + \Delta t) - f(t_0). \]

The ratio of the change in the number of individuals to the period of time for which this change occurred, i.e.

\[ \frac{\Delta y}{\Delta t} = \frac{f(t_0 + \Delta t) - f(t_0)}{\Delta t}, \]

represents the average rate of change in the population or the average productivity of the population vital activity. The limit value of the average rate of change in the population size at \( \Delta t \to 0 \):

\[ f'(t_0) = \lim_{\Delta t \to 0} \frac{f(t_0 + \Delta t) - f(t_0)}{\Delta t} \]

determines the productivity of vital activity at a time \( t_0 \). Thus, the derivative of the population size by time \( f'(t_0) \) is the productivity of the population vital activity at the moment of time \( t_0 \):

\[ f'(t_0) = \lim_{\Delta t \to 0} \frac{f(t_0 + \Delta t) - f(t_0)}{\Delta t}. \]

The same biological meaning must be given such important concepts as indefinite and definite integral.

If \( v = v(t) \) – the rate of population growth at a time \( t \), the indefinite integral

\[ \int v(t) \, dt \]

expresses the size of the population \( N(t) \) at a time \( t \) accurate to an arbitrary constant. If the size of the population is known at the initial time, then the size of the population \( N(t) \) is determined unambiguously at the time \( t \). A definite integral

\[ N = \int_{t_0}^{T} v(t) \, dt \]
is the growth of the population $N$ from the moment of time $t_0$ to $T$.

At the same time, a balance should be maintained between the strict formalism of the presentation of the material and its oversimplification; the biological interpretation of the concepts in question should not completely replace their mathematical essence.

2. Providing the relationship of higher mathematics course with special disciplines (for example, "Modeling of biological processes and biological systems", "Foundation of modeling in medicine and biology", "Methods of processing of biomedical signals and data") throughout the training period.

3. Consideration of examples and problems reflecting the relationship of biological and mathematical sciences, demonstrating the universality and accuracy of mathematical methods in solving bioengineering problems. The application of bioengineering tasks in the classroom for higher mathematics, as well as in the process of self-instruction of students allows not only to work out computational skills, but also to demonstrate the importance of the studied material, it’s possible applications in future professional activities. Formulation of problems in specific biological terms, understandable to students, eliminates the effect of abstraction and complexity of the mathematical objects. Students learn to translate a bioengineered problem into the symbolic language of mathematics, solve it by means of a mathematical apparatus and interpret the result in initial terms, i.e. they acquire the skills of research activity so important for a modern specialist.

Examples of problems include the following:

In the right atrium is introduced a sodium chloride containing 6 mg of contrast agent $A$. After that, the concentration of the agent $C(t)$ in the aorta is measured in mg/l for 12 seconds at one second intervals. Estimate cardiac output $F$ if $F(t) = 22t e^{-0.4(t+1)}$.

The pH value of a solution measures the concentration of hydrogen ions, denoted by $[H+]$, and is defined as $pH = -\log[H+]$. Use calculus to decide whether the pH value of a solution increases or decreases as the concentration of H+ increases [10, p.224].

A contaminated lake is treated with a bactericide. The rate of change in harmful bacteria days after treatment can be modeled by the equation $\frac{dB}{dt} = -\frac{3000}{(1+0.2t)^2}$, $t \geq 0$, where $B$ is the number of bacteria per milliliter of water and $t$ is the number of days since treatment. The initial number of bacteria is 10,000 per milliliter of water. Use the model to estimate the number of bacteria after 5 days. Will the number of bacteria be more than 2000 per milliliter of water? [12, p.381].

In lung physiology, the transport of a substance across a capillary wall has been modeled by the differential equation $\frac{dh}{dt} = -\frac{R}{V}\left(\frac{h}{k+h}\right)$, where $h$ is the hormone concentration in the bloodstream (in mg/mL), $t$ is time (in seconds), $R$ is the maximum transport rate, $V$ is the volume of the capillary, and $k$ is a positive constant that measures the affinity between the hormones and the enzymes that assist the process. Solve this differential equation to find a relationship between $h$ and $t$ [19, p.482].

3. Materials and methods

In the research took part Students of Ryazan State University, Ryazan State Radio Engineering University, Ryazan State Agrotechnological University. Two groups were formed – experimental and control, 40 students each. During the academic year, students of both groups studied the same program, studied the same topics in an equal amount of hours. The study of mathematics in the control group was carried out according to the traditional system, and in the experimental – in accordance with the bio-oriented approach. For the students of the experimental group the lecture material was provided with various examples of bioengineering nature, and the concepts studied were considered from a biological point of view. Seminars included the solution of biological problems by means of mathematical tools. Students also carried out research projects at the interface of biology and mathematics for the purpose to form research mathematical skills. For example, "Methods of numerical integration project": determine the photosynthetic potential of weeping birch on the available sample. During the work on the project, students learned to analyze a real problem that does not contain any formulas in its condition. From the course of biology, students knew that the photosynthetic potential is the product of the vegetative season and the leaf area of the plant. Thus, was carried out the transi-
tion from the formulation of the problem in biological terms to its formulation in the language of mathematical symbols. Photosynthetic potential of weeping birch: $F = S \cdot T$ where $T$ – vegetative season $S$ of the leaf area of the birch. To calculate the area, students used the numerical quadrature method, carrying out the solution of the problem at the abstract level. After calculating the value $F$, the students concluded in the initial biological terms of the photosynthetic potential of birch.

Performance evaluation of bio-orientation approach was carried out on four indicators: basic knowledge and skills in mathematics, research mathematical skills, motivation, desire for self-education. Students of both groups after passing their course of higher mathematics were asked to solve the test and answer the questions of the questionnaire. The control work consisted of two blocks, five tasks in each. The first five tasks were of standard content (for example, to calculate the derivative of the function, to solve the differential equation, etc.), and allowed us to conclude whether the students have basic mathematical knowledge and skills or not. The following five tasks were bioengineered (for example, "The causative agent of a rare form of pneumonia is the rod-shaped bacterium Friedlender's bacillus. The model of this bacterium is the body bounded by the surface formed by the rotation of the parabola $y = 0.01x^2 + 0.5$ around the axis Ox, and areas $x = \pm 2$. Find the volume of bacteria (мм³).") and allowed to evaluate the students' research skills. The questionnaire contained 12 questions (for example, "Do You think that formulas and theorems of mathematics will be useful for You as a bioengineer in your future professional activity? If so, what?", "Have You read any books, textbooks, articles on mathematics, biology or bioengineering in the last year? If Yes, then specify what?") and was aimed at identifying the motivation of students to study mathematics and the ability to self-education.

The solution of each task was evaluated on a five-point scale:
0 – The student did not start solving the problem.
1 – An attempt to solve the problem, but the course of the solution is wrong.
2 – The logic of reasoning is correct, but there are errors in computations.
3 – The correct answer is obtained, but the solution is insufficiently substantiated.
4 – The problem is solved correctly, the student reasoned and fully describes each stage of the solution, demonstrates a clear logic of reasoning. The maximum score for the first and second set of problems was 20 points.

Students' motivation to study mathematics was evaluated on a four-point scale:
1 point (low level) – There is no motivation to study mathematics.
2 points (intermediate level) – The student studies mathematics to pass the exam, the attitude to the discipline is neutral.
3 points (upper-intermediate level) – The student demonstrates a positive attitude to the study of mathematics, caused by personal interest, but does not believe that the studied material can be useful in professional activities.
4 points (high level) – The student demonstrates a high level of motivation caused by an inner consciousness of the importance of studying mathematics both for personal development and for the future profession.

The desire of students to self-education was evaluated on a four-point scale:
1 point (low level) – The desire for self-education is absent.
2 points (intermediate level) – The student has a desire for self-education in various fields of knowledge, but not in mathematics.
3 points (upper-intermediate level) – The student is interested in self-expansion of their knowledge and skills in mathematics, but only across the curriculum.
4 points (high level) – The student demonstrates a high desire for self-education, to improve knowledge and skills in the field of mathematics, beyond the curriculum.

4. Results
The Table 1 shows the number of students in the control and experimental groups who scored the appropriate number of points for each indicator.
Table 1. The results of empirical research.

| Indicators                             | Points (level) | 0-5 (low) | 6-10 (intermediate) | 11-15 (upper-intermediate) | 16-20 (high) |
|----------------------------------------|----------------|-----------|---------------------|---------------------------|--------------|
| Basic knowledge and skills in mathematics | I group        | 2         | 13                  | 16                        | 9            |
|                                        | II group       | 1         | 11                  | 18                        | 10           |
| Research mathematical skills           | I group        | 28        | 9                   | 2                         | 1            |
|                                        | II group       | 3         | 10                  | 19                        | 8            |
| Motivation                             | I group        | 12        | 20                  | 7                         | 1            |
|                                        | II group       | 6         | 12                  | 16                        | 6            |
| Desire for self-education              | I group        | 18        | 15                  | 6                         | 1            |
|                                        | II group       | 8         | 12                  | 14                        | 6            |

The analysis of the results allows us to conclude that the basic knowledge and skills in mathematics among students of both groups do not differ significantly (62.5% of students in the control group and 70% of students in the experimental group solved at least 3 tasks out of 5 correctly). Significant differences are observed among students in other indicators. The students of the experimental group coped with the tasks of bioengineering much more successfully – 67.5% of the students of the experimental group and only 7.5% of the students of the control group were able to solve at least 4 tasks of the second block of control work. Motivation to study mathematics and the desire for self-education were also higher among students of the experimental group.

It was found statistically significant that the reliance on bio-oriented approach to teaching higher mathematics to students of bioengineering specialties help forward:
- formation of research skills, the ability to operate mathematical tools in solving research problems;
- understanding the place of mathematical science in future professional activity, increasing students’ motivation to study mathematics;
- formation of a stable system of mathematical knowledge and skills, the ability to use the acquired knowledge and skills for real professional problems;
- formation of students' readiness and ability to independent educational and cognitive activity.

A comparative study of the results obtained in both groups allowed us to draw a conclusion about the effectiveness of the bio-oriented approach in the educational process in higher mathematics.

The results of the students of the experimental group allowed to answer the research question: the implementation of bio-oriented approach has a positive impact on the quality of mathematical training of bioengineered personnel.

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