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Teaching Higher Mathematics to Students of Natural Sciences: Problems and Solutions

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***Abstract*—The article is considered the possibility of solving the problems of mathemat-ical training of students of natural sciences. One of the main problems is the study of mathematical laws, theorems and formulas is carried out on an ab-stract level, isolated from the problems of biology, chemistry, geography etc., solved by mathematical tools. Having mastered the course of higher mathe-matics, learning to calculate derivatives and integrals, solve differential equa-tions and find statistical characteristics, students have no idea where this knowledge can be applied in their future specialty. This level of mathemati-cal training of students seriously reduces the space of professional tasks within their competence. The article presents the possible ways to eliminate the mathematical isolation and create interdisciplinary connections. The au-thor presents tasks of biological, chemical, ecological and other content which allows demonstrating the relationship of mathematics with the natural sciences increases the level of motivation and mathematical culture of the students of natural sciences.**

Keywords—Higher Mathematics, Mathematical Tasks of Natural Science Content, Stu-dents of Natural Sciences, Motivation, Validity of Mathematical Knowledge

I. Introduction

The essential part of professional activity of specialists in the field of natural sciences is the knowledge of mathematical methods, ability to carry out mathe-matical modeling of biological, chemical and ecological processes. The signifi-cance of mathematics in the development of natural sciences is noted by re-searchers from all over the world (Parcer, J.E. [16], Murray, J.D.[14], Grossman, S.I. [5], Smith, J.M. [18], Chasnov, J.R. [3], Kepchik, N.V. [9], Terent'ev, P.V. [20]). In this regard the students of natural sciences should be proficient not only in mathematics. They also should be able to apply their knowledge to solve cur-rent problems given by chemistry, biology, ecology, geography and other scienc-es.

Analysis of educational traditions of Russian universities revealed a number of problems in the higher mathematics teaching to the students of natural sciences:

- substitution of the mathematics course by other disciplines ("Biometrics", "Mathematical methods in biology", "Mathematical methods in chemistry", "Mathematical methods in geography", "Mathematical modeling of chemical pro-cesses" and so on), the study of which is reduced to discussion of mathematical statistics. Dropping of other sections of higher mathematics leads to a decrease in the level of mathematical education and professional competence of students and to a distorted interpretation of using the body of mathematics in their future pro-fessional activity.

- teaching of mathematics is carried out in a way disoriented to special sub-jects. The material of the higher mathematics course for the students of natural sciences differs from the course for the students of physicomathematical disci-plines by a simplified program (theorems are learned without proving, "useless" topics are excluded). The studied material is presented in a strictly formalized form, the examples are computational by nature, and their content is not associat-ed to the student specialization.

- limited educational literature for the students of natural sciences. Russian textbooks and teaching aids do not take into account the student specialization. For example, the teaching aids "Mathematics for Medical Colleges" [10], "Tasks in Higher Mathematics for Biologists" [1] do not have any examples of medical or biological content.

The students' misunderstandings of the role of mathematics in the future pro-fession, a distorted idea of importance of mathematics for development of sci-ence are the result of the specified problems. Students do not find the answers to the traditional questions: "Why should I learn Maths?", "How will mathematics help me in my future profession?" In addition, after passing the course of math-ematics students state that "biologists (chemists, geologists, ecologists) do not need Mathematics".

The wrong idea of students about the lack of demand for the studied mathemat-ical formulas, theorems and laws leads to a decreased motivation and forms a negative attitude to the mathematical science in a whole.

Later, the graduates of natural science specialities run into difficulties solving professional issues due to the limited mathematical education. Students, even knowing the obligatory formulas and laws, cannot use them in specific real situa-tions.

The analysis of works dedicated to the mathematics study (Evans, J, Wedege, T. [4]; Köller, O., Baumert, J., Schnabel, K. [11]; Hannula, M.S. [6]; Brown, M., Bibby, T. [2]; Onion, A.[15]; Hernandez-Martinez, P., Vos, P. [7]) reveals the similar problem in many countries: the students "found mathematics to be a dull subject and they could not see the use of mathematics in their future life, for their course or career plans" [13, p. 45].

The analysis of problems in organization of educational process in mathemat-ics helped formulate the main points of investigation: low level of motivation of the students of natural sciences to study higher mathematics and lack of under-standing of importance of the acquired knowledge for the future profession.

The research question was as follows: can the problem of low motivation of students and lack of understanding of importance of the acquired knowledge and skills in mathematics be eliminated by including mathematical tasks of natural science content in the educational process, also as the review of the analyzed mathematical concepts from the point of view of the future profession.

II. Mathematical Tasks of Natural Science Content

Solving problems in the mathematic classes is a relevant part of learning. At the same time, it is important to understand that "solving a problem means finding a way out of a difficulty. A way around an obstacle, attaining an aim which was not immediately attainable. Solving problems can be regarded as the most characteristically human activity" [17, p.9].

Mathematical tasks, aimed to increase motivation of students of natural sciences and their understanding of relevance of mathematical knowledge and skills, should represent a natural science issue which can be solved by tools of mathematics.

The purposes of use of mathematical tasks of natural science content are:

1. formation of the students' understanding of relevance of the knowledge and skills acquired in the process of the mathematics study;

2. training of computing skills;

3. training of research skills (analysis of the problem, its formulation, recording the problem in mathematical symbols, search for the solution, interpretation of the result);

4. increasing the level of students' motivation to study mathematics.

In order to make a mathematical task meet the goals, it must meet a number of requirements:

1. the content of the problem, the method of its solution and the result should demonstrate the relationship of mathematics and chemistry, biology, geography, oceanography, etc. (depending on the students' specialization).

For example, one and the same problem for calculating a definite integral can be given in different ways:

First formulation: calculate $\int_0^4 4e^{1,8t}\,dt$.

The second formulation: A bacteria colony increases in size at a rate of $4,05\ 53e^{1,8t}$ bacteria per hour. If the initial population is 46 bacteria, find the population four hours later [19, p.351].

Third formulation: It was experimentally established that the rate of water infiltration into the soil V over time t was determined by the formula $5e^{(-0,5t)}$ cm/h. How much water will be absorbed into the soil in the first 4 hours?

The fourth formulation: The rate of change in the concentration of the radiopharmaceutical drug is $V=2e^{(-0,8t)}$. Find the concentration of the drug after 4 hours.

In all problems it is required to calculate a definite integral of similar functions. However, the first formulation of the problem is strictly formalized and is not of professional interest for students. The second formulation allows demonstrating the biological meaning of the integral; the third one demonstrates application of integration in geography, the fourth one - in chemistry. All in all, one of the main concepts of mathematical analysis acquires a professionally important meaning and thereby stimulates students to cognitive activity.

2. the result should not contradict real biological, chemical, physical laws. For instance, if as a result of solving the problem about the rate of bacteria reproduction, the answer is 100 bacteria/day (when the real rate is 10 million bacteria/day), then this discrepancy leads to disappointment among students in the reliability of mathematical methods.

3. the mathematical tasks of natural science content should be formulated in accordance to the level of knowledge of students in the field of special disciplines. Do not use highly specialized terms, because it leads to the worsen perception of the problem conditions.

4. the method of solving a mathematical task of natural science content should be directed to the development of mathematical skills in accordance with the studied topic.

III. Materials and Methods

Efficiency of mathematical tasks in the educational process was checked during the empirical study within a 36-week, mathematics course for second year students-biologists in the Ryazan State University named after S.A. Yesenin. There were two experimental groups, of 20 students each. Students of both groups attended lectures and seminars. They studied the same topics about matrices and systems of linear algebraic equations, limits, vectors, differential and integral calculus, differential equations and systems.

In the first group study of mathematics was carried out according to the traditional system, in the second group – with the use of mathematical tasks of biological content. The lecture material for the students of the second group contained a variety of examples of use of the material in biology. Mathematical concepts were discussed from a biological point of view, for example, a derivative as a productivity of a population, an indefinite integral - a size of a population, a definite integral - an increase in a population over the period of time. In addition, the students weekly solved mathematical tasks of biological content. The problems were solved at the seminars in the process of individual or group work under the guidance of a teacher, as well as in the process of independent out-of-class work of the students. The students introduced solutions of the tasks in writing to the teacher for verification.

The mathematical tasks were selected to show the usefulness of mathematics to biology. For example:

1) Find the rate of growth of yeasts, if their mass over the time approximated by m(t)= 〖1,05〗 ^t where t is the time in hours.

2) An evergreen nursery usually sells a certain shrub after 6 year of growth and shaping. The growth rate during those 6 years is approximated by dh/dt=1,5t+5 where t is the time in years and h is the height in centimeters. The seedlings are 12 centimeters tall when planted (t=0). Find the height after t years. How tall are the shrubs when they are sold? [12, p. 374]

3) Assume that W(t) denotes the amount of radioactive material in a substance at time t. Radioactive decay is then described by the differential equation

dW/dt=-λW(t) with W(0)=W_0, where λ is a positive constant called the decay constant. Solve the differential equation. Assume that W(0)=123 gr and W(5)=20 gr and that time is measured in minutes. Find the decay constant λ and determine the half-life of the radioactive substance [8, p. 404].

In order to estimate the impact of mathematical tasks of biological content on the level of motivation of the students and their understanding of relevance of mathematical knowledge for biology, the students of both groups after their course of higher mathematics were asked to answer two questions and to solve three tasks.

The following questions were suggested:

1) Do you think that formulas and theorems of mathematics will be useful for you as a biology specialist in your future professional activity? If yes, which one(s)?

2) Would you like to study mathematics in future and why?

The first question was aimed at assessing the students ' understanding of relevance of mathematical knowledge for future professional activities. The second question allowed assessing the level of motivation of the students to study mathematics.

The following tasks were offered:

1. The average life expectancy of a wild reindeer is 25 years. In the second year of life females begin to bring forth - 1 fawn per year. The fecundity of females from the age of 12 reduces – on average 1 fawn per 2 years. Reproduction continues until the age of 20. Half of fawns live up to sexual maturity, 78% of which will reach the age of 12. The probability of a deer to live up to 20 and 25 years is 46% and 24% respectively. 1. Build a matrix model of the wild reindeer population. 2. Predict the dynamics of the reindeer population based on local field data (the number of females is taken in connection with the polygamy of males): newborns – 214, young deer from 2 to 12 years – 698, from 12 to 20 years – 320, older than 20 years – 58 individuals.

2. 500 bacteria are introduced into the culture medium. Determine the maximum number of bacteria, if the change in their number over time occurs by the law

B=500+500t/(50+t^2) .

3. Find the size of the population N(t), if at the initial time its size was 100 individuals and population growth is subject to the logistic equation dN/dt=2N(1-N/900).

The tasks were aimed at assessing the ability of students to use the mathematical knowledge and skills to solve real problems of the professional field.

The solution of each task was evaluated according to the 4-point scale:

1 point - the task is not solved, the student could not translate the problem condition into the mathematical language and solve it.

2 points - the student managed to see the mathematical basis of the problem, made an attempt to create a mathematical model of the described biological process, outlined the course of the solution.

3 points - the student correctly determined the mathematical component of the problem, translated the problem into the symbolic language of mathematics, however, in the course of solving the task at the abstract level, made minor errors of computational nature.

4 points - the task is completed correctly.

Answers to the questions were also evaluated according to the 4-point scale.

Evaluation criteria for the first question:

1 point-the student does not understand the importance and significance of the studied mathematical concepts, laws, formulas and theorems for future professional activity.

2 points-the student does not deny the possibility that some of the knowledge will be useful in the future, but can not specify the answer.

3 points-the student believes that certain formulas and theorems are of undeniable importance for the future profession, can give several examples of their use.

4 points-the student appreciates importance of mathematical methods for a biologist, understands what tools can be useful in future professional activity.

Evaluation criteria for the second question:

1 point-the student has a negative attitude to the study of mathematics, there is no motivation.

2 points-the student studies mathematics because of the need to pass the exam with a high score, the attitude to the discipline is neutral.

3 points-the student positively assesses the need to study mathematics, there is personal and professional interest, however, despite understanding of importance of the subject, doubts the possibility of self-study of mathematics in the future due to its complexity.

4 points-the student demonstrates a high degree of interest in the subject expresses a desire to deepen the knowledge, has a desire for self-education in mathematics and mathematical biology.

The groups were compared by three indicators:

1) motivation to study mathematics;

2) validity of mathematical knowledge for future professional activity;

3) mathematical competence of a biologist, i.e. the ability to apply mathematical knowledge, methods, skills of mental activity to the problems of biology, carrying out educational and search activity necessary for their solving, an objective assessment of results of the work, and a desire for self-education in the field of mathematical biology.

The level of mathematical competence C was calculated as an arithmetic mean of the points gained for the solution of three problems:

$$C = \frac{\sum_1^3 a_i}{3}, \quad (1)$$

where a_i is a point for i task.

IV. Results

The Table 1 shows the number of students in each group who scored the corre-sponding number of points for each indicator.

TABLE I. THE RESULTS OF EMPIRICAL RESEARCH

Indicators	Points (level)	1 (low)	2 (interme diate)	3 (upper-interme diate)	4 (hig h)
Motivation	I group	11	6	2	1
	II group	1	3	10	6
Validity of mathematical knowledge	I group	15	3	1	1
	II group	1	3	4	12
Mathematical competence	I group	14	4	2	0
	II group	3	7	8	2

Analysis of the answers of the first group students confirmed the existence of problems in the existing system of mathematical education of biology students. The students demonstrated low level of motivation to study mathematics, lack of understanding of the role of mathematics for development of biological science, difficulties in operating the existing mathematical knowledge and skills in trying to solve a non-standard problem of a professional nature. Only one student of this group said that "Mathematics is a very important discipline that allows you to solve problems in different fields of knowledge" and he would like to understand mathematics better.

The students of the second group answered questions and solved control tasks after including mathematical tasks of biological content in the course of education and consideration of the studied mathematical methods from the standpoint of importance for the biological science.

These students gave a positive assessment of the study of mathematics. At the same time, only 6 students expressed a desire to further in-depth study of this discipline. Other students explained their unwillingness to study mathematics further by its complexity, at the same time these students (except 4) understand the importance of knowledge of mathematical methods: "What we know now about the nature and mechanisms of many biological processes, would be impossible without mathematics". Most students (12 people) answered the question about mathematical formulas and theorems and their application in biology in a detailed way, giving various samples of use of mathematical tools in those areas of biology, which seemed the most important to them. Moreover, the students showed good results in solving control tasks.

The comparative analysis of the results obtained in both groups allowed drawing a conclusion about effectiveness of use of mathematical tasks of biological content, as well as adapted lecture material in the process of the mathematics study.

The results of the second group of students helped answer the research question: the use of mathematical tasks has a positive effect on the level of motivation of students and their understanding of relevance of the acquired mathematical knowledge.

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