Mathematical competence development of bachelor of engineering

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Abstract. The authors of this article draw attention to the fact that engineering education requires deep knowledge in mathematics and its methods that are fundamental for many disciplines and contribute to the development of a fundamental system of training students during their university study. Attention is focused on the need to introduce heuristic professional tasks into the studying process that develop mathematical competence among students, which includes motivational, value-based, cognitive, activity-based, reflexive and evaluative aspects. The need for the development of mathematical competence that increases intellectual base of a competitive specialist in modern society is determined in the article.

1. Introduction
Natural science disciplines the basis of which is mathematics play an important role in bachelor’s training in the field of engineering.

The solution of many tasks in various field of the state activity, no matter if it is economic, intellectual, military or any other activity, largely depends on the level of knowledge and qualification of personnel. Therefore, the issues of training and improving the talent pool are of high priority, which resulted in the inclusion of a competency-based approach into the system of education.

This component provides for the development of business qualities, independence in solving various problems and is aimed at students’ ability to gain, advance and apply the acquired knowledge both in the educational process and in real life situations.

The competency-based approach is also important for agricultural universities as the activity of bachelor engineering students is changing and improving in modern conditions, and, consequently, the requirements for their professional training are increasing steadily. Graduates of such HEIs should have good knowledge in the chosen field, be ready to work in any conditions, as well as be ready for self-education and self-development. In this article, the authors consider the mathematical competence of future engineers of an agricultural university. Besides, it should be kept in mind that the department of the Tyumen Region is ready to support future specialist as far as his/her employment is concerned [1]. In the long run the requirements for learning outcomes, taking into account the specific requirement of HEIs are reflected in the Federal Educational Standard in various areas of training.

Future engineers’ training in an agricultural institution is characterized by a number of features. Along with the general subjects students receive engineering education based on natural science
disciplines. The majority of students are young men, and according to the survey that was held at Northern Trans-Ural State Agricultural University in 2017 one of the priority values among young men is the job [2].

Engineering field of studies requires deep knowledge of mathematics, which is a fundamental aspect for many disciplines. It also contributes to the fundamental system of students’ training during the period of study at the university. The regional agricultural higher educational institution nowadays provide the areas of training necessary for the development of talent pool and planned work of agricultural industry [3, p. 79].

Future engineering specialists need to develop the skills of lifelong learning throughout their professional careers; they have to understand what role they play in the society and shall be ready to take right decisions of social importance. After all, as the future head of a company, he or she not only has to strengthen weak bonds, but also competently and professionally manage human resources [4]. The task of teachers is to train such competitive specialists whose thinking is flexible and open in order to cope with the growing information flow in the modern world. Employers need such graduates who can work in difficult conditions, who possess huge intellectual resources and who have practical skills.

As it is noted by R.S. Pionova, the fundamental character of education ‘can be ensured by fundamentalization of knowledge throughout all disciplines of general scientific, general professional and special training of students’ and as a result ‘the main features of fundamental knowledge and education content should be the integrity of perception of the scientific picture of the world; the disclosure of the essence of facts in the studied field; the development of ability to synthesize knowledge from different fields; the formation of interdisciplinary knowledge; a high level of flexibility, contributing to understanding the essence, the interrelation of facts and phenomena from various fields of science and practice’ [5, p. 91].

The aim of this study is to consider the development of mathematical competence aimed at shaping the ability to use sections of mathematics and its methods in solving professional problems that increase the intellectual resources of a competitive specialist in modern society.

The concept of competence or competency is a substantive generalization of theoretical and empirical knowledge presented in the form of concepts, principles and system-forming provisions [6]. The main component of professional competence is mathematical competence, which was studied by such scientists as L.V. Vasyak, V.V. Poladova, S.A. Tatyanaenko, and others. The professional competence of a future engineer depends on the quality of mathematical training based on mathematical competence.

According to N.A. Kazachek mathematical competence is represented as an integral property of personlity expressed by deep and solid knowledge in mathematics, the ability to apply existing knowledge in a new situation, ability to achieve significant results and quality in the activity. In other words, mathematical competence presupposes a high level of knowledge and experience of independent activity on the basis of this knowledge [7].

In the opinion of V.G. Plakhova the mathematical competence of students studying at engineering universities is the ability of the students to apply the system of acquired mathematical knowledge, skills and abilities when studying mathematical models of professional problems, including the ability of logical thinking, evaluation, selection and application of information, as well as making independent decisions [8].

On the basis of the foregoing it can be concluded that mathematical training of future bachelor students of engineering fields should be directed into the development of mathematical competence of students.

Knowledge of the discipline is driven by the need to translate into the mathematical language and to apply mathematical apparatus which represents an interconnected set of language, models and methods of mathematics for solving engineering issues in specific areas. This implies the need for students to master mathematical competence, which includes motivational, value-based, cognitive, activity-based, reflexive and evaluative aspects.

The problem of mathematical competence covers the following items: the regulation of terminology in this field of knowledge; identification of specific nature, properties, content, as well as the
establishment of components, levels and attributes of the development of this competence; choice of mechanisms, pedagogical methods, forms and tools for its development; conditions and opportunities for implementing this task in a specific engineering and educational environment. In the process of studying mathematics the idea of becoming a student agency consists in determining a student as a carrier of activity, initiative and individual experience, striving to disclose and implement his or her potential by virtue of the studied subject [9].

The development of subject knowledge and skills in the field of mathematics is carried out in the process of teaching students during the first and the second years of their study. To increase motivation of students in the study of mathematics, practical tasks are applied which are the link between mathematics and professional disciplines [10].

2. Objects and methods
The study was carried out on the basis of Northern Trans-Ural State Agricultural University in 2016-2018. The study involved 150 first year and second year students. The experiment was held during practical classes of mathematics. An experimental and control groups were determined. Classes with the control groups were held by other teachers on the basis of traditional methods. The groups of studied training areas in the engineering fields were examined in mathematics using tests of the Russian testing center. The analysis of test results showed there were no significant differences regarding knowledge and skills in mathematics in experimental and control groups. The following research methods were used: analysis of psychological, educational and methodological literature on the topic of the study, as well as comparison and generalization of the content of concepts and categories; comparative analysis of learning outcomes; qualitative and quantitative analysis of the data obtained.

3. Results and discussion
Mathematics course in the area of engineering training of Northern Trans-Ural State Agricultural University contains many tasks that correspond to the fundamental preparation of students. In the process of training, 7 ‘basic’ and 3 heuristic professional tasks were considered, including 5 scientific reports which were prepared on the topics of professional problems that reveal motivational and value-based aspects of mathematical competence.

The experiment was divided into four stages. The goals were set for each stage. Besides, the content was determined (practical tasks based on the model of future bachelor) and diagnostic tools (test works) were compiled according to the level of students’ preparation.

The subject content of each stage was presented in the form of modules, i.e. specific sections of mathematics course, in which, according to the purpose of the study, fundamental knowledge was broadened and practical skills in solving bachelor professional tasks were deepened. For the experimental groups a motivational module was introduced that revealed both motivational and value-based aspects of mathematical competence. Each module was delivered according to the following layout:

- solution of tasks which correspond to fundamental training;
- analysis of basic professional practical tasks;
- performance of standard calculations by students which include basic professional tasks;
- individual sessions with students aimed at solving heuristic professional tasks;
- individual work of students aimed at solving heuristic professional tasks.

The initial stage included module the main idea of which was to demonstrate the connection between mathematics and the profession. The module is aimed to develop mathematical competence and positive attitude for studying mathematics. The motivational module included tasks and tests that do not require knowledge of the university mathematics course [11]. The learning outcomes demonstrated students’ mastering of some basic knowledge of the main questions on discipline [12].
Examples of tasks and tests included in the initial stage of training module:

- **Task 1.** Calculate the area of the forest for cutting, if the area is bounded by lines: \( y = x^2 \) and \( y^2 = x \)?

- **Task 2.** It has been experimentally established that the dependence of gasoline consumption of a car on the speed \( v \) on 90 km path is expressed by the formula: \( Q = 15 - 0.3v + 0.003v^2 \), where \( 30 \leq v \leq 110 \). Determine the average gasoline consumption if the speed is \( 65 \text{-} 80 \) km/h.

- **Test** The angle between moving platforms the motion direction of which is characterized by the vectors \( \overrightarrow{AB} \) and \( \overrightarrow{AC} \), and is equal to ..., if A (-1; 2; -3), B (0; 1; -2), C (-3; 4; -5):
  
a) -0.33; b) 0; c) -1; d) 1.

The first stage included such training modules as linear algebra and analytical geometry; differential calculus.

In addition to fundamental knowledge mastering and solving abstract problems in these areas of mathematics, the emphasis was placed on the analysis of algorithms of basic professional tasks, as well as typical calculations that include basic professional tasks.

**Module: Algebra and Geometry**

**Task.** When recycling tires, an automatic machine is used.

Let \( V \) be the matrix of transfer functions:

\[
V = \begin{pmatrix} 2 & 1 \\ 3 & 5 \end{pmatrix}
\]

\( W \) is the matrix of regulators:

\[
W = \begin{pmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \end{pmatrix}
\]

It is required to synthesize correcting devices \( W_{12} \) and \( W_{21} \) in order to ensure the autonomous disconnection of the system (i.e. the diagonal elements are zero) if the open system has the following form: \( V_{pc} = W \cdot \bar{V} \). **Recommendations.** Use the matrix multiplication algorithm.

**Module: Differential Calculus**

**Task 1.** A 20 m long wire is required to enclose an experimental part of the forest which should have the shape of a circular segment. What should be the radius of the circle so that the area of the experimental part is the largest?

**Task 2.** It is necessary to build a container for tools. The perimeter of the container lid should be 30 cm. Determine the dimensions/size of container lid for which less material is required.

**Task 3.** Find the speed of a tractor at an arbitrary point of time \( t \) and at time \( t=2 \) h. The dependence of tractor’s distance (i.e. the length of plowed field) on time is expressed by the formula \( s(t) = \frac{at^2}{2} \).

The results of diagnostics of the first stage on the basis of control tests are presented in Fig. 1.
Module: Function of Two Variables

Task 1. Let \( u = 3x^2 + 2xy \) be the production function, where \( x \) is the cost of living labor, \( y \) is the cost of social labor. Find the elasticity of the function at the point \((1;1)\).

Module: Differential Equations

Task 1. The rate of increase in the area of a young leaf which has the shape of a circle is proportional to the radius of the leaf and the amount of the sunlight falling on it. The amount of the sunlight is proportional to the area of the leaf and the cosine of the angle between the direction of beams and the vertical to the leaf. Find the relationship between the area \( S \) of the leaf and the time \( t \) if at 5 a.m. this area was 1,500 cm\(^2\) and at 6 p.m. on the same day it was 2,400 cm\(^2\). The angle between the direction of the sun beam and the vertical at 5 a.m. and at 5 p.m. was 90°, and at noon it was 0°.

Task 2. The motor boat moves in calm water with the speed amounting to 22 km/h. At full speed its engine shuts off and 40 seconds after the speed of the boat is reduced to 9 km/h. The water resistance is proportional to the speed of the boat. Determine the speed of the boat 3 minutes after the engine shut off.

Figure 1. Results of diagnostics of the first stage of experiment.

Figure 2. Results of diagnostics of the second stage of experiment.
The analysis of the data obtained during the diagnostics of the second stage of experiment (Fig. 2) showed that the level of performance in the experimental group has increased in comparison with the control one. The average score in the control group was 12.5 and in the experimental group it was 14.7. This led to the conclusion that there were differences in practical skill regarding application of several variables, differential equations and series in the control and experimental groups.

The third stage included the following training modules: probability theory, mathematical statistics, optimization methods.

In addition to mastering fundamental knowledge and solving abstract tasks in the denoted areas of mathematics, the emphasis was placed on the individual work of students in solving heuristic professional tasks and problems. The heuristic task is the best way to instantly draw attention and stir cognitive interest, as well as to bring one step closer to the discovery. A holistic heuristic task requires the following skills: to analyze its conditions; to transform the main problems into a number of specific problems subordinated to the main one; to design a plan and stages of the solution; to hypothesize; to produce various directions of searches; to check the decision, etc. [13]. The second stage included the following training modules: functions of several variables; differential equations; series.

In addition to mastering fundamental knowledge and solving abstract tasks in these areas of mathematics, the emphasis was placed on individual studies with students in solving heuristic professional problems.

Examples of tasks included in the second stage of the training module.

**Module: Probability Theory**

Task 1. The probability that the height of the birch is more than 1.75 m is 0.85. Make a series of distribution of the number of birches with the height of more than 1.75 m from 6 available ones on the plot. Calculate the mathematical expectation and variance.

Task 2. There are three header-thresher Yenisei in the agricultural company, performing seasonal agricultural tasks. According to the technical condition during the task performance the first header-thresher can be sent for repairs with the probability of 0.05, the second header-thresher can be sent for repairs with the probability of 0.15 and the third one with the probability of 0.3. Define the probability of breaking down exclusion of header-thresher during the task performance.

**Module: Mathematical Statistics**

Task 1. Let some part of the forest plantation of the second class of bonitet with the 20 year old pines be fertilized. 10 years after, both the experimental and control plantations were measured which were similar 10 years ago, i.e. they had average diameters of 9.9 (control) and 10 cm (experiment), and ten years later they were 13.0 and 14.2 cm, respectively. The error of the mean value was 0.23 and 0.3 cm (30 years). Check the effect of the fertilizers using Student’s t-test.

Task 2. Find the equations of the linear regression $Y$ on $X$ if the dependence of the number $X$ (rpm/min) of the engine rpm speed and engine power $Y$ (kW/h) is given in Table 1.

| $x_i$ | 0 | 4 | 10 | 15 | 21 | 29 | 36 | 51 | 68 |
|------|---|---|----|----|----|----|----|----|----|
| $y_i$ | 66.7 | 71 | 76.3 | 80.6 | 85.7 | 92.9 | 99.4 | 113.6 | 125.1 |

**Module: Methods of Optimization**

Task 1. To improve the financial situation, the company’s management decided to increase the output. To do so it was necessary to install additional equipment in one of the workshops with area of 46 m$^2$. For the purchase of this equipment, 10 conventional monetary units (CMU) were allocated using which one can buy 2 different types of equipment: A - 1 set costs 1 CMU and allows to increase the output by 2 items and in this case 2 m$^2$ of the area are required; B - 1 set costs 3 CMU and allows to
increase the output by 4 items, which requires 1 m$^2$ of the area. Identify a set of additional equipment, which makes it possible to maximize the output. Task: solve the problem graphically.

Task 2. The farming company requires the pits of types 1 and 2 for agricultural needs. To accomplish the task, 3 excavators 30B 4421, 2 cranes 8T210, 2 bulldozers and 60 workers were allotted. The lead time is 15 hours. Determine what type and number of pits is appropriate to erect in order to occupy the largest area of the allocated field? Data to the task shall be taken from Table 2.

Table 2. Find the equations of the linear regression $Y$ on $X$.

| Indicators of resource use | Units | Pits for agricultural needs |
|---------------------------|-------|-----------------------------|
| Machine capacity          |       |                             |
| - excavation              | 1.5   | 1.5                         |
| - installation            | 1.25  | 1.15                        |
| - backfill                | 0.75  | 1.2                         |

$x$ is the number of pits of type 1; $y$ is the number of pits of type 2; $(x, y)$ is the maximum possible area.

Working group capacity on excavation:
1) three excavators for 15 operation hours - 45 machine-hour;
2) two cranes for 15 operation hours - 30 machine-hour;
3) two bulldozers for 15 operation hours - 30 machine-hour;
4) 60 workers for 15 hours of work - 900 man-hour.

Task 3. A specified number of tons of fuel and lubricant materials is stored at two railway stations. They need to be delivered to three farms in the Tyumen Region in the required quantities. The cost of transportation from the stations to the destinations is known (Table 2). It is required to make such plan of transportation where the total cost of transportation would be minimal. All numerical parameters of the task are specified in Table 3.

Table 3. Initial data for transportation task.

| Departure point | Destination | Stocks (t) |
|-----------------|-------------|------------|
|                 | B1 | B2 | B3 |         |
| A1              | 2  | 5  | 3  | 100      |
| A2              | 8  | 4  | 6  | 150      |
| Needs (t)       | 75 | 80 | 95 |          |

At the end of the third stage a final test was held the results of which are shown in Fig. 3.

The analysis of the data obtained during the diagnostics of the third stage of experiment showed a significant performance improvement in the experimental group as compared to the control group. The average score received by students in the control group was 12.4 and in the experimental group this number amounted to 15.1. This made it possible to draw a conclusion about the varying degree of development of practical skills in applying probability theory, mathematical statistics, and optimization methods in the experimental and control groups. Hence, it can be stated that mathematical competence is enhanced by activating cognitive interest in the study of mathematics by understanding the importance of the subject material in practical activity [14].
4. Conclusion

1. The form of the trainings and the method of knowledge representation depend on both subjective and objective factors. The traditional teaching methods should be combined with the innovative methods.

2. Modern educational methods should be applied to improve the mathematical competence of students and to better understand the material of engineering disciplines.

3. For the mathematical trainings of engineering students to be effective, it is necessary to include professional heuristic tasks containing special terms of engineering disciplines and the latest intellectual resources of the agro-industrial complex. Not in vain P. V. Zuev wrote in his famous monograph ‘the effectiveness of learning is a measure of achievement by both the student and the teacher of positive result of educational knowledge in the course of their joint activity with the rational use of resources of the subjects of this activity and the environment in which the learning process takes place’ [15].

4. One has to agree with S.V. Kulikova that ‘creation of good conditions for training of a competent specialist in the system of continuous education’ [16] ensures an intellectual base and mathematical competence formation that promotes the development of a mobile and skilled worker in the agrarian sector of the market.

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