RACIOCÍNIO DE ENGENHARIA E MEIOS DE INTRODUÇÃO EM ESTUDANTES DE INSTITUIÇÕES DE ENSINO SUPERIOR

ENGINEERING THINKING AND WAYS TO FORM IT IN STUDENTS OF HIGHER EDUCATIONAL INSTITUTIONS

ИНЖЕНЕРНОЕ МЫШЛЕНИЕ И СПОСОБЫ ЕГО ФОРМИРОВАНИЯ У ОБУЧАЮЩИХСЯ ВЫСШИХ УЧЕБНЫХ ЗАВЕДЕНИЙ

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Received 20 November 2018; received in revised form 09 December 2018; accepted 28 December 2018

RESUMO

A experiência prática de implementar as tecnologias de formação raciocínio de engenharia em estudantes de instituições de ensino superior é apresentada neste artigo. A formação do raciocínio de engenharia através da abordagem de competências é possível devido ao estudo não só do curso de aulas teóricas, mas também da solução de problemas práticos com a introdução de métodos de ensino interativos. Estudos têm demonstrado que o uso de várias técnicas no processo educativo aumentam significativamente a percepção do material teórico pelos alunos e, mais importante, o interesse em uma disciplina e a necessidade de adquirir, preservar, multiplicar conhecimentos.

Palavras-chave: *Raciocínio de engenharia, competência, métodos de ensino interativos, uma abordagem orientada para a prática.*

ABSTRACT

The practical experience of implementing the technologies of forming engineering thinking of students of higher educational institutions is given in the paper. The formation of engineering thinking through the competence approach is possible due to the study not only of the theoretical lecture course but also the solution of practical problems with the introduction of interactive teaching methods. Studies have shown that the use of various techniques in the educational process has markedly increased the perception of the theoretical material by the students, and, importantly, the interest in a discipline and the need for acquiring, preserving, multiplying knowledge.

Keywords: *engineering thinking, competence, interactive teaching methods, a practice-oriented approach.*

АННОТАЦИЯ

В работе приведен практический опыт реализации технологий формирования инженерного мышления обучающихся высших учебных заведений. Формирование инженерного мышления посредством компетентного подхода возможно благодаря изучению не только лекционного теоретического курса, но и решению практических задач с внедрением интерактивных методов обучения. Исследования показали, что использование различных приемов в образовательном процессе

заметно повысило восприятие обучающимися теоретического материала, а также, что немаловажно, интерес к дисциплине и потребность в приобретении, сохранении, приумножении знаний.

Ключевые слова: инженерное мышление, компетенции, интерактивные методы обучения, практико-ориентированный подход.

INTRODUCTION

At the beginning of the XXI century, a huge role belongs to machines and technology, which leads to a comprehension of the phenomenon of "engineering thinking", which is an object of study of various sciences: both humanitarian and engineering (Sazonova and Chechetkina, 2007; Pohlkov *et al.*, 2015; Rakhmankulova *et al.*, 2015, Rozhik, 2015; Igolnik, 2018).

An interdisciplinary approach for the formation of one of the most important types of thinking that is necessary for solving engineering problems, aimed at obtaining results, solving the set goal, is the main task of engineering education in the preparation of graduates (Shalai *et al.*, 2016; Prokhorov, 2016). Along with traditional knowledge, abilities, and skills, competencies based on a practice-oriented approach to the results of the educational process are brought to the forefront.

What is topical today is that the engineer's thinking should not only contain knowledge and skills in professional activity, but be based on the abilities of independent work, resourcefulness, ingenuity, creativity, responsibility, the ability to analyze, predict, and conduct research (Mustafina *et al.*, 2016; Zuev and Koscheeva, 2017). Therefore, the synthesis of deep theoretical and fundamental knowledge and highly developed practical skills is an important aspect of the education system of students (Piven and Pak, 2001; Rogotneva, 2013).

THE SUBJECT OF RESEARCH AND WAYS OF FORMING ENGINEERING THINKING IN STUDENTS OF HIGHER EDUCATION INSTITUTIONS

The subject of the study is the educational process using interactive teaching methods to form one of the priority areas in education – engineering thinking of students in higher education.

Since one of the main tasks of higher education is the preparation of graduates who are ready for professional work and possess engineering thinking, teachers with the help of various interactive teaching methods apply a competency-based approach in education aimed at the formation of general cultural (GC), general professional (GPC) and professional (PC) competences. The formation of a competency-based approach is possible due to the study not only of the lecture theoretical course but also the solution of practical problems, which is the subsequent formation and development of the graduates' engineering thinking (Khairullina, 2003; Khairullina, 2007; Kvashnina *et al.*, 2009). At the same time, various pedagogical technologies both in lectures and in practical and laboratory classes implement:

- information and communication technology;
- modular training technology;
- project-based learning technology;
- resource-saving and health-saving technologies;
- traditional technology based on the principles of didactics.

Also, in practical classes, critical thinking technology is used, for example, with the help of the following methods: the method of control questions on a given topic, "mutual interrogation," brainstorming, and essays.

It is very important in the process of training to prepare students for the practical orientation of the acquired knowledge, therefore, in the process of training with the purpose of forming engineering thinking, the following pedagogical methods can be used: simulation games that represent the relationship of simulation modelling and role behavior of participants in the process of solving typical professional and educational tasks. For example, according to the training manual for students of higher education institutions of the oil and gas profile "Environmental Protection" (Starikova *et al.*, 2000), published by teachers of our

department and admitted by the educational and methodological association of Russian universities in oil and gas education, while studying the discipline "Ecology" and considering the topic "Study of the cycles of substances in the environment" it is possible to organize a game "Carbon cycle", which gives an idea of the continuous cycle of carbon atoms in the biosphere. Also, elements of the game are used in the study of the discipline "Life Safety", which is the basic (compulsory) part of the professional cycle of disciplines of all specialties and training areas included in the federal state educational standards for higher education (FSSES HE) and curricula.

So, for example, the tasks of the business game "Public actions in emergency situations" are control of knowledge and skills on the topics "Emergency situations of civil and military time" and "First aid to victims"; development of speed-strength training; development of communicative abilities of students. The game-like form of the lesson is created with the help of various methods: inclusion of sound effects, carrying out of relay evacuation, the announcement of chemical danger, the creation of situations for the organizing a post for chemical observation, first aid to a teammate. Practice shows that the following elements should be included in the game scenario: introductory word of the instructor with the explanation of the tasks of the lesson, assessment system, signal of the civil defense "Attention to all!", emergency broadcast network announcement, relay-evacuation and dressing in personal protective equipment against the clock, as well as an algorithm for providing first aid to the victims.

Also in the learning process, the case method (Ekimova, 2014; Aitbaeva, 2015; Vinevskaya, 2015; Lipatnikova and Mechik, 2018) (the analysis of a specific situation and the solution of situational problems) is widely used, the advantage of which is the opportunity to optimally combine theory and practice, which seems to be quite important in the learning process. When developing engineering thinking, it is desirable for students to apply this approach repeatedly during the academic year or module, since in the future the graduate develops a stable skill in solving practical problems (Tolochina, 2013). Here are some examples of formulations of tasks: "Develop a method for the reclamation of oil-contaminated lands..."; "Draw up a flowchart and describe the sequence of actions..."; "Develop measures to clean up the

water body..."; "Draw up a structural diagram of the sequence of works on the reclamation of disturbed lands...". Also, with the help of the case method, it is proposed to conduct a practical work on the topic "Calculation of natural and artificial lighting in a production room", which is presented in the training manual for students of higher education institutions of the oil and gas profile "Life Safety and Industrial Safety", published by teachers of our department and admitted by the educational and methodological association of Russian universities in oil and gas education (Starikova, 2002) when studying the discipline "Life Safety". In the course of this practical work, students calculate the coefficient of natural light, luminous flux and are engaged in selecting lamps for a specific room.

In order to form a competence approach in the process of studying the material, the group method of training is used. As an example, let us take the method of "facilitation" (Kalashnikova and Malinin, 2014; Dimukhametov, 2006; Fil, 2013) as a professional organization of the process of group work, involvement, increasing the interest of students, as well as maximizing their potential and forming engineering thinking. A concise psychological dictionary explains this concept in the following way: "increasing the speed or productivity of an individual's activity due to the actualization in his mind of the image of another person (or group of people) acting as a rival or observer of the actions of that individual" (Rais, 2014). So, as an example, let us take a practical work on the topic "Investigating and recording accidents at work", which is performed by a group method. In the process of this work, subgroups consisting of 4-6 people conduct an investigation of an accident, make up an act in the form N-1, and draw conclusions (Starikova, 2002).

Also, the method of facilitation of group work can be applied when performing practical work on the topic "Study of individual psychological properties and personality relations by the method of generalized independent characteristics." The method of generalized independent characteristics, developed by K.K. Platonov, involves generalizing judgments about the personality properties of the person being studied. According to this method, a number of persons (who know him well), for example, classmates, are asked questions about the characteristics of the activity, behavior based on typical cases of the life of the assessed employee. Generalization of estimates makes it

possible to neutralize random judgments, while stable forms of behavior are reflected in the consistency of estimates. Ultimately, there is a way to evaluate the properties "by life indicators," which has long been recognized in labor psychology (Starikova, 2002). In the course of this practical work, students are divided into subgroups of 4-6 people, one person is assessed by all representatives in the subgroup, which reduces the role of chance. Then a psychogram of the individual and a psychogram of the profession are built, a comparative analysis of the correspondence between the properties of the personality and the requirements to these properties of the profession is made, the most important professional qualities are singled out.

The technology of modular training is used for students of the area "Technospheric Safety": disciplines are grouped into modules, which presupposes the formation of new experience and its theoretical comprehension through practical application. The theoretical lecture course is consolidated by practical studies on production and pre-diploma practices. Continuous practical training of students is realized with the purpose of expansion and consolidation of theoretical knowledge obtained at the university through the gradual study of production processes at industrial sites of enterprises, as well as mastering advanced technologies, professional skills, methods of work and management, and gaining experience in the production team. The educational process for modular training is organized by alternating theoretical training, implemented on the basis of the university and practical training, carried out at production sites. In addition to practices, teachers of the department regularly arrange field trips to industrial enterprises for students in order to form their engineering thinking.

Solving the tasks of modern education is impossible without increasing the role of independent work of students compared to study material, increasing the responsibility of teachers for developing independent work skills, stimulating professional growth of students, fostering their creative activity and initiative. Independent work of students (IWS) is a planned work of students, performed on the instructions and with the methodical guidance of the teacher, but without his direct involvement (Petrov and Filipovskaya, 2016; Petrova and Filipovskaya, 2016). At the department "Technospheric Safety" the following types of IWS have realized: an extracurricular independent work; classroom

independent work, which is carried out under the direct supervision of the teacher; creative work, including research work. Extracurricular activities include, for example, the assignment "Collection of minerals" in the discipline "Earth Sciences": students are encouraged to take photographs of various minerals used in the construction of buildings, structures, architectural monuments in Tyumen with their detailed description. Training for the discipline "Expertise of industrial safety" involves working in groups and conducting an independent examination of the industrial safety of a hazardous production facility. At the end of the semester, students present the report to the teacher.

The use of software tools in the field of computational modeling in the preparation of students for the area "Technospheric Safety" is aimed at the formation of general professional and professional competencies: the ability to perform computer modelling of the studied processes, as well as to take into account the current trends in the development of information technology in their professional activities. Therefore, the use of software today should not be just a recommendation, but an integral part of the educational process and must be included in a compulsory program that ensures effective and high-quality training of students. To date, some of the most popular software tools are from the field of numerical simulation. Their use helps to solve a number of tasks to ensure industrial and environmental safety, in particular, relevant for the area of "Technospheric Safety".

With a traditional training system, performing laboratory work on real installations can be difficult in terms of safety. For example, when carrying out the laboratory work "Study of the flame-extinguishing process in the gap," it is necessary to use flammable chemicals, some of which also refer to extremely hazardous substances from a toxicological point of view (for example, benzene). To solve this problem in the discipline "Life Safety" several virtual laboratory works have been developed:

- Study of the effect of the height of the suspension of light fixtures on the illumination of workplaces and the voltage deviation from the nominal;
- Study of lighting parameters of artificial light sources;
- Study of the flame-extinguishing process in the gap;

– Study of the fire hazard of building materials.

To write the algorithm for such works, real installations were used, which are available in the laboratory of life safety of the department "Technospheric Safety". Virtual laboratory work allows using any substances, regardless of the degree of their danger. Virtual laboratory works are quite an effective and safe replacement of traditional works performed on real installations and can be successfully used in teaching technical disciplines.

For the purpose of forming professional competencies of students, work programs, for example in the disciplines "Ecology", "Life Safety", can be supplemented with sections (topics) that correspond to the qualification characteristics that the graduate needs to carry out a certain type of professional activity, function, i.e. work programs must include the federal state educational standard in various areas of training and the professional standard. So, according to FSES HE in the area of training 20.03.01 "Technospheric Safety" (bachelor's level), the field of professional activity of graduates who mastered bachelor's programs includes ensuring human security in the modern world, creating a technosphere that is comfortable for human life and activity, minimizing the technogenic impact on the environment, preservation of human life and health through the use of modern technical means, methods of monitoring and forecasting (Order of the Ministry of Education..., 2016). Let us give an example of a number of professional standards:

– a specialist in environmental safety (in the industry), the main objective of the professional activity is developing a set of organizational and technical measures aimed at ensuring environmental safety, minimizing the negative impact of economic and other activities in the industry on the environment (Order of the Ministry of Labour..., 2016);

– a specialist in the field of labor safety – the prevention of accidents at work and occupational illnesses, the reduction of the level of impact (elimination of impact) of harmful and (or) hazardous production factors, occupational risk levels on workers (Order of the Ministry of Labour..., 2014);

– a specialist in ensuring industrial safety in the operation of equipment operating under

excessive pressure and/or lifting structures – the organization and provision of industrial safety for the operation of lifting structures and equipment operating under excessive pressure (Order of the Ministry of Labour..., 2015).

As the experience of teaching with the use of resource-saving technologies shows, it is possible to achieve higher results in training, since only in an atmosphere of psychological comfort and emotional uplift the work capacity of students markedly increases. Therefore, in the educational process, it is important to take into account individual traits and capabilities of the learner; in this regard, it is necessary to promote the saving of mental resources (Makuseva, 2012). So, for example, with the purpose of a positive moral and psychological climate of the team, the study of the processes of developing and adopting a group decision, as well as discovering the leadership qualities of students, in curatorial hours of academic groups the business game "Shipwrecked" is used. It is described in the book "Group Psychotherapy" by Kjell Rudestam, an American psychologist, member of the Academy of Clinical Psychology (Rudestam, 2001). The practice has shown that extracurricular educational work, in particular, curatorial hours using interactive teaching methods, contributes to the creation of a strong, friendly, efficient team of the student group (Kuryachaya, 2017; Mamaeva et al., 2016; Popova, 2015; Ezroh, 2016).

It is also very important to use health-saving technologies in the educational process, namely, to consider the microclimate parameters in the classroom, the correct alternation of activities, the use of business games and group methods in training, the well-being of students and teachers, as all this leads to a better mastery of knowledge, and, as a consequence, to better results.

ANALYSIS OF THE EFFECTIVENESS OF THE USE OF INTERACTIVE TEACHING METHODS:

In the understanding of "engineering thinking" we are in agreement with the opinion of researchers (Ivanov, 1995; Dontsova and Arnautov, 2014) who define this phenomenon as a special kind of thinking that emerges and manifests itself in the solution of engineering problems, allowing quickly, accurately and ingeniously solving tasks aimed at meeting

technical requirements for knowledge, ways, and methods for the creation of technical means and organization of technologies. Therefore, in order to determine the effectiveness of the use of interactive teaching methods, proposed by us in paragraph 2, the questionnaires of students were conducted. 42 people participated in the survey who actively participate in the development of the curriculum, consciously chose the engineering profession and achieve good learning outcomes. The questionnaire offered to evaluate the importance of the proposed competencies in their future profession and the level of their implementation in the learning process.

Each of the competencies proposed in the questionnaire characterizes the development of an element of engineering thinking which has the following structure:

- technical thinking – the ability to analyze the composition, structure, organization, and operation of technical objects in changed conditions;

- constructive thinking – the construction of a specific model for solving the problem posed or a task, which is understood as the ability to combine theory with practice;

- research thinking – the definition of the novelty in the task, the ability to compare with known classes of problems, the ability to argue one's actions, results and draw conclusions;

- economic thinking – the reflection of the quality of the process and the result of the activity from the standpoint of market requirements (engineers need not only knowledge in their field, but also the ability to present their capabilities and realize the result of the activity) (Dontsova and Arnautov, 2014; Mustafina, 2011).

A questionnaire survey shows that students understand the importance of competencies that characterize the formation of engineering thinking. We have discovered that the level of implementation of the proposed competencies, characterizing the development of both the technical, constructive, research and the economic element of engineering thinking is higher in comparison with the importance of the relevant competencies in their future profession (Figure 1). The results of the questionnaire show the high effectiveness of practice-oriented learning and interactive ways of conducting classes at the university.

CONCLUSION:

Thus, the use of various interactive methods in the educational process contributes to the formation of engineering thinking in graduates. This structure of the educational process gives the graduate the ability to analyze technical devices, identify hazards and build models to solve goals and tasks, obtain results, build arguments for their actions, determine the novelty of their research, be ready to solve professional problems. The practice has shown that the introduction of various techniques in the educational process has markedly increased the perception of theoretical material by trainees, and, importantly, has increased the interest of students in the discipline and the need to acquire, preserve and multiply knowledge.

The formation of engineering thinking makes it possible to effectively implement the competencies obtained during training in final qualification papers (Permyakov *et al.*, 2016, Permyakov *et al.*, 2016). Students learn independently and knowingly the subject of papers, analyze literary sources, under the guidance of teachers to conduct research, develop programs. Graduates become highly qualified specialists with the skills of engineering thinking and are ready to practice or continue their studies on masters and post-graduate programs.

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Figure 1. Levels of importance and implementation of engineering thinking skills