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DEVELOPMENT OF PROFESSIONAL ACTIVITIES OF ENGINEERS WITHIN UNIVERSITY STUDY COURSE IN PHYSICS

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Abstract

The article presents the results of the study on methods for developing techniques of design-and-engineering and technological activities that was implemented within a basic course in physics for engineering students of university. Developing techniques of professional activity implementation is theoretically based on the idea that educational goals cannot be developed without specifying a system of profession-focused tasks that are relevant to engineer's professional activities. A distinctive feature of the methodology is the unambiguous definition of the content and methods of organizing physics classes at the university. A training process starts with development of certain actions, carried out by students, that are a part of techniques for design-and-engineering and technological activities, while analyzing specific situations that emerge in engineering practice and that are solved with the use of knowledge gained from a physics course. The results of introducing this method show that students are capable of implementing profession-focused projects and solve real engineering problems on the basis of generic techniques of conducting the activities under study.

Keywords: Design-and-engineering and technological activities, project-focused management, teaching physics

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1. Introduction

An engineer faces complex engineering problems in his/her professional activities. So, his/her reputation of high-skilled expert depends on how efficient these problems are being solved. Engineers must understand and be aware of the complexities of the environment in which they carry out their work. They must be able to recognize the interrelation, circumstances, risks, coincidences, dangers of all phenomena and, consequently, accept to live with uncertainty. Living with the unpredictable favors critical thinking and responsible and creative decision-making in the face of possible alternative scenarios (Sánchez-Carracedo et al., 2021). Universities are capable of training an engineer that will succeed in solving problems related to new equipment development, design and implementation of efficient innovative technologies.

A need of the modern society and industrial production for skillful innovative engineers makes higher education institutions review the traditional training methods. University professors and world professional communities are looking for ways to solve this problem.

2. Problem Statement

To enhance efficiency of engineering training, the Russia's government awarded to a group of higher education institutions a specific status – National Research Universities (NRU). According to Naumkin et al. (2015) it enables to strengthen and integrate a university's scientific, technical and educational potential and to turn it towards inventing a comprehensive strategy for the country's innovative development.

The teaching approaches that were established in Russian universities do not allow students to fully apply gained knowledge for addressing professional tasks (Pokholkov et al., 2020). The analysis of Russian engineering education carried out by the Association for Engineering Education of Russia showed that graduates are insufficiently prepared for conducting professional activities. Pokholkov et al. (2018) identifies the following problems of Russian engineering education: disproportionality between the distribution of higher educational institutions by regions of Russia and the territorial distribution of production facilities, seclusion from international educational networks and low quality of admission (weak school knowledge of many prospective students). Purysheva and Isaev (2020) states that the average score for the exam in physics does not change over time and averages 52 points.

Engineer's activities result in a technical object with the following stages of its cycle of a technical object: identifying a need for the item design and development; design and engineering; production and testing; operation, repair, maintenance and subsequent disposal.

Crawley et al. (2014), an American professor, developed CDIO – a holistic approach to engineering education that describes general principles of training engineers capable of conceiving a new product, embodying this idea into a real object, implementing it in the production and end-of-life disposal, which corresponds to the stages of a technical object life cycle. Crawley et al. (2018) talks about the experience of implementing CDIO standards at MIT with the aim of transforming engineering education. Currently, more than 100 universities from 30 countries, including Astrakhan State University, are implementing this approach in the educational process.

The research of Kamaleeva (2018) has shown that even in the region with a rather high level of economic development the interested part of teachers has come to an understanding that natural-science and vocational training of students has to meet the requirements of modern labour market according to the requirements of the developed professional standard. The analysis of professional activities which the Bachelor students of most engineering majors in Russia are prepared for allowed to identify that the main of them are design-and-engineering, production-and-technological, management and scientific-and-research activities. These very activities contribute to training of new-generation engineers that can adapt to changing conditions and technologies (Krutova & Valisheva, 2012). Despite the fact that types of activities which are to be mastered by different-major engineers during their studies are the same, their implementation will result in different end products.

Implementing these activities is impossible without knowledge in physics. Many engineering activities involve professional tasks that require knowledge in physics. Physics forms the basis of equipment and technology and offers wide range of opportunities for teaching students to address professional tasks.

During the study of physics, it is can to prepare the student for the professional activities. In order to master these activities, students are to study a certain system of actions that can be widely applied anywhere. It is necessary to teach them how to plan and implement this system of actions and to develop a generic technique for activities implementation.

Any type of activities has its own way of implementation that is a sequence of interconnected actions. An action is the main unit of an activity. An action turns into operation if a repeatedly-achieved goal becomes strongly associated with the way of its achievement, if it stops being conscious and starts being automatic and becomes a condition for performing the next action in the activity structure (Talyzina, 2019).

Each activity action has its goal that is intermediate in respect to the activity main goal. Actions are logically connected, as the end product of each previous action is used in the following one as an object or means (Talyzina, 2019). Actions sequencing leads to the goal achievement and gaining the end product. The goal achievement activity must pass through the cycle stages of goal-setting, planning, implementation and control. If the result obtained at the last stage does not correspond to the planned one, it is necessary to go back to the first stage and undergo all four stages from the very beginning in order to obtain the best result.

3. Research Questions

At the research is to find the answer to two questions emerge:

- What professional activities must engineers be prepared for at university?
- What methods must be applied for training engineers in order to prepare them for addressing professional tasks?

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4. Purpose of the Study

The purpose of the study is to theoretically substantiate and develop a methodology for the formation of students in technical areas of training methods for performing design and technological activities. The methodology for the formation of methods for performing these types of activities among bachelors is implemented in teaching physics. It is designed for students, training "Mechanical Engineering", profile "Equipment and technology of welding processes".

5. Research Methods

The study involved BA students of the major “Mechanical Engineering”, specialization “Equipment and Technology of Welding Engineering”. Physics methods allow to develop design-and-engineering and technological activities in engineers undertaking these study course. As noted above, these activities have different end products, which is connected with specificity of an engineer’s field of study. Let us specify the BA students’ design-and-engineering and technological activities by goal and end product that can be developed through studying physics: 1) activities on design and development of a technical object (drawing and designing); 2) activities on developing a technology for quality control over a technical object as a whole or its separate element (technological); 3) activities on developing a technology to eliminate defects of a technical object as a whole or its separate element (technological).

At this stage of the product development, it is necessary to describe correctly all stages of the production process. Apart from manufacturing technology, professional activities of Bachelors of welding must also include development of technologies for 1) quality control over a technical object as a whole or its separate element, and 2) eliminating defects of a technical object as a whole or its separate element.

Inability to conduct professional activities related to structural design, develop welding equipment and ensure welding technology compliance leads to accidents at hazardous industrial facilities. Therefore, the main activity of a welding engineer is to master three types of his/her professional activities:

Design and development of a technical object (drawing and designing activity). The content of the developed generic technique is presented in Table 1.

Table 1. Content of the generic technique for design and development of technical objects

Action	Operations on carrying out the action
Defining activity goal	To determine the activity type → to specify its end product (object) and its properties.
Identifying a physical phenomenon that is the basis of the designed object operating principle	To designate a physical phenomenon; to define the object under study → to choose an actor → to determine conditions of their interaction → to describe an expected result of their interaction.
Plotting a schematic diagram of the designed object	To enumerate all the elements of a schematic diagram → to choose legend keys for the elements → to identify how separate elements are linked → to connect all the elements in the appropriate sequence → to make sure that the plotted diagram can reproduce the designed object functioning.
Calculating parameters that describe essential characteristics of the designed object.	To specify the calculation goal → to sort out parameter(s) describing operation capacity of the designed object → to describe processes that occur as a result of interaction between the object under study and the actor → to write equations describing this interaction → to solve the obtained equations relative to a required

	physical value → to calculate the values of the parameters that describe essential characteristics of the designed object.
Selecting necessary equipment (materials, devices).	To determine materials and devices necessary to produce the object → to mark out the equipment operational factors that correspond to the calculated parameters → to determine whether this equipment can be used in the given conditions → to determine rules of the equipment operation and connection.
Drawing up the algorithm to produce the designed object	To describe actions that allow to achieve the goal if done sequentially.

Development of a technology for quality control over a technical object as a whole or its separate element (technological activity). The content of the developed generic technique is presented in Table 2.

Table 2. Content of the generic technique for development of a technology for quality control over a technical object as a whole or its separate element

Action	Operations on carrying out the action
Defining activity goal	To determine the activity type → to specify its end product (object) and its properties.
Identifying a physical phenomenon that allows to control the technical object quality.	To determine the object or its part to be monitored → to mark out those monitored parameters of the object status that must correspond to standard parameters → to specify the standard parameters of the object status → to mark out the physical phenomena, processes and effects that allow to fix, measure and determine characteristics (numerical and visual) of the object deviation from the standard.
Plotting a schematic diagram of the device that allows to detect the technical object defects.	To define the object under study → to choose an actor → to determine the conditions of their interaction where the specified physical phenomena, processes and effects are possible to implement → to determine which actions (and in which sequence) are to be carried out in order to fix the monitored characteristics of the object status parameters → to develop a schematic diagram of the facility (technical equipment) that allows to fix the monitored characteristics of the object status parameters.
Selecting necessary equipment (materials, devices).	To determine materials and devices necessary to produce the object → to select necessary equipment by operational factors and to determine whether this equipment can be used in the given conditions → to determine rules of the equipment operation and connection.

Development of a technology to eliminate defects of a technical object as a whole or its separate element (technological activity). The content of the developed generic technique is presented in Table 3.

Table 3. Contents of the generic technique of carrying out activities on developing a technology to eliminate defects of a technical object as a whole or its separate element

Action	Operations on carrying out the action
Defining activity goal	To determine the activity type → to specify its end product (object) and its properties.
Identifying a physical phenomenon that is the basis of the designed object operating principle	To define a physical phenomenon → to define the defect of the object under monitoring → to determine rated parameters of the condition of this object and compare them with the defected ones → to specify the physical phenomena, processes and impacts that cause the defects to emerge.
Plotting a schematic diagram allowing to detect defects of a technical object	To define the object of studies → to choose actor → to determine conditions of their interaction providing for full elimination of the cause of defect or conditions permitting to decrease defects, in case it is impossible to eliminate the cause → to determine the necessary actions and their sequence to eliminate defects or reduce them → to develop a conceptual installation scheme (of a technical device), providing for full elimination of the cause of defect or conditions permitting to decrease deviations from the rated parameters of the object.

So, over the period of studying physics at university, students must learn how to design and develop a technical object. A technical object of mechanical engineering is understood as an individual element that is a part of machines, devices and structures or an assembly of the elements that are a structure as a whole and that are made through welding or are used in it. This very object is to be designed and developed by a welding engineer. Having designed and developed it, an engineer is to think about a manufacturing technology and production management. Numerous technologies are implemented in welding engineer's professional activities. Technology types can be sorted out through analyzing basic processes of mechanical manufacturing. As noted above, a life cycle of a technical object starts with its design. This stage includes research and developmental activities, preproduction engineering and different organizational issues of manufacturing.

In order to master these activities, students are to study a certain system of actions that can be widely applied anywhere. It is necessary to teach them how to plan and implement this system of actions and to develop a generic technique for activities implementation.

The proposed method was tested at Astrakhan State University within the course of physics for engineers studying "Mechanical Engineering".

Developing the defined techniques of carrying out design-and-engineering and technological activities in students should take place at practical lessons of physics while solving a system of profession focused tasks. Each action comprising the contents of the generic technique has its own goal which is also an intermediate goal for the general purpose of the activity and requires special training by means of solving problem-exercises in physics with formulations describing situations comparable to professional ones but requiring the knowledge of only one physics topic.

It is rational to develop the techniques of carrying out the mentioned engineer's activities in the sequence corresponding to the life cycles of a technical object, thus, we can define the stage when each type of activities is developed within the framework of studying university course of physics.

In the first term the techniques of design-and-engineering activities, corresponding to the second stage of the life cycle of a technical object, is developed, the second term is dedicated to the techniques of activities on developing a technology for quality control over a technical object as a whole or its separate element (the third stage of the life cycle), the third term is intended to master the techniques of activities on developing a technology on eliminating defects of a technical object as a whole or its separate element (the fourth stage of life cycle). The stage of the life cycle of a technical object and process when the demand for the design and production of a product arises corresponds to the goal specification and precedes any type of activity.

Development of the techniques of carrying out professional activities is based on the idea stating that mastering engineers' professional activities should be included into engineering education goals. For this purpose, it is necessary to define the system of profession focused tasks comparable to engineer's professional activities and teach students to solve them referring to the generic techniques.

These types of activities can be developed if a system of profession focused tasks is used in the process of teaching physics. This system includes tasks of three levels: 1 –problem-exercises in physics, 2 problem-tasks in physics, 3 – profession focused projects. The formulations of the tasks describe situations comparable to professional activity.

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When students solve problems included into the system in a stage-by-stage manner, they develop the skills of implementing the techniques of specific types of professional activity. In particular, solving problems-exercises helps to promote carrying out separate actions comprising the techniques of conducting each type of engineer's professional activity. Repeated solving problems-exercises models the techniques of carrying out professional activities upon the whole. The mastered techniques are implemented in the professional activities when professional focused projects are carried out after the course of physics is finished.

Let us cite an example of solution of such tasks.

To model the action connected with specifying physical phenomenon, related to the determining of a physical phenomenon underlying a definite phenomenon or working principle, the students can be asked to solve the following problem-exercise: *define the phenomenon causing coloring of steel in the process of hardening or welding of steel products*.

The next example illustrates a problem-exercise providing for the modeling of students' actions related to plotting a schematic diagram of a device: *Plot a schematic diagram of a device intended to measure wedge angle of plates and working on the basis of optical phenomena*.

It is possible to model actions related to the calculation of parameters describing relevant characteristics of an object when computing problems-exercises are solved. The following problem-exercise can serve as an example: *Define which welding cable should be chosen to gain more advantages: an aluminum cable or a copper one, taking into consideration that 1 kg of a copper cable costs three times more than an aluminum one, but the durability of the former is 1.5 times longer. The welding current is 220 A*.

The process of solving problem-exercises models the techniques of carrying out professional activity upon the whole. Let us give an instance of a problem-exercise aimed at mastering the technique of carrying out design-and-engineering activities: *Design a device (mechanism) automatically feeding a 1-mm diameter welding wire into the welding area at the speed equal to 9 m/min.*

The next example illustrates a problem-exercise helping to master the technique of developing a technology for quality control over a technical object: *Develop a technology of detecting welding seam defects based on optical phenomena.*

The techniques of carrying out professional activities are mastered while studying the course of physics, and they are employed when profession focused projects are realized upon finishing the course of physics. For example, in the course of teaching "Calculating and designing welding constructions", students are asked to design truss floors for a factory shop according to work specification.

A distinguishing feature of this system of profession focused tasks is their orientation towards sequential development of the techniques of carrying out professional activities.

6. Findings

To assess the development of students' design-and-engineering and technological activities in solving profession focused problems, the following tasks were set:

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- to form generic techniques of carrying out design-and-engineering and technological activities among students;
- to assess quality development of generic techniques of carrying out design-and-engineering and technological activities among students;
- to assess students' ability to apply generic techniques of carrying out design-and-engineering and technological activities for implementing problem focused projects.

7 teachers and 243 students took part in a training experiment.

In the course of the experiment, the development level of the following skills was determined:

- defining type of professional activity according to the purpose and to the activity end product;
- determining techniques of carrying out professional activities in general;
- applying activities of the defined techniques to the solution of a certain profession focused problem-tasks;
- applying generic techniques for conducting design-and-engineering and technological activities in the implementation of educational, research projects and projects that reflect the problems of real production.

The assessment took place during the final check, which was carried out over the last university semester for the students, while executing the training, research projects and projects reflecting the real production problems. Final results were obtained after students defending different projects that reflected professional direction.

These results were assessed as well as the last semester questionnaire dedicated to the frequency assessment of the applying generic techniques on professional activities implementation while executing the graduation project and tasks needed to be completed during the internship.

The questionnaire form for students consisted of 7 questions (4 open questions and 3 "yes-no" questions). The questionnaire was carried out in absolute anonymity.

The results showed that 83% respondents of the experimental group regularly apply the generic techniques on professional activities implementation in welding production while executing the graduation project. 72% respondents state the necessity of using knowledge of physics while completing the tasks of graduation projects and 65% - during the period of graduation internship.

7. Conclusion

The analysis of the state of the problem of professionally directed training in physics for bachelors of technical universities, are prepared that the lack of research aimed at shaping design and technological activity in bachelor students and substantiating the need to develop a methodology for teaching physics specified professional activities.

A distinguishing feature of this system of profession focused tasks is their orientation towards sequential development of the techniques of carrying out professional activities.

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The authors developed the models of methodology intended to develop the generic techniques of carrying out professional activities in engineers. It is allows to succeed in developing the techniques of conducting professional activities in students. Experimental teaching that proves the following fact: training BA students of the major "Mechanical Engineering" ways to complete profession-focused tasks in studying physics enables to form professional activities types in welding production among students.

The developed teaching methodology can be applied in order to form methods of completing professional tasks by engineer in different areas: shipbuilding, instrument making industry, automotive engineering, aircraft industry.

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