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A System of Pedagogical Support for the Implementation of an Activity-Based Approach in the Training of Competent Engineers

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***Abstract*— The article substantiates the theoretical and methodological foundations for the introduction of an activity-based approach to training competent engineers when studying a course of physics. Contemporary requirements of the agro-industrial complex require integration of the fundamental knowledge with practical skills, which makes this approach the key element of the educational process when studying a course of physics. There are considered the concepts and principles of teaching, aimed at the development of professional thinking, the ability to make decisions in non-standard situations and efficient work with digital technologies, when studying the course of physics. There are identified the pedagogical tools that promote the development of critical thinking, independence and continuous self-development of the students in the process of mastering physics. Methodological recommendations are provided for the creation of a productive educational environment, including interaction with agro-industrial enterprises and individualization of learning when studying the physics course. An analysis of the implementation of the activity-based approach showed its efficiency: the average score of the students in the experimental group increased by 15–20%, and the success rate of completing the practical assignments increased by 20–25% when studying the physics course. The project activities contributed to the development of systems thinking and an innovative approach to solving the production problems, which is especially important when mastering physics. A conclusion is made about the need to introduce an activity-based approach to train competitive specialists, adapted to the modern challenges of the agro-industrial complex, which, in turn, contributes to the formation of an innovative educational environment, focused on the development of professional competencies, engineering creativity and practical training of the students when studying the physics course.**

Keywords — activity-based approach, engineers, innovations, practice-oriented training, professional training, Introduction

I. Introduction

The rapid development of the agro-industrial sector gives rise to a demand for training specialists of a fundamentally new format, who possess not only a solid theoretical base but who are also able to solve prompt y applied problems, to master contemporary technologies and implement innovations in practice, which is especially important when studying a course of physics. The traditional models of education often do not allow the future engineers to acquire to the full extent the required practical skills and abilities, which becomes noticeable when mastering physical disciplines.

In this regard there is a need to introduce a multifaceted activity-based approach that gives the students an opportunity to design independently professional assignments, seek out non-standard solutions and improve critical thinking, especially when studying a course of physics. However, the implementation of such an approach is often faced with the problem of the lack of a systemic pedagogical support that would combine the optimal selection of methods, effective assessment tools and full-fledged mentoring.

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The traditional teaching practices do not always provide sufficient orientation to the development of activity-based, project and research skills in the future engineers, which becomes especially evident when studying the course of physics. The lack of a comprehensive system of pedagogical support for the introduction of an activity-based approach into the educational process hinders the development in the students of the necessary competencies, flexibility of thinking and the ability to make independent decisions in difficult production conditions, which negatively affects the study of physics.

Over the past decade's issues of implementing an activity-based approach in training specialists have retained the status of one of the main topics of scientific discussions, invariably arousing interest of the researchers and teachers. The research into the problem of the activity-based approach among the specialists of various profiles was revealed in the scientific works of [1] - [4] and others.

The works [5] – [7] present the results of a study on the introduction of the active learning methods (team projects, debates, presentations) in the training of the future agricultural engineers. The authors emphasize the importance of a systematic methodological support and mentoring of the teachers, which ensures efficient assimilation of theory and simultaneous acquisition of practical skills, including when writing scientific papers [8].

In the investigation there are treated interdisciplinary approaches to training engineers, including the integration of agricultural, engineering, economic and environmental disciplines. The researchers analyse the results of the embedded courses and seminars that helped the students to think systematically and solve multidisciplinary problems [9].

Application of digital simulations and virtual models in the educational process is described in the works [10] – [13]. Interactive tools have been shown to enhance the understanding of complex technological operations and allow the students to experiment safely with the parameers of the production system. It is shown how the interactive tools enhance understanding of complex technological processes and allow the students to experiment safely with the parameters of the production system.

Although scientific and methodological investigations analyse carefully the problem to be considered, they often lack practical recommendations and particular solutions for its efficient elimination when studying a course of physics. The substantiation and development of a system of pedagogical support for the implementation of an activity-based approach in the training of the future engineers, aimed at integrating fundamental knowledge with practical skills, the development of professional thinking, critical analysis and the ability to make decisions in real production conditions when studying the physics course became the main goal of our study. Modern approaches and methods for solving scientific and practical problems, considered by the researchers in various fields come to the help here [14], [15].

This article is aimed at theoretical substantiation and presentation of a model of the system of pedagogical assistance that promotes comprehensive implementation of an activity-based approach to the training of engineers who are studying a course of physics, as well as at presenting the results of its experimental testing in a real educational process.

Thus the search and scientific substantiation of an efficient mechanisms for the pedagogical support of this process is an urgent task, the solution of which will increase the competitiveness of the graduates in the labor market and ensure their contribution to an innovative development of the agro-industrial complex when studying the course of physics.

II. MATERIALS AND METHODS

The activity-based approach expresses an idea that the main condition for successful learning is the involvement of the students in active and conscious activities that are close to real professional practice. In the context of training engineers, the students' activities should include analytical, design and technological components that reflect the key aspects of their future specialty. The practice-oriented way of training ensures the formation of professional competencies, necessary for the development, operation and maintenance of agricultural machinery, the implementation of digital solutions in the agro-industrial complex and rational use of natural resources.

To achieve this complex result, educational programs, based on the activity-based approach are needed: laboratory and practical classes, the research and project works, as well as industrial practices. However, the key factor in the efficiency of such programs is a systematic support of the teachers who provide methodological, advisory and organizational assistance to the students at all stages of their studies. To implement the activity-based approach, we used the following implementation principles:

A. Activity and independence.

This principle involves a transition from passive perception of information by the students to their conscious and active participation in the educational process. It is implemented through the creation of conditions in which the students do not simply receive ready-made knowledge but are actively involved in the development and implementation of their own projects; they formulate hypotheses, and look for ways how to solve practical problems. The teacher here plays the role of a consultant and mentor, helping the students develop self-study skills and determine their own learning path. The principles of activity and independence in teaching physics to the engineers are aimed at involving the students into the learning process, developing their ability to solve problems independently and apply the knowledge in practice. Here are some examples of their use:

1. Creating a model of a solar panel for a farm (the students independently study the materials about the physics of solar energy; they calculate the coefficient of

efficiency of the panel and select appropriate parameters for a particular region).

2. Development of a setup for measuring the soil moisture (the students independently design the experiment, select sensors, determine the influence of the physical factors, such as temperature and pressure).

3. Modelling the operation of the irrigation system (the students solve problems about calculation of pressure in the system, required for uniform distribution of water across the field; they must select independently the parameters of the pump, take into account the lift height and losses in the pipes).

4. Reducing the energy costs for cooling the grain storage facilities (the students study the heat transfer processes, perform calculations for the wall insulation, and select optimal materials and cooling methods).

This approach helps the engineering students understand better physics and its application in their professional activities.

As a result of such an educational project, the future engineers learn to apply physical and engineering laws to solve very real problems in the agricultural sector. Active involvement and independence at every stage – from calculations and design to the analysis of the obtained data – forms a deep understanding of the theory and increases motivation for further development of more complex technological solutions.

B. Practical orientation approach.

For this purpose, examples and cases, reflecting the modern requirements of the market o fan agro-industrial complex are introduced into the training program, whether it be research into new agricultural technologies, analysis of digital solutions in the agro-industrial complex, or the development and testing prototypes of technical devices. A practice-oriented approach helps the students to understand the value of their knowledge and skills, it helps them to establish a link between theory and practice, and also develops the ability to make decisions in conditions that are as close as possible to real production situations (Table 1):

TABLE 1. PRACTICE-ORIENTED APPROACH IN STUDYING THE COURSE OF PHYSICS

The task	Practical application
Studying of mechanical properties of materials, used in agricultural machinery.	Conducting the laboratory work to determine the modulus of elasticity, tensile strength and plasticity. This can be linked to the analysis of the choice of materials for ploughs, seeders or other machines.
Studying of Newton laws and the dynamics of rotational motion.	Calculation of torque and angular velocity of the shaft of a tractor or other agricultural machine, followed by the analysis of their efficiency in real operating conditions.
Studying of the heat transfer and basic laws of thermodynamics.	Modelling the operation of grain dryers or the engine cooling systems. For example, you can perform an experiment to calculate the heat loss and select materials for insulating the drying chambers.
Studying of the basics of electromagnetism and the laws of electrical circuits.	Building an electrical circuit for the irrigation systems or greenhouse lighting. You can also study the use of electromagnetic motors in modern agricultural installations.
Studying of the laws of hydrodynamics (for example, the Bernoulli equation).	Analysis of a pump operation in the irrigation systems, calculation of pressure in the pipelines and their capacity.
Study of the principles of operation of optical devices and light radiation.	Studying of the optimal light spectrum for growth of plant in greenhouses and calculation of the required power of lamps.

This approach not only increases the students' interest but also prepares them better for real professional work.

C. Integrativeness.

One of the key features of the training of engineers is the need to combine engineering, agronomic, economic and managerial aspects. The principle of integration implies the development of a systemic vision of the production processes in the students and the ability to use knowledge from different areas as a complex. This can be accomplished through interdisciplinary modules, group projects and research tasks that require the students to draw knowledge from multiple disciplines. Due to this the future specialists are able to interact more efficiently with various participants in the agro-industrial process and offer solutions that take into account the technological, economic and environmental factors. The principle of integration in the teaching of physics to the engineers proposes combination of the knowledge from different disciplines, an interaction between theory and practice, and the application of physical principles in professional activities. This allows the students to see physics as part of a complex system of knowledge and understand better its applied significance. An integrated approach to studying physics for engineers allows for efficient linking of physical processes with other sciences and professional tasks. In integration with biology the students study the heat exchange in the plants, such, as moisture evaporation through the leaves, and they model microclimates in the greenhouses, analysing changes in temperature and humidity depending on the time of the day and external conditions. The inclusion of chemistry helps to understand the corrosion processes of the agricultural equipment, where the students conduct experiments to study the effects of various conditions on the metal corrosion and develop methods to prevent it. Integration with mathematics is manifested through the calculation of the vibration parameters of the agricultural machinery, such as amplitude, frequency and period of oscillations, with the creation of mathematical models for the analysis of their impact on the quality of work. The use of the computer science allows the students to model electromagnetic fields and develop computer models of electrical circuits to automate, for example, irrigation systems, using the software tools, such as MATLAB or COMSOL Integration with engineering design includes tasks on calculating irrigation systems taking into account the hydraulic resistance, where the students create drawings of such systems using the engineering software, such as AutoCAD. Such an approach develops systemic thinking, strengthens the link between theory and practice, and develops skills for the solution of complex tasks.

The application of the principle of integration in the study of physics allows one to strengthen the link between theory and practice, which makes the learning process more meaningful and useful for the students. This promotes the development of systemic thinking, allowing the students to see the interrelationships between different disciplines and apply the physical laws to the real-world tasks. During the training process skills for complex analysis of professional tasks are developed, which are necessary to solve practical problems in engineering. In addition, demonstrating the applied significance of physics in professional activities increases the students' motivation to study it, making education more interesting and oriented to the future career. In addition, demonstration of applied importance of physics in the professional activities increases the students' motivation to study it, making education more interesting and career-oriented.

D. Continuity.

Pedagogical support and organization of the educational process should be structured in such a way that the students have a constant opportunity to receive the feedback, to correct their actions and reflect on the material covered. In practice this principle is manifested in systematic consultations, regular monitoring of the academic performance with analysis of achievements and mistakes, and involvement in reflective activities (diaries, reports, group discussions). The continuous way of learning promotes conscious acquisition of the new material and the students' ability to maintain professional fitness in the rapidly changing agricultural sector. The principle of continuity in the study of physics for engineers ensures consistent and systematic development of the knowledge and skills, related to their professional activities. The training is structured in such a way that each new stage is based on the previous one: from studying the basics of mechanics and thermodynamics to an in-depth understanding of electromagnetism and hydrodynamics. The constant link between theory and practice is achieved through the laboratory work, project assignments and solution of professional asks, such as the analysis of the irrigation systems, the calculation of thermal processes in greenhouses or the study of the dynamics of agricultural machinery. Interdisciplinary integration with mathematics, chemistry and biology strengthens the understanding of physics as part of the engineering system. As a result, the students gain a holistic understanding of the subject, strengthen their skills in solving complex tasks, and better understand the practical significance of the processes being studied.

III. Results and discussion

The experimental testing was accomplished with the aim of testing the efficiency of an introduction of the system of pedagogical support for an activity-based approach into the educational process of training the future engineers.

The experiment was conducted at the institution of higher education "Podolsk State University" among the students of the specialty 208 "Agroengineering" with a total number of participants of 120 people, divided into experimental and control groups of 60 students each. Approbation of the methods was made on the course of one semester. At the main stage the students in the experimental group completed projects and practical assignments, worked in teams, and regular feedback through questionnaires contributed to a prompt adjustment of the educational process. The results were assessed using a complex approach: the academic performance was analysed, testing, expert assessments and questionnaires were conducted, which made it possible to compare the data of the experimental and the control groups (Table 2).

TABLE 2. RESULTS OF THE EXPERIMENT ON THE IMPLEMENTATION OF THE METHODS OF AN ACTIVITY-BASED APPROACH

Indicator	The experimental group	The control group
Average score of academic performance	Increase from 70 to 84 (increase by 20%)	Insignificant change: from 70 to 72
Indicators of practical skills	Rating – 90 points (growth from 75 to 90, +20%)	Stable level: 75 points
Level of involvement	90% positive feedback, based on the survey results	70% positive reviews
Number of completed projects	13 projects (30% increase, in comparison with 10 basic)	10 projects

The statistical analysis revealed a significant impact of the new methods on the quality of learning: the average score of the experimental group increased by 15–20%, compared to the control group, and the indicators of practical skills improved by an average of 25%. These numerical data have demonstrated the high efficiency of the implementation of the activity-based approach and become the basis for formulating conclusions and recommendations for its further application in the educational practice.

In the research the assessment of the formation of professional competencies was performed in a complex manner. Each of the key indicators – the skills of the project work, the ability to apply theoretical knowledge, the teamwork, critical thinking and independent solution of professional problems – was assessed on a scale from 1 to 10. The students filled out questionnaires where they independently determined their level of proficiency in competencies, and the experts (the teachers and invited employers) gave objective assessments, based on the analysis of practical work, presentations, and the results of completed assignments.

Below is a table in which the results of the assessment of the students' key professional competencies in the experimental and the control groups are compared, indicating the values for both the self-assessment and the expert's assessment:

TABLE 3. RESULTS OF THE ANALYSIS OF THE FORMATION OF PROFESSIONAL COMPETENCIES

Key competencies	**The experimental group**		**The control group**	
	self-assess-ment	***expert assess-ment***	***self-assess-ment***	***expert assess-ment***
Skills of the project activities	8.3	8.0	7.5	7.2
Ability to apply theoretical knowledge	7.8	7.5	7.0	6.8
Teamwork	8.5	8.3	7.8	7.6
Critical thinking	7.6	7.2	7.0	6.5
Independent solution of professional tasks	8.0	7.8	7.4	7.1

The students of the experimental group showed higher results in all aspects considered: the skills of the project activities, an ability to apply theoretical knowledge, the teamwork, critical thinking and an ability to solve independently professional tasks. For example, in the field of the project activities, self-assessment was 8.3, and the expert assessment was 8.0, which significantly exceeds the indicators of the control group (7.5 and 7.2, respectively). A similar picture is observed for the other competencies, which indicates the positive impact of the applied activity-based approach methods. The difference between the groups' assessments confirms that the integration of practical assignments, the teamwork and the systematic feedback contributes not only to the improvement of the students' perception of their own capabilities but also to the objective growth of professional skills, which generally has a positive effect on the development of the professional competence.

The obtained results became the basis for further improvement of the educational programs in studying the course of physics: the areas, where significant discrepancies were noted, received additional attention, and the successful aspects were integrated into the general teaching methods in studying the physics course. Such a method allowed not only to assess the current level of professional training of the students in physics but also to identify particular recommendations how to improve the quality of education and develop the key professional competencies when studying a course of physics. Such a complex approach allows for a comprehensive assessment of the development of the key competencies using both the quantitative and the qualitative methods of analysis.

As part of the study, the students' satisfaction with the learning process was assessed using a questionnaire. Comparative results of the control and experimental groups for the following indicators: average score; successful completion of practical assignments; the skills of project work; the teamwork and students' satisfaction are presented in Fig. 1.

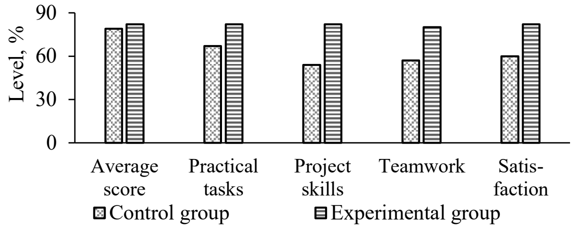

Fig. 1. Comparative results of the control and the experimental groups.

The experimental group showed significant improvement in all parameters, confirming the efficiency of the activity-based approach in the educational process.

It is recommended to expand the use of the activity-based approach to the other academic disciplines, including natural sciences and humanities, which will allow for the development of interdisciplinary thinking and the application of knowledge in practice. Particular attention should be paid to the project activities and the teamwork, which contribute not only to the deepening of professional knowledge but also to the development of soft skills, such as communication, leadership and time management. It is also important to increase the frequency and quality of feedback, providing students with detailed guidance and support to increase their motivation and involvement.

IV. CONCLUSIONS

Experimental testing confirmed that the system of the pedagogical support for the activity-based approach significantly improves the educational results and the students' satisfaction. This approach allows not only to improve the academic performance but also to develop the key professional competencies, necessary for the future engineers to successfully work in the agro-industrial complex. A comparative analysis of the indicators of the experimental and the control groups revealed that the students who studied, using the innovative methodology, demonstrated significant growth in all the key indicators: the average academic performance score increased by 15–20%, and practical skills by 20–25%, which was confirmed by both self-assessment and the expert assessment (the teachers and invited employers). An integrated approach to the assessment, including testing, questionnaires and expert observation, made it possible to objectively identify the positive impact of the activity-based methods on the development of the project skills, application of theoretical knowledge, the teamwork, critical thinking and independent solution of professional tasks.

However, the key feature of our study is not only a quantitative assessment of the efficiency of the project-based learning but also a deep analysis of its impact on the development of the engineering creativity and the students' ability to solve independently real tasks of production. Unlike most investigations where the emphasis is on the traditional forms of training or the use of individual elements of practice-oriented methods [1] – [4] [8] our work examines the comprehensive integration of the project activities, the engineering modelling and interaction with real manufacturing enterprises. This not only improves the students' academic performance but also develops the key skills that are in demand in the agricultural sector.

One of the unique aspects of our research is the inclusion of multi-component engineering problems into the educational process, requiring from the students not only theoretical training but also active application of the knowledge in the conditions of uncertainty. Such an approach helps develop in the future engineers systemic thinking, innovative approaches and the teamwork skills. This aspect is rarely considered in the domestic and foreign investigations where, as a rule, the emphasis is on the use of individual digital tools without a comprehensive assessment of their impact on the students' professional training [9].

Thus our research not only confirms the efficiency of the activity-based approach but also demonstrates new promising methods for training engineers that have not received sufficient treatment in other works. The developed methodology combines elements of the project-based learning, the engineering modelling, flexible educational trajectories and active interaction with the real production processes, which makes it a significant step forward in the field of engineering education. The prospects for further research include the development of digital tools for the individualization of learning, the development of new criteria for assessment of engineering competencies, and the expansion of interaction between educational institutions and agro-industrial enterprises.

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