Innovative Technologies in Teaching Theoretical Mechanics for Agri-Engineers

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Abstract — **The article deals with innovative technologies of teaching theoretical mechanics for agro-engineering education. This discipline forms the basic engineering knowledge critical for the agro-industrial complex. In the context of digitalization, it is relevant to improve teaching methods using digital simulators, interactive platforms and adaptive online courses that visualize complex mechanical processes and facilitate the understanding of theoretical foundations. Special attention is given to the practice-oriented approach that allows students to apply knowledge in real engineering problems. The benefits of innovative technologies include: increasing the accessibility of educational material, developing analytical and engineering skills through simulations, reducing the burden on teachers by automating the verification of calculations, and developing the systemic thinking necessary to solve interdisciplinary problems. The results of the study showed that the integration of innovative technologies into the process of learning theoretical mechanics contributes to increasing the level of material assimilation by 30-40%, increasing student motivation by 30% and improving the quality of engineering calculations by 25% compared to traditional teaching methods. It is concluded that the introduction of innovative technologies in the teaching of theoretical mechanics allows optimising the educational process, making it more interactive, practical and adaptable to the individual needs of students. In order to further improve the quality of engineering education, it is recommended to strengthen interdisciplinary integration, to involve experts from the agro-industrial sector in the development of teaching materials, and to make more active use of digital educational ecosystems that ensure the continuous professional development of future specialists.**

Keywords — *agroengineering, digital simulations, innovative technologies, interactive learning, theoretical mechanics.*

I. INTRODUCTION

With the development of digital technologies and automation in the agricultural sector, there is a need to modernise the methods of teaching technical disciplines, especially theoretical mechanics. The use of innovative approaches makes it possible to provide students with the necessary knowledge and skills to effectively solve practical problems related to the design, operation and maintenance of agrotechnical equipment. The modern development of agroengineering requires a high level of theoretical and practical training of specialists capable of applying knowledge of theoretical mechanics to solve applied problems. However, traditional teaching methods often do not provide a sufficient level of material

assimilation, which reduces the effectiveness of the educational process.

The main problems are: low level of students' motivation to study complex theoretical disciplines; insufficient integration of digital technologies and interactive teaching methods; complexity of visualization of mechanical processes and phenomena; insufficient practical orientation of the course, which makes it difficult to apply the acquired knowledge in future professional activity.

Over the past decades, issues related to the educational information environment in higher education continue to be at the centre of academic discussions. Johnson A., Lee B. [1], Kumar S., Patel R. [2], Lopez R., Gonzalez M. [3], Martinez L., Rodriguez P. [4], Smith J., Brown T. [5], Wang X., Li H. [6] and others.

The combination of traditional teaching methods with online components in teaching theoretical mechanics to agroengineering students is reviewed [1], [2], [3], [4]. The authors analyse the advantages and challenges of blended learning and its impact on students' academic performance. Methodological foundations and pedagogical strategies that allow effective integration of modern information technology in the teaching process are analysed in the work of Zheng, Y. Y. et al.

Xiaomin Shan proposes an innovative approach to teaching theoretical mechanics based on the concept of outcome-oriented education. The author points out the limitations of traditional methods that focus solely on knowledge transfer and justifies the need to introduce a student-centred approach to develop students' autonomous thinking, creative skills and practical competence [7].

Smith, J., Brown, T., Wang, X., Li, H. consider the implementation of innovative methods of teaching theoretical mechanics in the context of agroengineering [5], [6]. The authors consider the use of online simulations, interactive modules, project-based learning and augmented (AR) and virtual reality (VR) technologies in teaching theoretical mechanics to improve student learning. Applying the experience of mathematical modelling and analysis [8], [9] when considering engineering processes allows students to clearly form cause-and-effect relationships and improve learning of even complex material.

A significant contribution to the development of methods of teaching theoretical mechanics using innovative technologies, contributing to the improvement of the quality of education for future agro-engineers was made by: Smirnova N. E., Prishlyak V. M., Boychuk I. P., Morozova O. I., Bat M. I., Janelidze G. Yu. I., Bat M. I., Janelidze G. Yu. V. and others.

The authors [10], [11], [12] consider the introduction of interactive teaching methods for students of agroengineering specialties. The authors analyse the effectiveness of using such technologies as multimedia presentations, virtual laboratories and online tests in increasing the level of material assimilation by students.

Smirnova N. E. analyses modern approaches to teaching theoretical mechanics in the context of agrarian and engineering education. The author points out the shortcomings of traditional methods focused solely on the transfer of knowledge, limiting the development of practical skills and critical thinking of students [12].

Despite many years of scientific discussions, the issues related to the development and implementation of educational information environment in the system of higher education remain relevant. Some aspects, such as the effectiveness of digital technologies in learning, the adaptation of educational platforms to the individual needs of students, as well as the impact of the information environment on the quality of the educational process, require further study. The lack of elaboration of these issues emphasizes the need for additional research aimed at improving the educational ecosystem and increasing its efficiency.

This confirmed the purpose of our research, which was to develop and argue for effective methods of teaching theoretical mechanics for training future agroengineers using innovative educational technologies. In order to assess the effectiveness of innovative technologies in teaching theoretical mechanics for agroengineers, a combination of theoretical and empirical methods was employed. The theoretical methods included analysis and synthesis of scientific literature, modelling of educational processes, generalisation and systematisation of data. The empirical methods comprised pedagogical experiment, observation of the learning process, questionnaire survey of students and teachers, knowledge testing, analysis of teaching materials and digital educational resources. In addition, statistical processing of the data was carried out, including quantitative and qualitative analysis, as well as expert evaluation of the effectiveness of the proposed methodology. This comprehensive approach facilitated the acquisition of an objective depiction of the impact of innovative technologies on the training of future agroengineers.

Taking into account these challenges, it is necessary to introduce innovative technologies in the teaching of theoretical mechanics, which will contribute to improving the quality of education, enhancing the understanding of the material and developing the practical skills of agricultural engineering students.

II. MATERIALS AND METHODS

Application of digital technologies in the teaching of theoretical mechanics contributes to a more effective assimilation of the material by students. In particular, the use of specialized software allows the study of complex mechanical phenomena and contributes to their better understanding.

One of the key areas of digitalization of the teaching process is computer simulation, which allows creating and analysing interactive models of mechanical systems. Such models help students gain a deeper understanding of the regularities of body motion, analyse the equilibrium of structures and study dynamic processes. Modern software

tools such as MATLAB, ANSYS, COMSOL Multiphysics, FreeCad, Autodesk Fusion, Inventor Nastran, allow to perform numerous calculations, visualize results and conduct experimental studies in a virtual environment.

In the course of theoretical mechanic's students study the kinematics and dynamics of mechanisms, in particular, the crank-rod mechanism (CRM), which is the basis of the piston internal combustion engine.

To simulate the operation of the piston mechanism of the tractor and assess the load on its parts in different operating modes, you can use software packages such as MATLAB, FreeCad or MSC Adams.

For example, performing kinematic and dynamic analysis of the tractor piston mechanism and estimation of loads and mechanical stresses includes three main steps:

1. Kinematic analysis – determining the position, velocity and acceleration of the piston, connecting rod and crankshaft.

2. Dynamic analysis – calculation of forces of inertia, moments of forces, reactions in joints.

3. Mechanical stress evaluation – analyse stresses and deformations in piston mechanism parts.

Students proceed to the study of crank mechanism by basic concepts and visualization (Fig. 1). To deepen the knowledge when familiarizing with the algorithm of investigation of working mechanisms, it helps well to study the results of modern scientific research in this industry [13-17].
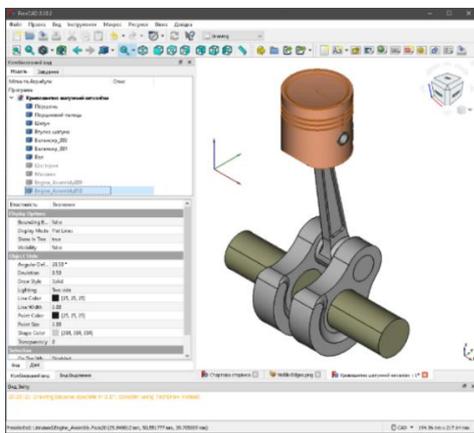

Fig. 1. 3D model of crank connecting rod mechanism in the FreeCad program.

At the first stage, they work with drawings and schematics of the mechanism, determining the main geometric parameters such as the radius of the crank R, the length of the connecting rod L, the position of the piston x, the angular velocity of rotation ω, θ - the angle of rotation of the crank. Using these values, students perform simple calculations such as finding the position of the piston at different phases of crank motion. This helps them to develop an understanding of the kinematic features of the mechanism and prepare for further calculations (Fig. 2).
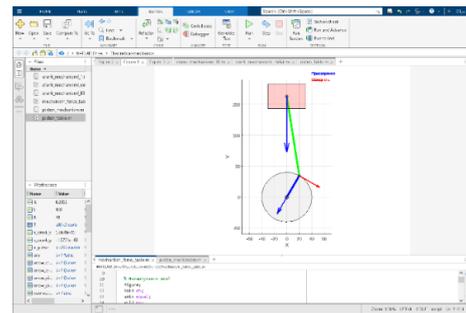

Fig. 2. Model of crank connecting rod mechanism in MATLAB program.

Education applicants are tasked with determining: piston position, linear velocity and acceleration of the piston, angular velocity and acceleration of the connecting rod. We do this by applying the formulas for determining kinematic characteristics:

$$x = R \cdot \cos\theta + \sqrt{L^2 - R^2 \cdot \sin^2\theta} \qquad (1)$$

$$v_x = -R\omega\sin\theta \left(1 + \frac{\cos\theta}{\sqrt{1-\left(\frac{R}{L}\right)^2 \cdot \sin^2\theta}} \right) \qquad (2)$$

$$a_x = -R\omega^2\sin\theta \left(1 + \frac{1-2\sin^2\theta}{\sqrt{1-\left(\frac{R}{L}\right)^2 \sin^2\theta}} \right) \qquad (3)$$

$$\omega_s = \frac{v_x}{(L \cdot \cos\varphi)} \qquad (4)$$

$$\varphi = \arcsin\left(\frac{R \cdot \sin\theta}{L} \right) \qquad (5)$$

$$a_s = \frac{a_x \cdot L \cdot \cos\varphi - v_x^2 \cdot \sin\varphi}{L \cdot \cos^2\varphi} \qquad (6)$$

When students gain enough experience with theoretical calculations, they move on to using software tools to analyse the mechanism. They learn engineering programs such as MATLAB that allow them to perform numerical differentiation and perform automated calculations (Fig. 3). This allows them to quickly analyse the motion of the mechanism under different parameters and build more accurate graphs and models. The use of software helps students to better understand complex processes and prepare for practical application of the acquired knowledge.
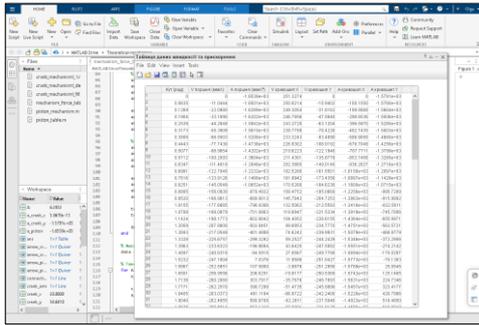
Fig. 3. Calculation of kinematic characteristics of crank connecting rod mechanism in MATLAB program.

In addition, they construct graphs illustrating the change in position, velocity and acceleration of the piston as a function of the crank angle (Figure 4). This allows a better understanding of the dynamics of the mechanism and the influence of its parameters on overall performance.
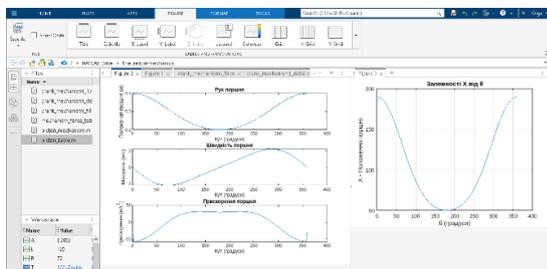

Fig. 4. Graphs of dependence of position, velocity and acceleration of the piston on the angle of rotation of the crank in MATLAB program.

This approach allows students to gradually expand their knowledge from simple calculations to complex mathematical modelling, providing a thorough understanding of the principles of crank mechanism operation.

III. RESULTS AND DISCUSSION

The pedagogical experiment was aimed at studying the effectiveness of innovative technologies in the learning process. The task of the pedagogical experiment was:

a. To determine the level of students' mastering of the material when using traditional teaching methods.

b. To develop and implement a set of innovative technologies for teaching the discipline.

c. To compare the results of learning activity of students of the control and experimental groups.

d. To evaluate the effectiveness of the implemented methods on the basis of testing, questionnaires and analysis of academic performance.

The pedagogical experiment involved 80 students of specialty 208 "Agroengineering" HEI "PSU", distributed into two groups: control (40 students) and experimental (40 students). The experiment was conducted in two stages:

1. Stating stage – this stage was aimed at establishing the initial level of students' knowledge and their perception of the educational process. It was conducted: diagnostic

testing, which included a set of questions covering the basic concepts of theoretical mechanics. This made it possible to determine students' basic knowledge, their gaps and level of understanding of the subject before the experiment. Questionnaire survey of students to assess their attitude to the learning process, to identify the level of motivation, interest in the discipline and wishes on teaching methods. analysing the preliminary results of the training, which allowed to identify weaknesses in the assimilation of the material and outline ways to improve the teaching of the discipline.

2. Formative stage – implementation of innovative teaching methods in the experimental group, which included: use of specialized software for modeling mechanical processes (MATLAB, SolidWorks, AutoCAD, ANSYS) interactive lectures with multimedia accompaniment, involving the use of: animations and videos demonstrating mechanical principles in action; presentations with step-by-step explanations of complex processes; online simulators that allowed students to experiment with mechanical models in real time.

The comparative analysis of the results of the control (without the use of software) and experimental (innovative methods) groups showed high efficiency of using innovative techniques (Table 1):

TABLE 1. THE RESULTS OF COMPARATIVE ANALYSIS OF THE CONTROL GROUPS

Indicator	Control group	Experimental group
Average test score	65%	85%
Activity in classes	50%	90%
Motivation level	55%	88%
Satisfaction with the methodology	60%	92%
Success in accomplishing tasks	58%	89%
Time of learning new material	120 min.	80 min.
Execution of practical exercises	62%	91%

The introduction of multimedia materials such as interactive lectures, animations and videos has significantly improved the perception of the material. Students expressed positive feedback regarding the use of digital technology, noting that learning has become more interesting and accessible. Online simulators that allowed students to experiment with mechanical models, which contributed to a better understanding of real-world processes and patterns.

Optimization of learning time in the experimental group became possible due to a number of innovative approaches:

Application of adaptive learning platforms made it possible to individualize the learning process by providing students with materials appropriate to their current level of knowledge.

Visualization of complex processes through animations and interactive models contributed to accelerated understanding of theoretical aspects.

Modelling of real problems with the help of software (MATLAB) gave students the opportunity to apply theoretical knowledge in practice, which significantly reduced the time for learning new material.

A flexible testing system and instant feedback allowed students to quickly analyse their mistakes and re-learn difficult topics without having to wait for a long time for explanations from the instructor.

As a result, the time of material assimilation in the experimental group decreased from 120 minutes to 80 minutes, which indicates an increase in the effectiveness of training and better assimilation of knowledge. The success rate of tasks and practical exercises in the experimental group reached 91% against 62% in the control group. As a result, the students of the experimental group showed significantly better results in practical activities, which indicates an increase in their professional competencies and ability to apply knowledge in practice.

CONCLUSIONS

As a result, the use of digital educational technologies and interactive methods contributes to a deeper understanding of the material, the development of practical skills, an increase of 30% in the success rate in completing tasks, and even a 40% increase in group activity. The use of digital simulators, interactive platforms and adaptive online courses makes it possible to visualise complex mechanical processes, which facilitates the assimilation of theoretical principles, increases student motivation and helps to significantly reduce the average training time from 120 to 80 minutes. Unlike other studies, our work focuses on specific professional examples, allowing students to apply their knowledge to real-world agricultural engineering tasks. In addition to analysing the impact of digital technologies, we developed unique teaching modules in which each theoretical mechanics topic is supported by practical cases from the field of agricultural engineering. This allowed us to show students a direct link between theoretical knowledge and its application in professional activities, which significantly increased the level of engagement and efficiency of learning. The results of the study show that further expanding the use of digital educational technologies and adapting teaching methods to the modern requirements of engineering education are promising directions that will improve the quality of agro-engineering education, adapt it to the challenges of digital transformation and strengthen interdisciplinary links in the educational process.

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