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THE USAGE OF MODERN INFORMATION TECHNOLOGIES AND SPECIALIZED SOFTWARE TOOLS FOR MODERNIZATION THE TEACHING OF MATHEMATICAL AND PHYSICAL ORIENTATION'S COURSES

Abstract. In the context of the rapid development of the information society and technological progress, there is a growing necessity to adapt the higher education system to new requirements for specialist training. The problem of teaching courses of mathematical and physical orientation effectively becomes particularly relevant, as traditional teaching methods do not fully ensure the formation of the necessary competencies in the conditions of education digitalization. The implementation of modern information technologies, specialized software, special equipment and additional interactive elements can be a key factor in addressing this problem. This article examines current challenges in modernizing the teaching of the mentioned courses through the complex implementation of effective information technologies and specialized software. In this regard, existing technologies and tools that can be effectively applied in the educational process have been analyzed, including virtual laboratories, mathematical packages, computer mathematics systems, interactive online platforms, animation tools, computer visualization and modelling programs for processes and systems, interactive textbooks and guidebooks containing multimedia elements, online trainers and simulators, mobile applications, etc. Based on the results of the analysis, an experimental study was conducted at two higher education institutions in Ukraine (Zaporizhzhia National University and Dmytro Motornyi Tavria State Agrotechnological University) to assess the effectiveness of implementing the proposed set of technologies in teaching core and non-core courses. The experiment results indicated a significant increase in levels of student academic performance and involvement in the educational process, quality of practical skills acquisition, motivation to learn and ability to work independently. The proposed approach enhances the effectiveness of teaching complex courses, ensures interactivity in the educational process, and expands opportunities for conducting scientific and practical research.

Keywords: digitalization of education, courses of mathematical and physical orientation, information technologies in education, educational software, educational content visualization, learning effectiveness.

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ВИКОРИСТАННЯ СУЧАСНИХ ІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ ТА СПЕЦІАЛІЗОВАНИХ ПРОГРАМНИХ ІНСТРУМЕНТІВ ДЛЯ МОДЕРНІЗАЦІЇ ВИКЛАДАННЯ ДИСЦИПЛІН МАТЕМАТИЧНОЇ ТА ФІЗИЧНОЇ СПРЯМОВАНОСТІ

Анотація. В умовах стрімкого розвитку інформаційного суспільства та технологічного прогресу виникає необхідність адаптації системи вищої освіти до нових вимог підготовки фахівців. Особливої актуальності набуває проблема ефективного викладання дисциплін математичного та фізичного спрямування, оскільки традиційні методи навчання не повною мірою забезпечують формування необхідних компетентностей в умовах цифровізації освіти. Впровадження сучасних інформаційних технологій та спеціалізованого програмного забезпечення може стати ключовим фактором у вирішенні цієї проблеми. У статті розглядаються актуальні питання модернізації викладання зазначених дисциплін шляхом комплексного впровадження ефективних інформаційних технологій, спеціалізованого програмного забезпечення, спеціального обладнання та додаткових інтерактивних елементів. В цьому контексті проаналізовано існуючі технології та інструменти, що можуть бути ефективно застосовані в освітньому процесі, зокрема віртуальні лабораторії, математичні пакети, системи комп'ютерної математики, інтерактивні онлайн-платформи, засоби анімації, програми комп'ютерної візуалізації та моделювання процесів та систем, інтерактивні підручники та посібники з мультимедійними елементами, онлайн-тренажери та симулятори, мобільні додатки тощо. За результатами здійсненого аналізу проведено експериментальне дослідження на базі двох закладів вищої освіти України (Запорізького національного університету та Таврійського державного агротехнологічного університету імені Дмитра Моторного) щодо ефективності впровадження запропонованого комплексу технологій при викладанні як профільних, так і непрофільних дисциплін. За результатами експериментального дослідження встановлено значне підвищення показників успішності студентів, рівня залученості до освітнього процесу, якості засвоєння практичних навичок, мотивації до навчання та здатності до самостійної роботи. Запропоновані підходи дозволяють підвищити ефективність викладання складних дисциплін, забезпечити інтерактивність навчального процесу та розширити можливості для проведення наукових і практичних досліджень.

Ключові слова: цифровізація освіти, дисципліни математичної та фізичної спрямованості, інформаційні технології в освіті, програмне забезпечення в освіті, візуалізація навчального матеріалу, ефективність навчання.

Problem statement. In the context of accelerated digitalization in education and the enforced mandatory distance learning, there arises a challenge in perceiving and assimilating theoretical knowledge acquired through the learning process. This issue is particularly acute in studying courses of mathematical and physical orientation, both for students of physical and mathematical, technical, and engineering specialities and for students from those courses where mathematics and physics are not the primary focus. The difficulties in perceiving theoretical knowledge in these areas stem from the complexity of abstract concepts, a lack of visual aids during material explanation, and limited opportunities for conducting practical and laboratory sessions in distance learning conditions [1-5]. All of this necessitates the search for effective methods for delivering educational content online, especially for the above-mentioned courses. These methods not only aim to address the outlined problem but also expand the potential for scientific and practical research for both researchers and students.

This paper proposes to explore one of the possible approaches, which is based on using a complex of innovative technologies aimed at overcoming identified problems in the educational process.

Analysis of recent research and publications. The implementation of information technologies in the educational process has been actively researched by scholars from various countries around the world [6-25]. This is driven by the need to adapt the education system to the demands of the information society and to prepare specialists capable of functioning amidst rapid technological advancements effectively. A number of studies have focused on examining the role of information technologies in enhancing the quality and effectiveness of the educational process. For instance, Gürdür Broo et al. [11], Siemens [16], investigate the influence of digital technologies on teaching and learning, emphasizing the necessity of developing new pedagogical approaches. In turn, Cuban [17] analyzes the experience of technology implementation in higher education and identifies factors that promote or hinder the effective integration of information and communication technologies (ICT). Significant attention is given to student motivation for independent work and continuous learning in the context of education informatization. For example, Suyono et al. [26], Abou El-Seoud et al. [27] study the impact of technology usage on student motivation and their engagement in the learning process, while Star et al. [28] research effective strategies for enhancing motivation for independent learning through ICT. The role of the instructor in the new conditions of education informatization is also actively discussed. Specifically, Koehler et al. [18], Mishra [19], Niess [20], Papanikolaou et al. [21] study the Technological Pedagogical Content Knowledge (TPACK) framework, which defines the necessary competencies for educators to effectively integrate technologies into the teaching process. Albion et al. [29] examine the influence of teachers' professional development on the implementation of ICT in teaching. Some studies are dedicated to the development and implementation of innovative approaches to the usage of information technologies in education. For instance, Kaya et al. [22], Ke et al. [23] analyze the application of virtual and augmented reality technologies in education, while Talan et al. [24] investigate the effectiveness of using digital games in the educational process. In the scientific discourse the issues of education informatization are also in focus among researchers. In particular, da Silva et al. [8] examine the theoretical and practical aspects of using ICT in the educational process, and Verbivskyi et al. [25] study the problems of education informatization and their solutions. Nevertheless, despite numerous studies, the effective implementation of both information technologies and additional innovative tools (visualization tools, specialized equipment, elements of gamification, etc.) in higher education remains relevant and requires further exploration to find optimal solutions and develop innovative approaches.

The purpose of the article is to highlight the results of an analysis of the integrated usage of modern information technologies and specialized software tools for modernizing the teaching courses of mathematical and physical orientation. This analysis identifies the most effective currently available technologies and tools that can be integrated into the educational process, allowing for an expansion of opportunities for conducting scientific and practical research. Additionally, it aims to enhance students' perception of theoretical information in the studied knowledge areas, automate labour-intensive mathematical calculations, enhance the level of interpretation of obtained results, and broaden students' practical experiences with the application of acquired theoretical knowledge and the applied software used for research.

It is expected that the results of the analysis conducted in this work will contribute to the modernization of the higher education system according to the demands of the information age, improve the quality of training specialists in line with the requirements of the information society, and foster in graduates the necessary skills for lifelong learning, critical thinking, digital literacy, and readiness to effectively work with modern information technologies, thereby ensuring their high competitiveness and successful integration into the job market.

Modern information technologies, software tools, and specialized equipment for addressing the challenges of enhancing the effectiveness of teaching courses of mathematical and physical orientation. Based on the results of the analysis of modern technologies that can be used in the educational process in teaching the courses of mathematical and physical orientation, to solve the outlined problem, the paper proposes the usage of interactive teaching methods with the usage of modern information technologies, software tools, special equipment and additional interactive elements. In particular, the usage of virtual laboratories and simulators that allow conducting virtual experiments in distance learning can be highly effective. 3D modelling and animations of physical and mathematical processes can also be useful, as they will help to understand abstract material better and thus facilitate the perception of difficult concepts. The usage of interactive online courses, video lectures and webinars will help to enhance students' cognitive activity. Using gamification elements and visualization tools will also increase the motivation and efficiency of learning. In addition, the usage of AR- and VR-technologies is also quite effective. For example, the usage of AR-technologies (augmented reality technologies) will allow visualizing abstract concepts, to see processes from the inside, from different angles, and this will greatly facilitate the understanding of the material. For example, the usage of AR-technologies will allow overlaying digital 3D models on the real environment, providing a better comprehension of abstract concepts. The usage of VR-technologies (virtual reality technologies) will enable full immersion in the virtual environment and interaction with objects, modelling various physical and mathematical processes, contributing to the deeper acquisition of knowledge. Using the mentioned approach in implementing such technologies in the educational process will provide the university with opportunities to improve the quality of education, attract applicants with innovative technologies, improve its image as a modern educational institution, and organize high-level distance learning. Students will have the opportunity to get a better comprehension of complex material, develop spatial thinking, increase motivation and interest in the course, gain high-quality knowledge regardless of the learning format. Thus, the implementation of interactive and visual learning technologies will help to overcome the problems of distance learning effectively.

In addition to the above-mentioned tools, the following information technologies and software tools can be implemented in the educational process when teaching courses of mathematical and physical orientation:

- *mathematical packages and computer mathematics systems* that enable complex mathematical calculations, function visualization, graph plotting, modelling of studied processes and phenomena of arbitrary physical nature, and animation creation. Among the most powerful and widely used packages are Mathematica, MathCAD, Maple, and MatLab. By implementing these tools, universities can train students to work with modern mathematical packages that are used in IT and scientific research. Furthermore, through visual representation of mathematical relationships, these tools facilitate optimal absorption of theoretical material. Students benefit from an enhanced understanding of mathematical and physical concepts through visualization, simplified execution of labour-intensive calculations, and acquisition of practical experience with powerful mathematical systems;
- *computer visualization and modelling programs* for processes and systems of arbitrary physical nature in general, and physical processes in particular, which enable the investigation of complex processes and phenomena through computer simulation. Notable examples of such software tools include Comsol Multiphysics (a powerful tool for modelling and visualizing physical processes such as heat propagation, fluid motion, and structural deformation, capable of constructing complex 3D models and conducting computational experiments); ANSYS (a software complex for engineering analysis and numerical modelling of physical processes, utilized for structural strength analysis, computational fluid dynamics, heat conduction, thermodynamics, and electromagnetism, including coupled multidisciplinary problems such as thermomechanics and magnetoelasticity); and SolidWorks (a program for 3D modelling and prototyping used in mechanical engineering that proves valuable for visualizing geometric concepts and mechanical processes). The primary advantages of implementing such software tools in the educational process include providing universities with the capability to demonstrate the modelling of complex processes, including physical phenomena that are difficult or impossible to demonstrate in a real laboratory, the ability to visualize abstract concepts, and the opportunity to prepare students for work with modern professional software. Consequently, students gain opportunities for a deeper understanding of physical and mathematical concepts and patterns through visualization, conducting virtual experiments, and developing practical skills in modelling and data processing. These programs significantly enhance the effectiveness of theoretical material absorption and ensure the acquisition of practical experience in data handling;
- *interactive online platforms,* such as Lectur.ED, for creating virtual laboratories in physics and mathematics. The implementation of such platforms in the educational process enables the conduct of virtual laboratory work and experiments in distance learning conditions, significantly expanding the possibilities for theoretical material comprehension and ensuring the acquisition of practical experience by students when applied in real-world situations.

The usage of the aforementioned software tools substantially expands the possibilities of teaching and learning the complex material in courses of mathematical and physical orientation both in conditions of traditional and distance learning.

In addition to the technologies already mentioned, there are some other technologies and tools that can be effectively used to teach courses of mathematical and physical orientation:

● *interactive textbooks and guidebooks* containing multimedia elements such as videos, animations, and 3D models. Such resources facilitate a better understanding of the material through visualization. The most interesting examples of such textbooks include those from Ukrainian publishers ”Ranok,” ”Geneza,” ”Svit Znan,” and ”Navchalna Knyha - Bohdan,” which contain video lessons, 3D models, and animations illustrating physical and mathematical concepts. For instance, the interactive algebra textbook from ”Ranok” publishing house includes video lessons, function graph animations, and interactive exercises; the geometry textbook from ”Geneza” contains rotating and decomposable 3D models of geometric figures; the physics textbook from ”Svit Znan” includes videos of physical experiments and process animations; the physics textbook from ”Navchalna Knyha - Bohdan” contains video demonstrations of experiments and 3D models. Textbooks from foreign publishers such as ”Pearson”, ”Cengage”, ”McGraw Hill”, ”Cambridge University Press”, ”CK-12 Foundation”, and ”Lumos Learning” are also quite interesting. For example, the interactive textbook ”Algebra I” by ”Pearson” contains interactive graphs of functions, built-in calculators; ”Fundamentals of Physics” by ”Cengage” contains videos of physical experiments and interactive simulations; ”Geometry” by ”McGraw Hill” contains 3D models of geometric bodies that rotate and intersect; ”Calculus” by ”Cambridge University Press” contains animated graphs of functions and derivatives. These electronic publications with visual multimedia content significantly facilitate the comprehension of complex information in courses of mathematical and physical orientation. Through the implementation of interactive textbooks and guidebooks containing multimedia elements, universities can provide students with modern educational materials, while students benefit from enhanced information comprehension through visual and interactive presentation;

● *online trainers and simulators* for practising practical skills in physics and mathematics. These tools are especially useful for self-study. Examples of such tools include PHET, Physlets, and GeoGebra, which allow you to model physical and mathematical processes using convenient 3D modelling tools, provide opportunities to manipulate models, change parameters, conduct statistical analysis, and at the same time, provide the ability to see the result immediately. GeoGebra is quite popular for interactive teaching of geometry, algebra, mathematical analysis, 3D modelling, etc., due to the possibility of its free distribution. With the usage of online simulators and trainers, the university can provide students with modern technologies for interactive learning and self-study, and students have additional opportunities to practice the skills and abilities acquired during the course of study, through the opportunities provided to check the assimilation of the material studied immediately;

● *virtual laboratories* allowing to interactively simulate real laboratory equipment and conduct experiments and tests in a virtual way, provide opportunities to manipulate models of objects, observe various processes, simulate processes and phenomena that are difficult or impossible to implement in real conditions. The following laboratories are among the most useful for implementation: Virtual Mathematical Laboratory (contains interactive models in geometry, algebra, and mathematical analysis), Mathematica Online (a cloud-based version of a popular mathematical package for graphing, visualizing functions, etc, which also has an online version), Mathigon (a virtual laboratory for learning mathematics with interactive models), PhET (contains simulations in physics, chemistry, biology, mathematics), Labster (offers virtual laboratory works in natural sciences), virtual physical laboratory developed by Igor Sikorsky Kyiv Polytechnic Institute (for experiments in mechanics, optics, and electricity), Virtual Chemistry Lab (a virtual chemical laboratory with the ability to conduct experiments). The usage of virtual laboratories by the university makes it possible to organize the teaching of courses of mathematical and physical orientation with maximum efficiency by conducting virtual experiments, makes it possible to visualize the studied objects and processes, abstract mathematical and physical concepts, saves resources for the equipment of real laboratories, allows organizing safe experiments and experiments, and makes the learning process more visual. At the same time, students get the opportunity for a better understanding of abstract mathematical and physical concepts, the ability to perform laboratory works independently in an interactive mode gaining the necessary practical skills, the ability to perform virtual experiments safely without risk of injury, virtual laboratory works at a convenient time, and to increase the efficiency of acquiring practical skills in the study of natural sciences;

- *automated knowledge verification systems,* such as testing programs. Such systems and programs make it possible to assess the level of learning quickly and, therefore, provide opportunities for accelerating the exchange of information between the teacher and students. As an example of such testing systems, we can mention the Ukrainian Testing Board, MyTestXPro, etc., which allow the creation of test task banks and automation of the testing and evaluation process. With the usage of the above-mentioned automated testing systems, the university gets the opportunity to accelerate the process of knowledge assessment, and students benefit from the increased convenience of taking tests online;
- *mobile applications* with the ability to scan and recognize mathematical formulas. As examples of such applications, the following can be mentioned: Physics Solver, PhotoMath, Mathematica, Microsoft Math Solver. Mobile applications are characterized by their ability to perform calculations, including time-consuming ones, recognize formulas using a smartphone camera, and thus make it easier for both students and teachers to work with formulas. The usage of mobile applications in the educational process provides an opportunity for quick access to educational materials at any time and the ability for quick verification of computational calculations;
- *interactive boards, projectors, online boards* (e.g., Padlet), *video conferencing systems,* etc. for demonstrating necessary information during lectures.

The usage of these tools in the educational process significantly enhances the visibility of the material;

- *QR codes*, which may contain links to additional training materials or videos with problem solving. With the usage of QR codes in educational activities, the university gets the opportunity to provide quick access to additional educational materials, and students get the possibility to use additional materials in the fastest and most convenient way.

In addition to the aforementioned, there are several other useful programs and environments for visualizing mathematical and physical concepts, as well as modelling processes in studying courses of mathematical and physical orientation:

- *Blender* - a powerful tool for creating 3D graphics and animation, and can be used to visualize complex mathematical surfaces;
- *Wolfram Mathematica* - a powerful environment for computing and visualization, containing functions for graphing, creating animations, and generating fractals;
- *Autodesk 3ds Max* - a professional program for 3D modelling and animation, which is also used in the film industry and game development;
- *Unity* - a game engine for creating interactive 3D applications that allows visualization of physical processes in the game environment;
- *Desmos* - an online graphing calculator for graphing functions and studying equations;
- *Geogebra 3D Grapher* - an application for constructing 3D graphs of mathematical functions of varying complexity;
- *Physics Toolbox Suite* - an application for modelling physical processes on mobile devices.

The software tools mentioned above allow students to have a better understanding of abstract mathematical and physical concepts through their visualization, and the implementation of such software tools will improve the efficiency and quality of teaching courses of mathematical and physical orientation, significantly increase the efficiency of learning theoretical knowledge and provide ample opportunities for students to acquire practical skills in physics and mathematics.

Experience of implementation. Results and discussion. In order to determine the effectiveness of the implementation of modern information technologies and software tools in teaching courses of mathematical and physical orientation, a complex research was conducted during the 1st and 2nd semesters of the academic year 2023-2024 based on two higher education institutions of Ukraine - Zaporizhzhia National University and Dmytro Motornyi Tavria State Agrotechnological University. The research involved 263 bachelor’s and master’s students of various specialities, for whom courses of mathematical and physical orientation are both core and non-core (“Higher Mathematics” for bachelor’s students majoring in Management; “Applied Mathematics” for bachelor’s students majoring in “Accounting and Taxation”; “Higher and Applied Mathematics” for bachelor’s students majoring in “Agroengineering”;

"Computer Modelling of Industrial Problems", "Methods of Optimization and Operations Research" and "Theory and Methods of Decision-making" for bachelor's students majoring in "Applied Mathematics"; "System Analyses" and "Theory of Decision-making" for bachelor's students majoring in "Computer Sciences"; "Statistical Methods of Analysis and Mathematical Modelling in Food Technologies" for master's students majoring in "Food Technologies").

The experimental research was conducted in three stages:

- Preparatory stage (January 2023 - June 2023) - development of a methodology for the implementation of information technologies and software tools, preparation of training materials and adaptation of technologies to specific courses.
- The main stage (September 2023 - June 2024) - direct implementation of technologies into the educational process with regular monitoring of results.
- Analytical stage (September 2024 - September 2025) - analysis and processing of the obtained data, drawing conclusions.

For assessing the effectiveness of the implementation of information technologies and software tools, the following criteria were identified:

- the level of academic performance of students (measured by analyzing the average grade of students in the course, obtained by the results of intermediate and final control of knowledge, including grades for module tests, practical/laboratory works, individual work, final exam/quiz, and also by analyzing the qualitative indicator of performance (percentage of students who received grades "good" and "excellent") obtained before and after the implementation of information technologies and software tools);
- the level of involvement in the educational process (determined by a complex assessment of attendance (registration of presence at classes), activity in classes (number of reports, answers to questions, participation in discussions), timeliness of assignments (percentage of works submitted on time), activity in the distance learning system (frequency of logging in, the time spent on working with materials));
- quality of practical skills acquisition (assessed by indicators of the correctness of practical tasks using the studied technologies, validity of the obtained results);
- the level of motivation to learn (determined by analyzing the dynamics of the execution of additional (optional) tasks, students' activity in the classroom and while performing their individual works);
- the ability for self-study (assessed by the quality of completing the individual works, the results of independent work on additional materials, the activity in usage of IT-resources offered in the courses outside the mandatory program, the ability to conduct the individual researches and analysis of information).

All measurements were conducted at the end of the academic semesters during the academic year and compared with the similar indicators of the previous academic year. All comparisons were conducted on two homogeneous groups (experimental –

using technologies, control – without technologies) for each training course before and after the implementation of information technologies and software tools. The homogeneity of each pair of such groups for all courses was checked using Student's *t*-criterion before the beginning of the experiment, which confirmed the absence of statistically significant differences between the studied groups and, consequently, the representativeness of the samples and the correctness of the conditions for conducting the experiment.

The analysis of the obtained results of the implementation of information technologies and software tools showed a significant increase in the efficiency of the educational process according to all the defined indicators, both for core and non-core courses in the defined specialities.

Let us consider more closely the results of the implementation obtained for each of the groups of the considered courses.

During the teaching of a group of non-core courses - "Higher Mathematics" (for the major "Management"), "Applied Mathematics" (for the major "Accounting and Taxation"), "Statistical Methods of Analysis and Mathematical Modelling in Food Technologies" (for the major "Food Technologies") - the following complex of information technologies and software tools was introduced: virtual laboratories (GeoGebra, Mathigon), the MathCAD computer mathematics system, mobile applications for formula recognition (PhotoMath, Mathematica), the Calculus interactive textbook, and the Desmos online graphing calculator. Similarly, during the teaching of a group of core courses - "Higher and Applied Mathematics" (for the major "Agroengineering"), "Computer Modelling of Industrial Problems", "Methods of Optimization and Operations Research" and "Theory and Methods of Decision-making" for bachelor's students majoring in "Applied Mathematics"; "System Analyses" and "Theory of Decision-making" for bachelor's students majoring in "Computer Sciences") - the following set of information technologies and software tools was introduced: virtual laboratories (GeoGebra, Mathigon), computer mathematics systems (Maple, MathCAD), online trainers and simulators (Physlets, GeoGebra), mobile applications for recognizing formulas (PhotoMath, Mathematica), interactive textbooks ("Calculus", "Fundamentals of Physics"), and the online graphic calculator Desmos.

The results of monitoring students' learning in both groups of courses showed a significant increase in the indicators of the effectiveness of the implementation of the selected information technologies and software tools for students (tables 1, 2).

Table 1. Dynamics of the values of selected indicators for assessing the effectiveness of the implementation of information technologies and software tools in teaching non-core courses

Indicator	Value before implementation	Value after implementation	The growth, %
Average grade of students in the course	3.82	4.16	8.82
Qualitative indicator of performance, %	62.10	78.15	16.05
Level of involvement, %	54.32	81.97	27.65
Ability to self-study, %	48.15	76.47	28.32
Quality of practical skills acquisition:			
- Correctness of task execution, %	58.4	75.2	16.8
- Validity of the obtained results, %	55.8	73.6	17.8
Level of motivation to learn:			
- Execution of additional tasks, %	42.3	68.5	26.2
- Students’ activity in the classroom, %	51.2	77.8	26.6
- Students’ activity during self-study, %	49.28	79.36	30.08

Table 2. Dynamics of the values of selected indicators for assessing the effectiveness of the implementation of information technologies and software tools in teaching core courses

Indicator	Value before implementation	Value after implementation	The growth, %
Average grade of students in the course	3.87	4.24	9.45
Qualitative indicator of performance, %	65.65	83.33	17.68
Level of involvement, %	58.47	85.42	26.95
Ability to self-study, %	51.91	78.89	26.98
Quality of practical skills acquisition:			
- Correctness of task execution, %	61.8	79.5	17.7
- Validity of the obtained results, %	59.2	77.8	18.6
Level of motivation to learn:			
- Execution of additional tasks, %	45.6	72.4	26.8
- Students’ activity in the classroom, %	54.8	81.2	26.4
- Students’ activity during self-study, %	51.32	80.91	29.59

According to the results of the analysis presented in table 1 and table 2, implementing the mentioned technologies and software tools positively impacted all indicators for core and non-core courses. Particularly noticeable is the increasing of students’ involvement into the educational process, the level of self-studying ability, and the values of motivation to learn, where the increase is over 26% for both types of courses. There is also a significant improvement in the level of students’ academic performance and the quality of acquisition of practical skills. These improvements are evident in increasing the average grade of students in the course, the qualitative performance indicator, and the indicators of correctness of task performance and validity of obtained results. These results indicate that there is a significant improvement in students' understanding of mathematical and physical concepts in the study of courses of the identified groups, and, therefore, the main goal of the experiment was achieved.

The received results indicate high efficiency of implementing modern information technologies in teaching courses of mathematical and physical orientation. It is especially important that positive dynamics are observed for both core and non-core specialities. In our opinion, the key success factors are the individualization of the educational process, increased visibility of complex material, the possibility of practical application of the acquired theoretical knowledge, interactivity of the educational process, and the availability of materials for self-study. In addition, it is worth mentioning that the most effective were complex solutions that combine different technologies and approaches to teaching. Such solutions allow satisfying different teaching styles and ensure students' motivation and involvement in the educational process.

Conclusions. The article, based on the analysis of modern information technologies, software tools and special equipment that can be used in the educational process in teaching courses of mathematical and physical orientation, presents approaches to enhancing the efficiency and quality of teaching courses of mathematical and physical orientation in higher education institutions for students of physical, mathematical, technical and engineering specialities (areas of study), as well as for students of those specialities where the courses of mathematical and physical orientation are non-core.

The widespread implementation of modern information technologies, software tools and special equipment in teaching courses of mathematical and physical orientation, as defined in the article, allowed:

- to increase the efficiency and accessibility of teaching complex courses of mathematical and physical orientation;
- to improve the visibility of teaching through computer visualization of complex mathematical and physical concepts (e.g., building interactive 3D-models of geometric objects, graphs of functions, demonstration of physical processes using animations and simulations);
- to ensure interactivity of the educational process through virtual laboratories, simulators, online educational platforms where students can conduct virtual experiments and see the results immediately;
- to automate routine calculations, graphing, and solving complex problems using computer mathematics and modelling systems;
- to expand the educational process with the development of online courses, video lectures, and webinars that are available to a large group of students at the same time;

- to organize convenient distance learning through educational management systems and online platforms;
- to facilitate the perception and understanding of abstract concepts due to their visual representation and the possibility of interaction with computer models;
- to conduct virtual experiments and laboratory works that are close to real situations and conditions;
- to train practical skills in problem-solving, graphing, working with formulas using specialized computer tools;
- to individualize the educational process through adaptive online courses, the ability for students to choose their own learning speed and complexity of tasks;
- to increase students' motivation to study the subject through the usage of game elements and easier access to materials;
- to automate knowledge testing with the assistance of test systems to provide instant feedback for students;
- to expand significantly the opportunities for self-study out of the classroom and class schedule.

The results of the conducted experiment on implementing the outlined modern information technologies and software tools in teaching core and non-core courses of mathematical and physical orientation for students of two universities in Ukraine indicate high efficiency of implementation, considering that all technologies and software tools have been implemented into the educational process in a complex way, combining different technologies and approaches to teaching.

Thus, the complex use of modern information technologies, software tools and special equipment in education opens up new perspectives for teaching complex courses in the field of exact sciences, is an effective tool for improving the quality of teaching courses of mathematical and physical orientation in higher education institutions in the training of highly qualified and competitive specialists which significantly expands the possibilities for improving the quality of conducting and presenting the results of scientific and practical researches in the chosen field of knowledge.

References:

1. Bobyliev, D. Y., Vihrova E. V. (2021). Problems and prospects of distance learning in teaching fundamental subjects to future Mathematics teachers. *Journal of Physics: Conference Series*, 1840(1), 012002. DOI https://doi.org/10.1088/1742-6596/1840/1/012002.

2. Bustami, Ngadimin, Farhan, A. (2020). The Difficulty Factors of Students to Understand Mathematics Physics 1 at Physics Education Department FKIP Unsyiah. *Asian Journal of Science Education,* 2(1), 1-10. DOI https://doi.org/10.24815/ajse.v2i1.14725.

3. Huda, S., Firmansyah, M., Rinaldi, A., Sugiharta, I., Astuti, D. W., Fatimah, O., Prasetyo, A. E. (2019). Understanding Of Mathematical Concepts In The Linear Equation With Two Variables: Impact Of ELearning And Blended Learning Using Google Classroom. *Jurnal Pendidikan Matematika,* 10(2), 261-270. DOI https://doi.org/10.24042/ajpm.v10i2.5303.

4. Wangchuk, D., Wangdi, D., Tshomo, S., Zangmo, J. (2023). Exploring Students' Perceived Difficulties of Learning Physics. *Educational Innovation and Practice*, 6**.** DOI https://doi.org/ 10.17102/eip.6.2023.03. Retrieved from https://eip.sce.edu.bt/index.php/eip/article/view/57.

5. Bouchée, T., de Putter Smits, L., Thurlings, M., Pepin, B. (2021). Towards a better understanding of conceptual difficulties in introductory quantum physics courses. *Studies in Science Education***,** 58(2), 183-202. DOI https://doi.org/10.1080/03057267.2021.1963579.

6. Brunetti, F., Matt, D. T., Bonfanti, A., De Longhi, A., Pedrini, G., Orzes, G. (2020). Digital transformation challenges: strategies emerging from a multi-stakeholder approach. *TQM Journal,* 32**(**4), 697-724. DOI https://doi.org/10.1108/TQM-12-2019-0309.

7. Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration,* 6, 1-10. DOI https://doi.org/10.1016/j.jii.2017.04.005.

8. da Silva, L. B. P., Barreto, B. P., Treinta, F. T., de Resende, L. M. M., Yoshino, R. T., Pontes, J. (2022). Evolution of soft skills for engineering education in the digital era. *Optimization, Learning Algorithms and Applications;* ed. Pereira A. I., Kosir A., Fernandes F. P., Pacheco M. F., Teixeira J. P., Lopes R. P. Cham: Springer International Publishing, 640-653. DOI https://doi.org/10.1007/978-3-031-23236-7_44.

9. Rossi, A.H.G., Marcondes, G.B., Pontes, J., Leitao, P., Treinta, F.T., De Resende, L.M.M., Yoshino, R.T. (2022). Lean Tools in the Context of Industry 4.0: Literature Review, Implementation and Trends. *Sustainability,* 14(19), 12295. DOI https://doi.org/10.3390/su141912295.

10. Abad-Segura, E., González-Zamar, M. D., Infante-Moro, J. C., García, G. R. (2020). Sustainable management of digital transformation in higher education: Global research trends. *Sustainability,* 12(5), 2107. DOI https://doi.org/10.3390/su12052107.

11. Gürdür Broo, D., Kaynak, O., Sait, S. M. (2021). Rethinking engineering education at the age of industry 5.0. *Journal of Industrial Information Integration,* 25, 100311. DOI https://doi.org/10.1016Zj.jii.2021.100311.

12. Soto-Acosta, P. (2020). COVID-19 Pandemic: Shifting Digital Transformation to a High-Speed Gear. *Information Systems Management,* 37(4), 260-266. DOI https://doi.org/10.1080/10580530.2020.1814461.

13. Aditya, B. R., Ferdiana, R., Kusumawardani, S. S. (2022). Identifying and prioritizing barriers to digital transformation in higher education: a case study in Indonesia. *International Journal of Innovation Science*, 14(3-4), 445-460. DOI https://doi.org/10.1108/IJIS-11-2020-0262.

14. Suárez, L. M. C., Núnez-Valdés, K., Alpera, S. Q. Y. (2021). A systemic perspective for understanding digital transformation in higher education: Overview and subregional context in Latin America as evidence. *Sustainability,* 13(23), 12956. DOI https://doi.org/10.3390/su132312956.

15. Ilmi, R., Arnawa, I. M., Yerizon, Bakar, N. N. (2021). Development of an Android-Based for Math E-Module by using Adobe Flash Professional CS6 for Grade X Students of Senior High School. *Journal of Physics: Conference Series,* 1742(1), 012026. DOI https://doi.org/10.1088/1742-6596/1742/1/012026.

16. Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning,* 2(1), 3-10. Retrieved from http://www.itdl.org/Journal/Jan_05/article01.htm.

17. Cuban, L. (2001). Oversold and underused:Computers in the classroom. Cambridge, Massachusetts; London, England: Harvard University Press, 256 p. Retrieved from https://stu.westga.edu/~bthibau1/MEDT%208463-Moller/Cuban%20article%20-%20oversold.pdf.

18. Koehler, M. J., Mishra, P., Kereluik, K., Shin, T. S., Graham, C. R. (2014). The Technological Pedagogical Content Knowledge Framework. New York, NY: Springer New York, 101-111. DOI https://doi.org/10.1007/978-1-4614-3185-5_9.

19. Mishra, P. (2019). Considering contextual knowledge: The tpack diagram gets an upgrade. *Journal of Digital Learning in Teacher Education,* 35(2), 76-78. DOI https://doi.org/10.1080/21532974.2019.1588611.

20. Niess, M. L. (2011). Investigating tpack: Knowledge growth in teaching with technology. *Journal of Educational Computing Research,* 44(3), 299-317. DOI https://doi.org/10.2190/EC.44.3.c.

21. Papanikolaou, K., Makri, K., Roussos, P. (2017). Learning design as a vehicle for developing tpack in blended teacher training on technology enhanced learning. *International Journal of Educational Technology in Higher Education,* 14**,** 34. DOI https://doi.org/10.1186/s41239-017-0072-z.

22. Kaya, O. S., Bicen, H. (2019). Study of augmented reality applications use in education and its effect on the academic performance. *International Journal of Distance Education Technologies,* 17(3), 25-36. DOI https://doi.org/10.4018/ijdet.2019070102.

23. Ke, F., Hsu, Y. C. (2015). Mobile augmented reality artifact creation as a component of mobile computer-supported collaborative learning. *The Internet and Higher Education,* 26(1), 33-41. DOI https://doi.org/ 10.1016/j.iheduc.2015.04.003.

24. Talan, T., Doğan, Y., Batdi, V. (2020). Efficiency of digital and non-digital educational games: A comparative meta-analysis and a meta-thematic analysis. *Journal of Research on Technology in Education,* 52(4), 474-514. DOI https://doi.org/10.1080/15391523.2020.1743798.

25. Verbivskyi, D., Zhukovskyi, S., Usata, O., Fonariuk, O., Humeniuk, V. (2024). Use of digital technologies for innovation in teaching: Comparison of international and domestic approaches. *Scientific Herald of Uzhhorod University. Series Physics,* 56, 2587-2599. DOI https://doi.org/ 10.54919/physics/56.2024.258hf7.

26. Suyono, Nisak, S. K., Riyanto, Arsyad, M., Rusliana. (2024). Exploring the impact of technology integration on student engagement and achievement in science education. *Journal of Educational Research Excellence,* 3(2), 691-696. DOI https://doi.org/10.55299/ijere.v3i2.1048.

27. Abou El-Seoud, M., Taj-Eddin, I., Seddiek, N., El-Khouly, M., Nosseir, A. (2014). E-learning and students' motivation: a research study on the effect of e-learning on higher education. *International Journal of Emerging Technologies in Learning,* 9(4), 20-26. DOI https://doi.org/ 10.3991/ijet.v9i4.3465.

28. Star, J. R., Chen, J. A., Taylor, M. W., Durkin, K., Dede, C., Chao, T. (2014). Studying technology-based strategies for enhancing motivation in mathematics. *International Journal of STEM Education,* 1, 7. DOI https://doi.org/10.1186/2196-7822-1-7.

29. Albion, P. R., Tondeur, J., Forkosh-Baruch, A., Peeraer, J. (2015). Teachers' professional development for ict integration: Towards a reciprocal relationship between research and practice. *Education and Information Technologies,* 20(4), 655-673. DOI https://doi.org/10.1007/s10639-015-9401-9.

Література:

1. Bobyliev, D. Y., Vihrova E. V. (2021). Problems and prospects of distance learning in teaching fundamental subjects to future Mathematics teachers. *Journal of Physics: Conference Series*, 1840(1), 012002. DOI https://doi.org/10.1088/1742-6596/1840/1/012002.

2. Bustami, Ngadimin, Farhan, A. (2020). The Difficulty Factors of Students to Understand Mathematics Physics 1 at Physics Education Department FKIP Unsyiah. *Asian Journal of Science Education,* 2(1), 1-10. DOI https://doi.org/10.24815/ajse.v2i1.14725.

3. Huda, S., Firmansyah, M., Rinaldi, A., Sugiharta, I., Astuti, D. W., Fatimah, O., Prasetyo, A. E. (2019). Understanding Of Mathematical Concepts In The Linear Equation With Two Variables: Impact Of ELearning And Blended Learning Using Google Classroom. *Jurnal Pendidikan Matematika,* 10(2), 261-270. DOI https://doi.org/10.24042/ajpm.v10i2.5303.

4. Wangchuk, D., Wangdi, D., Tshomo, S., Zangmo, J. (2023). Exploring Students' Perceived Difficulties of Learning Physics. *Educational Innovation and Practice,* 6**.** DOI https://doi.org/ 10.17102/eip.6.2023.03. https://eip.sce.edu.bt/index.php/eip/article/view/57.

5. Bouchée, T., de Putter Smits, L., Thurlings, M., Pepin, B. (2021). Towards a better understanding of conceptual difficulties in introductory quantum physics courses. *Studies in Science Education***,** 58(2), 183-202. DOI https://doi.org/10.1080/03057267.2021.1963579.

6. Brunetti, F., Matt, D. T., Bonfanti, A., De Longhi, A., Pedrini, G., Orzes, G. (2020). Digital transformation challenges: strategies emerging from a multi-stakeholder approach. *TQM Journal,* 32**(**4), 697-724. DOI https://doi.org/10.1108/TQM-12-2019-0309.

7. Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration,* 6, 1-10. DOI https://doi.org/10.1016/j.jii.2017.04.005.

8. da Silva, L. B. P., Barreto, B. P., Treinta, F. T., de Resende, L. M. M., Yoshino, R. T., Pontes, J. (2022). Evolution of soft skills for engineering education in the digital era. *Optimization, Learning Algorithms and Applications;* ed. Pereira A. I., Kosir A., Fernandes F. P., Pacheco M. F., Teixeira J. P., Lopes R. P. Cham: Springer International Publishing, 640-653. DOI https://doi.org/10.1007/978-3-031-23236-7_44.

9. Rossi, A.H.G., Marcondes, G.B., Pontes, J., Leitao, P., Treinta, F.T., De Resende, L.M.M., Yoshino, R.T. (2022). Lean Tools in the Context of Industry 4.0: Literature Review, Implementation and Trends. *Sustainability,* 14(19), 12295. DOI https://doi.org/10.3390/su141912295.

10. Abad-Segura, E., González-Zamar, M. D., Infante-Moro, J. C., García, G. R. (2020). Sustainable management of digital transformation in higher education: Global research trends. *Sustainability,* 12(5), 2107. DOI https://doi.org/10.3390/su12052107.

11. Gürdür Broo, D., Kaynak, O., Sait, S. M. (2021). Rethinking engineering education at the age of industry 5.0. *Journal of Industrial Information Integration,* 25, 100311. DOI https://doi.org/ 10.1016Zj.jii.2021.100311.

12. Soto-Acosta, P. (2020). COVID-19 Pandemic: Shifting Digital Transformation to a High-Speed Gear. *Information Systems Management,* 37(4), 260-266. DOI https://doi.org/10.1080/10580 530.2020.1814461.

13. Aditya, B. R., Ferdiana, R., Kusumawardani, S. S. (2022). Identifying and prioritizing barriers to digital transformation in higher education: a case study in Indonesia. *International Journal of Innovation Science,* 14(3-4), 445-460. DOI https://doi.org/10.1108/IJIS-11-2020-0262.

14. Suárez, L. M. C., Núnez-Valdés, K., Alpera, S. Q. Y. (2021). A systemic perspective for understanding digital transformation in higher education: Overview and subregional context in Latin America as evidence. *Sustainability,* 13(23), 12956. DOI https://doi.org/10.3390/su132312956.

15. Ilmi, R., Arnawa, I. M., Yerizon, Bakar, N. N. (2021). Development of an Android-Based for Math E-Module by using Adobe Flash Professional CS6 for Grade X Students of Senior High School. *Journal of Physics: Conference Series,* 1742(1), 012026. DOI https://doi.org/10.1088/1742-6596/1742/1/012026.

16. Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning,* 2(1), 3-10.

17. Cuban, L. (2001). Oversold and underused:Computers in the classroom. Cambridge, Massachusetts; London, England: Harvard University Press, 256 p. https://stu.westga.edu/~bthibau1/ MEDT%208463-Moller/Cuban%20article%20-%20oversold.pdf.

18. Koehler, M. J., Mishra, P., Kereluik, K., Shin, T. S., Graham, C. R. (2014). The Technological Pedagogical Content Knowledge Framework. New York, NY: Springer New York, 101-111. DOI https://doi.org/10.1007/978-1-4614-3185-5_9.

19. Mishra, P. (2019). Considering contextual knowledge: The tpack diagram gets an upgrade. *Journal of Digital Learning in Teacher Education,* 35(2), 76-78. DOI https://doi.org/10.1080/ 21532974.2019.1588611.

20. Niess, M. L. (2011). Investigating tpack: Knowledge growth in teaching with technology. *Journal of Educational Computing Research,* 44(3), 299-317. DOI https://doi.org/10.2190/EC.44.3.c.

21. Papanikolaou, K., Makri, K., Roussos, P. (2017). Learning design as a vehicle for developing tpack in blended teacher training on technology enhanced learning. *International Journal of Educational Technology in Higher Education,* 14**,** 34. DOI https://doi.org/10.1186/s41239-017-0072-z.

22. Kaya, O. S., Bicen, H. (2019). Study of augmented reality applications use in education and its effect on the academic performance. *International Journal of Distance Education Technologies,* 17(3), 25-36. DOI https://doi.org/10.4018/ijdet.2019070102.

23. Ke, F., Hsu, Y. C. (2015). Mobile augmented reality artifact creation as a component of mobile computer-supported collaborative learning. *The Internet and Higher Education,* 26(1), 33-41. DOI https://doi.org/ 10.1016/j.iheduc.2015.04.003.

24. Talan, T., Doğan, Y., Batdi, V. (2020). Efficiency of digital and non-digital educational games: A comparative meta-analysis and a meta-thematic analysis. *Journal of Research on Technology in Education*, 52(4), 474-514. DOI https://doi.org/10.1080/15391523.2020.1743798.

25. Verbivskyi, D., Zhukovskyi, S., Usata, O., Fonariuk, O., Humeniuk, V. (2024). Use of digital technologies for innovation in teaching: Comparison of international and domestic approaches. *Scientific Herald of Uzhhorod University. Series Physics*, 56, 2587-2599. DOI https://doi.org/10.54919/physics/56.2024.258hf7.

26. Suyono, Nisak, S. K., Riyanto, Arsyad, M., Rusliana. (2024). Exploring the impact of technology integration on student engagement and achievement in science education. *Journal of Educational Research Excellence,* 3(2), 691-696. DOI https://doi.org/10.55299/ijere.v3i2.1048.

27. Abou El-Seoud, M., Taj-Eddin, I., Seddiek, N., El-Khouly, M., Nosseir, A. (2014). E-learning and students' motivation: a research study on the effect of e-learning on higher education. *International Journal of Emerging Technologies in Learning,* 9(4), 20-26. DOI https://doi.org/10.3991/ijet.v9i4.3465.

28. Star, J. R., Chen, J. A., Taylor, M. W., Durkin, K., Dede, C., Chao, T. (2014). Studying technology-based strategies for enhancing motivation in mathematics. *International Journal of STEM Education,* 1, 7. DOI https://doi.org/10.1186/2196-7822-1-7.

29. Albion, P. R., Tondeur, J., Forkosh-Baruch, A., Peeraer, J. (2015). Teachers' professional development for ict integration: Towards a reciprocal relationship between research and practice. *Education and Information Technologies,* 20(4), 655-673. DOI https://doi.org/10.1007/s10639-015-9401-9.