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Methodology for teaching physics based on the use of software tools

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Abstract. In this article, the content of a methodological system aimed at teaching physics through the use of software tools in technical higher education institutions, as well as its impact on learning effectiveness, is analyzed. During the pedagogical experiment, a comparative analysis was conducted between a control group (traditional instruction) and an experimental group (instruction based on software tools). Learning outcomes were evaluated using the χ^2 statistical criterion, which revealed a significant increase in the level of knowledge acquisition, motivation, and analytical thinking skills in the experimental group. The findings confirm that a methodology grounded in the use of software tools serves as an effective factor in improving the quality indicators of physics education.

INTRODUCTION

The rapid development of information and communication technologies has created the need for a fundamental renewal of the modern education system. The integration of software tools, virtual laboratories, and interactive learning platforms into the teaching of physics has significantly improved the content, structure, and methodological support of the educational process.

However, in many educational institutions, primary emphasis is still placed on traditional lecture–practical formats, which limits the overall effectiveness of instruction. Therefore, providing scientific justification for a methodological system based on the use of software tools in physics education represents an urgent research task.

The aim of this study is to determine the impact of a software-based instructional system on the level of knowledge acquisition among engineering students, to analyze the obtained results using statistical criteria, and to develop scientifically grounded conclusions.

EXPERIMENTAL RESEARCH

Previous research on the implementation of digital learning technologies in physics education highlights their influence on learning effectiveness and students' cognitive engagement from various perspectives.

In the context of the rapid development of digital technologies, the use of virtual laboratories, simulations, and software tools in physics education is significantly transforming students' learning processes. De Jong, Linn, and Zacharia (2013) emphasize in their studies that virtual laboratories make it possible to safely model complex physical processes and contribute to the meaningful acquisition of theoretical knowledge [1].

Zacharia (2015) considers virtual laboratories as an effective didactic tool that complements traditional experiments, arguing that they activate students' problem-solving skills. Meanwhile, the meta-analysis conducted by Brinson (2015) demonstrates that virtual and remote laboratories often produce learning outcomes comparable to those of real laboratories, and in some cases, even higher levels of effectiveness are achieved [2,3].

Clark and Mayer (2016) substantiate that the scientific management of cognitive load in lessons designed with multimedia technologies is a key factor in enhancing learning effectiveness. Smetana and Bell (2012) scientifically prove that the use of computer simulations helps students link abstract physical concepts with real processes, thereby facilitating deeper understanding [4,5].

As highlighted by Wieman and Perkins (2005), interactive simulations transform the learning process into experiment-oriented active learning and encourage students to engage in scientific inquiry. Hofstein and Lunetta (2004) justify the essential role of laboratory work in developing scientific thinking and research culture, while the National Research Council (2012) places particular emphasis on the importance of integrated STEM learning environments [6-8,16,17].

The meta-analysis conducted by Means et al. (2014) shows that blended learning models (online + traditional) have a positive effect on students' academic performance. The OECD (2021) report further notes that the effective use of digital technologies is directly linked to teachers' digital competencies [9-10].

In recent years, Uzbek researchers have also been conducting studies in this field. For example, Qodirov and Davletov (2025), drawing on AIP conference materials, scientifically substantiate that teaching physics through simulations significantly enhances students' thinking and visualization abilities. These findings indicate that virtual laboratories develop not only subject knowledge but also higher-order cognitive skills [11].

Thus, the reviewed scholarly sources scientifically confirm that virtual laboratories and simulations:
•deep theoretical knowledge;
 • strengthen practical engagement;
 • develop scientific-research skills;
 • stimulate motivation for independent learning.

This, in turn, further reinforces the relevance of the present research [12-15].

The process of implementing the methodological system for teaching physics through software-based instruction in the Energy Engineering specialization was carried out in several stages. These included the preliminary (diagnostic), pilot (probationary), instructional (teaching), and final (control) phases. After analyzing the results of each stage, appropriate corrections and recommendations were introduced into the instructional phases of the pedagogical experiment.

The study was conducted at Urgench State University named after Abu Rayhon Beruni. Surveys administered among students and instructors during the experiment, as well as discussions held at various conferences, revealed that software-based interactive approaches play a particularly significant role in enhancing lecture classes and organizing practical sessions in modern formats. This made it possible to develop a system that takes into account the advantages of contemporary software tools and demonstrates higher effectiveness compared to traditional forms of instruction.

The outcomes of the pedagogical experiment showed that the proposed methodological approaches improve the quality and effectiveness of teaching physics. Various elements of the methodological system were tested step-by-step over the course of two semesters and were implemented throughout the entire course.
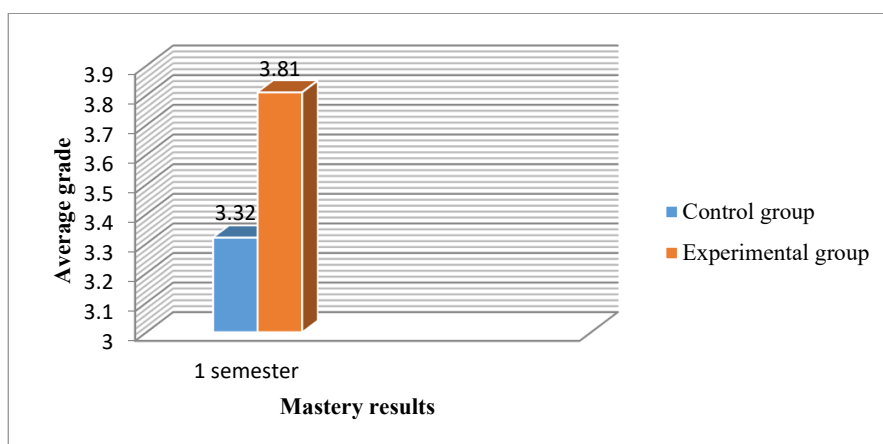
The following hypotheses were tested during the experiment:

Organizing the content of the physics course and the learning process on the basis of methodological and interdisciplinary alignment increases students' interest in the subject and significantly enhances their level of achievement. The introduction of a rating-based diagnostic assessment system in lectures, i.e., the use of continuous feedback mechanisms, stimulates active student participation and strengthens their interest in learning.

The use of software tools in practical classes ensures deeper mastery of knowledge by students, while also developing their independent learning and self-management skills, thereby establishing a steady academic work rhythm throughout the semester. The integration of the developed methodological system into the teaching of physics in higher education institutions offering Energy Engineering programs increases students' motivation and interest in the subject and improves overall learning performance.

The experiment involved a control group (50 students) and an experimental group (50 students). For each semester, the following indicators were recorded: mid-term assessment results and final examination scores. These indicators made it possible to analyze students' learning activity and overall academic achievement.

The average scores of the assessments conducted throughout the semester are presented in Figure 1.
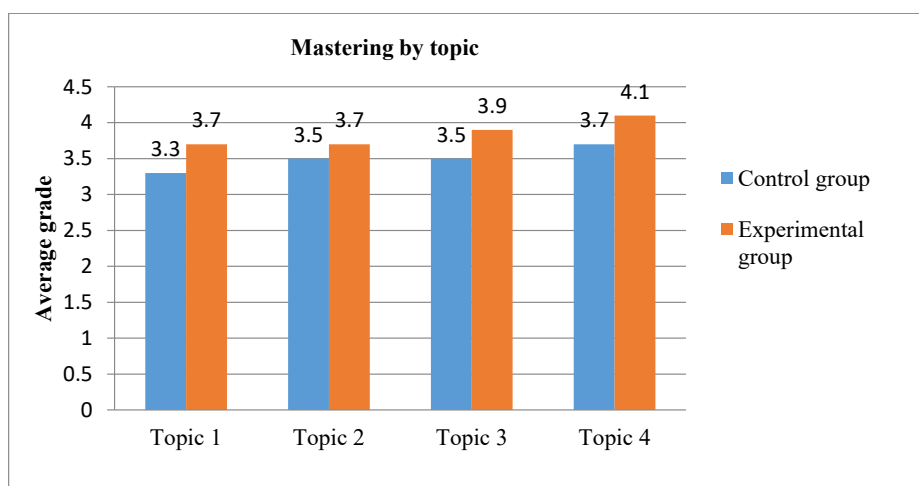
FIGURE 1. Average scores of the assessments conducted during the semester

The results of the pedagogical experiment indicate that the proposed methodological approach to teaching physics namely, the integrated organization of lectures, practical classes, and instructional materials offers several advantages over traditional instructional systems. This approach ensures more effective assimilation of the learning material, activates students' engagement throughout the entire learning process, and helps to develop strong motivational foundations that enhance learning effectiveness.

Analyses indicate that this system significantly improves students' class attendance and assessment outcomes. These improvements serve as a crucial factor in developing students' self-regulation skills and independent learning activities.

Furthermore, based on the results of the formative assessments presented in Figure 3, the impact of the proposed instructional system on the development of students' analytical thinking skills in physics education was also evaluated. These skills were particularly enhanced in situations requiring independent work.

FIGURE 2. Results of the formative assessments

Although students in the control group demonstrated results in theoretical knowledge acquisition comparable to those of the experimental group, they faced difficulties in organizing and classifying learning information and performing deep analytical tasks. In contrast, students in the experimental group exhibited higher-level intellectual skills, demonstrating the ability to connect acquired knowledge across different subjects and to integrate it into a progressively expanding conceptual framework.

Based on the experimental results described above, it can be concluded that the systematic use of software tools at all stages of the learning process significantly enhances students' engagement in independent study and activity. Additionally, structuring physics instruction based on interdisciplinary links and a theoretical approach ensures the internal logical coherence of the learning process, thereby fostering comprehensive development of knowledge, thinking, and visualization skills in students within higher education institutions offering Energy Engineering programs.

As a result of this approach, students' professional competence is developed not only within individual subject areas but also through a systemic integrative approach. This, in turn, contributes to achieving overall educational objectives and addressing specific learning outcomes within distinct academic disciplines.

Statistical Analysis of Pedagogical Experiment Results

In the quantitative analysis of the pedagogical experiment, the χ^2 (chi-square) statistical method was employed. This method was used to assess the statistical reliability of the data obtained during the experiment.

During the experiment, two independent student groups were formed, each consisting of at least 50 participants. The learning outcomes of each group were evaluated according to four categories:

- Category 1: Unsatisfactory (0–59.9 points)
- Category 2: Satisfactory (60–69.9 points)
- Category 3: Good (70–89.9 points)
- Category 4: Excellent (90–100 points)

RESEARCH RESULTS

STAGE 1. At the preliminary (diagnostic) stage, students took a computer-based entrance test. Based on the test results, the instructors responsible for each group assessed the overall knowledge level of students and identified topics and questions that caused the greatest difficulties. This allowed lectures and theoretical sessions in the subsequent stages to be organized in a way that effectively enhances students' learning outcomes.

The following notation was used for calculating the χ^2 statistic:

- N_1 and N_2 – number of students in the control and experimental groups, respectively
- C – number of assessment categories (in this study, C = 4)
- P_{1i} – probability of a student in the control group receiving a grade in category i
- P_{2i} – probability of a student in the experimental group receiving a grade in category i
- n_{1i} – number of students in the control group falling into category i
- n_{2i} – number of students in the experimental group falling into category i
- v – degrees of freedom for the selected confidence level

If the confidence level is set at P = 0.05 (i.e., a 5% probability of error) and C = 4 categories, then the degrees of freedom are calculated as v = C-1 = 3. In this case, the critical value of the χ^2 statistic is: $\chi^2 : \chi^2_{(crit)} \geq 7.81$

To assess the initial level of students' knowledge, the data from two independent groups were analyzed based on the results of the entrance-stage test.

The null hypothesis (H_0) stated that the initial knowledge levels of both groups are identical, i.e.:

$p_{11} = p_{21}$, $p_{12} = p_{22}$, $p_{13} = p_{23}$, $p_{14} = p_{24}$

The alternative hypothesis (H_1) posited that, for at least one category, the probabilities differ, i.e.: $p_{1i} \neq p_{2i}$

In the experiment, the χ^2 statistic was calculated using the following formula:

$$\chi^2 = \frac{1}{N_1 \cdot N_2} \sum_{i=1}^{C} \frac{(N_1 \cdot n_{2i} - N_2 \cdot n_{1i})^2}{n_{1i} + n_{2i}} \quad (\qquad\qquad 1)$$

Based on the results of the initial assessment of students' knowledge in the physics sections studied during the first semester, the calculated χ^2 values are presented in Table 1.
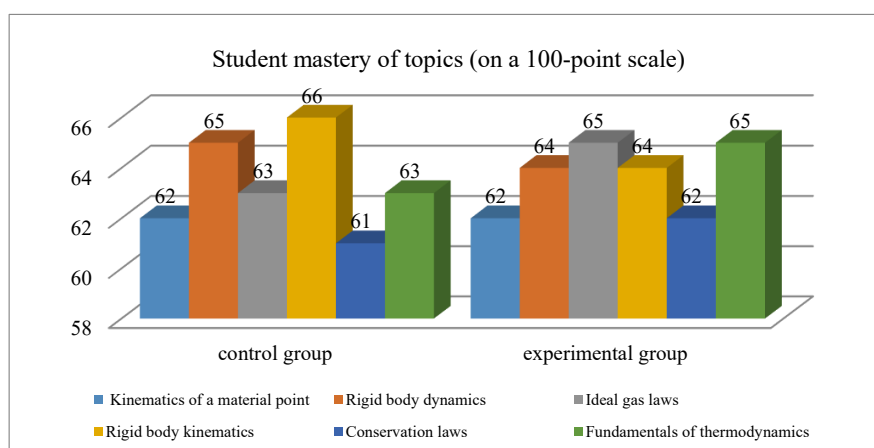
Entrance Assessment.

TABLE 1. Calculated χ^2 values for students' initial knowledge in physics sections

Section	Mechanics	Molecular Physics and Thermodynamics
$\chi^2_{(experiment)}$	2.44	1.17

Based on the table data, the calculated $\chi^2_{(experiment)}$ values for all sections are smaller than the critical χ^2 value (7.81). This indicates that there is no statistically significant difference between the initial test results of the control and experimental groups.
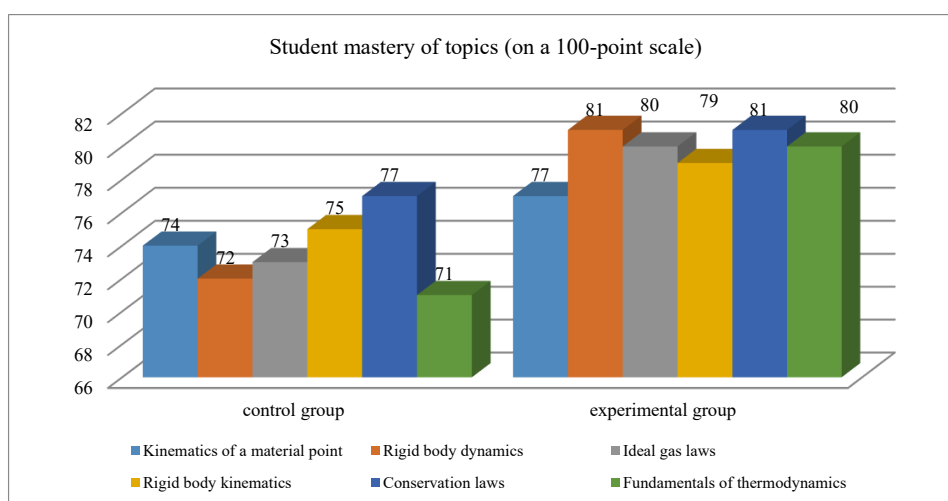
Thus, at the beginning of the experiment, both groups were in equivalent conditions in terms of knowledge level, which provides a reliable basis for evaluating the effectiveness of the applied methodological approach observed during the experiment.

Figure 3. Results of the entrance assessment in the topics: "Mechanics; Molecular Physics; Thermodynamics" (at the beginning of the experiment)

Thus, when forming the experimental and control groups for the instructional stage, their composition characteristics and initial knowledge levels were set as the primary criteria to ensure equivalence.

STAGE 2. In the next stage, students continued their studies in their respective specializations. For the control group, the traditional lecture format using "blackboard and chalk" was retained during the instructional process. In contrast, the experimental group received instruction entirely through a methodological teaching system developed on the basis of information technologies. This system is designed to teach physics in technical higher education institutions using a modern, technology-based approach.

FIGURE 4. Assessment results of the control and experimental group students in the sections "Mechanics; Molecular Physics; Thermodynamics" (at the end of the experiment)

At the end of each section, formative assessments were conducted to evaluate students' knowledge. The results of these assessments indicate that students in the experimental group achieved higher scores compared to those in the control group (see Figure 4).

To determine the positive impact of a methodological teaching system based on information technologies on the effectiveness of physics learning in a technical university, the results of assessments conducted over three semesters with students studying physics were analyzed. During this analysis, the final assessment outcomes of the control and experimental group students (Tables 1–4) served as the primary evidence.

Based on the formative assessment results, the null hypothesis (H_0) was tested to determine whether the results of the control and experimental groups were identical. The null hypothesis (H_0) stated that the probabilities across all C = 4 assessment categories are equal, i.e.: ($p_{11} = p_{21}, p_{12} = p_{22}, p_{13} = p_{23}, p_{14} = p_{24}$). The alternative hypothesis (H_1) posited that, for at least one category, these probabilities differ, i.e.: ($p_{1i} \neq p_{2i}$).

According to the statistical analysis, the calculated $\chi^2_{(experimental)}$ value exceeded the critical χ^2 value ($\chi^2_{(experimental)} > \chi^2_{(critical)}$). This indicates that the null hypothesis was rejected and the alternative hypothesis H_1 was accepted.

Thus, these results confirm that the assessment outcomes of students in the two groups differ significantly across the grading categories, indicating a real difference between the groups in terms of the studied characteristics.

Table 2. Formative assessment results for the sections "Mechanics; Molecular Physics; Thermodynamics"

Topic	Material Point Kinematics	Rigid Body Kinematics	Rigid Body Dynamics	Laws of Motion Conservation	Ideal Gas Law	Introduction to Thermodynamics
$\chi^2_{(experimental)}$	13.86	12.44	12.74	9.43	14.74	10.11

These values indicate that, within the scope of the experiment, there are significant differences between the control and experimental groups for each topic. This confirms the effectiveness of the applied methodological approach.

TABLE 3. Formative assessment results for the topic "Material Point Kinematics"

Group	Category 1 (0–59.9)	Category 2 (60–69.9)	Category 3 (70–89.9)	Category 4 (90–100)
Control (N_1=50)	$n_{11} = 12$	$n_{12} = 15$	$n_{13} = 16$	$n_{14} = 7$
Experimental (N_2=50)	$n_{21} = 5$	$n_{22} = 6$	$n_{23} = 18$	$n_{24} = 21$
$\chi^2_{(experimental)}$	13.86			

Analysis of the results indicates that the experimental group had a substantially higher number of students achieving top scores. Specifically, for Category 4 (90–100 points), only 7 students in the control group reached this level, whereas 21 students in the experimental group attained it. These findings demonstrate that the applied methodological approach significantly enhanced learning effectiveness.

Control Results: Comparative Analysis

TABLE 4. Formative assessment results for the topic "Rigid Body Kinematics"

Group	Category 1 (0–59.9)	Category 2 (60–69.9)	Category 3 (70–89.9)	Category 4 (90–100)
Control (N_1=50)	$n_{11} = 8$	$n_{12} = 19$	$n_{13} = 18$	$n_{14} = 5$
Experimental (N_2=50)	$n_{21} = 3$	$n_{22} = 10$	$n_{23} = 19$	$n_{24} = 18$
$\chi^2_{(experimental)}$	12.44			

Analysis of the results shows that the number of students achieving top scores (Category 4) in the experimental group is more than three times higher than in the control group (18 vs. 5 students), demonstrating the effectiveness of the applied methodological approach.

TABLE 5. Formative assessment results for the topic "Rigid Body Dynamics"

Group	Category 1 (0–59.9)	Category 2 (60–69.9)	Category 3 (70–89.9)	Category 4 (90–100)
Control	11	15	16	8
Experimental	4	7	17	22
$\chi^2_{(experimental)}$	12.74			

The results indicate that 22 students in the experimental group achieved scores in Category 4 (90–100), demonstrating a higher level of mastery in this topic.

TABLE 6. Formative assessment results for the topic "Laws of Motion Conservation"

Group	Category 1 (0–59.9)	Category 2 (60–69.9)	Category 3 (70–89.9)	Category 4 (90–100)
Control	7	18	16	9
Experimental	3	9	17	21
$\chi^2_{(experimental)}$	9.43			

In the experimental group, 21 students scored in Category 4, confirming a high level of material mastery.

TABLE 7. Formative assessment results for the topic "Ideal Gas Law"

Group	Category 1 (0–59.9)	Category 2 (60–69.9)	Category 3 (70–89.9)	Category 4 (90–100)
Control	9	19	14	8
Experimental	3	7	20	20
$\chi^2_{(experimental)}$	14.74			

Similarly, in the experimental group, 20 students achieved top scores (Category 4), demonstrating a significant advantage over the control group.

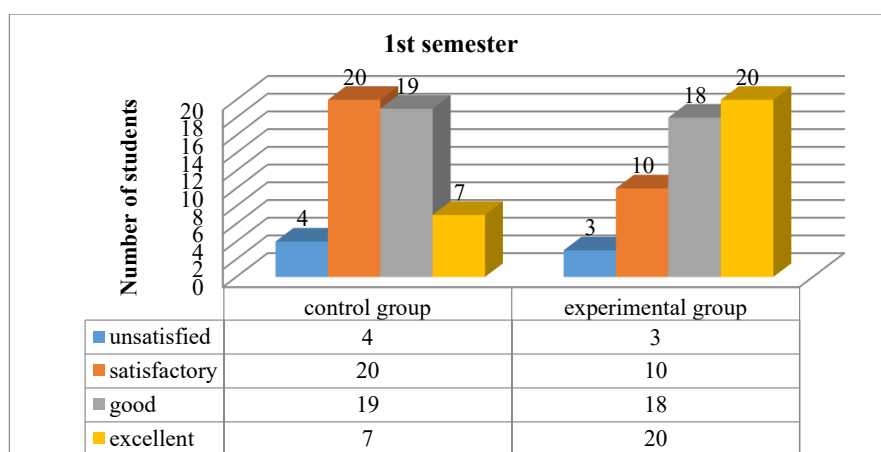**TABLE 8**. Formative assessment results for the topic "Introduction to Thermodynamics"

Group	Category 1 (0–59.9)	Category 2 (60–69.9)	Category 3 (70–89.9)	Category 4 (90–100)
Control (N_1=50)	12	12	16	10
Experimental (N_2=50)	3	10	15	22
$\chi^2_{(experimental)}$	10.11			

These results show that the number of students achieving top scores (Category 4) in the experimental group was significantly higher than in the control group, indicating that the methodological system positively influenced learning effectiveness.

STAGE 3. Semester Final Assessment. The third stage of knowledge evaluation involved the semester final assessment. The histogram presented in Figure 5 shows that students studying physics using the developed methodological system and software tools demonstrated higher levels of knowledge mastery.

In the experimental group, the number of "Satisfactory" grades was significantly lower than in the control group. As a result, the number of "Good" and "Excellent" grades increased. That is, some students who previously received "Satisfactory" grades improved to "Good," and those who were "Good" advanced to "Excellent" (see Figure 5).

1st semester

	control group	experimental group
unsatisfied	4	3
satisfactory	20	10
good	19	18
excellent	7	20

FIGURE 5. Distribution of semester final grades (histogram)

TABLE 9. Final examination results in Physics for the 1st semester

Group	Category 1 (Unsatisfactory)	Category 2 (Satisfactory)	Category 3 (Good)	Category 4 (Excellent)
Control (N = 50)	$n_{11} = 4$	$n_{12} = 20$	$n_{13} = 19$	$n_{14} = 7$
Experimental (N = 50)	$n_{21} = 3$	$n_{22} = 10$	$n_{23} = 18$	$n_{24} = 20$
χ^2(experimental)	9.76			

Tables 9-present the final examination results across all studied sections of the physics course for the groups participating in the experiment.

CONCLUSIONS

The conducted pedagogical experiment, statistical analysis, and review of theoretical sources demonstrate that the methodological system aimed at teaching physics based on software tools constitutes a highly effective pedagogical technology aligned with modern educational requirements. The learning process, organized using software tools, promotes the thorough formation of theoretical knowledge, develops students' ability to apply this knowledge in real practical situations, and enhances research-oriented thinking skills.Analysis based on the Chi-square (χ^2) statistical criterion reliably confirmed that the performance of students in the experimental group was significantly higher than that of the control group. These results are not random but are explained by the scientific grounding and didactic advantages of the applied methodological system. The software-based learning environment encourages students to engage consciously in lessons, actively participate, and cultivate independent learning habits.

The study further revealed that the use of software tools strengthens interdisciplinary integration, facilitates deep understanding of complex physical phenomena through modeling, and improves feedback mechanisms. Consequently, the proportion of students with low grades decreased, while the number of "Good" and "Excellent" grades increased sharply. This indicates that the methodological system positively influences not only knowledge acquisition but also motivation, responsibility, and analytical thinking.

Another significant aspect is that the software-based methodological system allows students to repeatedly study educational material under various didactic scenarios, thereby ensuring knowledge retention. At the same time, this approach does not replace traditional laboratory sessions; rather, it complements them effectively and creates a comprehensive, integrated model of the learning process.

Overall, the research results clearly indicate that the implementation of a software-based methodological system in physics education for technical disciplines:

- Enhances the quality of education;
- Balances theoretical and practical training;
- Develops students' professional competencies;
- Cultivates a culture of independent work in a digital learning environment;
- Contributes to the development of skills demanded in the modern labor market.

Therefore, it is advisable to systematically integrate a scientifically grounded blended approach that combines traditional teaching methods with digital technologies in physics education. In the future, this methodological system can be applied to other natural sciences, the capabilities of virtual laboratories can be further expanded, and their impact on learning outcomes can be studied in greater depth.

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