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The role of artificial intelligence in modernizing higher education in the natural sciences

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Abstract

The article examines the impact of using artificial intelligence (AI) tools on the assimilation of topics in natural science disciplines by students of technical specialties. The aim of the study is to assess the effectiveness of AI as an auxiliary tool in learning complex theoretical and practical topics in electrical circuits. Within the framework of a pedagogical experiment, students in the experimental group, in addition to traditional learning, used AI tools ChatGPT, Wolfram Alpha, and PhET Simulations for problem-solving, modeling, and process visualization. The results of the final testing among students from universities in Kazakhstan (Almaty University of Power Engineering and Telecommunications named after G. Daukeyev, Almaty Technological University, Caspian University of Technology and Engineering named after Sh. Yessenov and Civil Aviation Academy) showed that the knowledge gain in the experimental group was 18.1 points, which is almost 2.5 times higher than in the control group. A survey confirmed a high level of engagement and a positive perception of AI among students. The conclusions highlight the potential of AI as an effective tool for personalized learning, provided it is methodologically integrated into the educational process.

Keywords: ChatGPT, Competence, PhET simulations, Physics, Student, University, Wolfram alpha.

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1. Introduction

Modern engineering education requires not only deep theoretical knowledge but also the development of technical competencies, especially in the field of core natural science disciplines (such as physics, mathematics, and computer science). However, in the process of studying these subjects, students often face significant difficulties. These disciplines demand abstract thinking, well-developed analytical skills, as well as a systematic and consistent approach to learning. As a result, many students struggle both with mastering theoretical material and applying it in practice [1].

One of the key factors reducing the effectiveness of education is the lack of an individual approach. In the context of mass education, it is difficult for an instructor to take into account each student's level of preparation, perception style, and personal needs. This leads to superficial knowledge acquisition, decreased motivation, and diminished interest in subjects, especially those of a technical nature. In light of these challenges, there is a growing need to reconsider traditional teaching methods and implement personalized educational strategies that can increase student engagement and academic outcomes [2-4].

In this regard, the application of artificial intelligence (AI) in the educational environment is becoming increasingly important. Modern EdTech (Educational Technology) tools, including intelligent tutoring systems, are opening new horizons for the individualization and optimization of the learning process. The use of AI allows for the automation of routine tasks, the adaptation of learning content to the student's level, and the provision of instant feedback. This is particularly relevant in engineering education, where it is essential not only to memorize theory but also to learn how to apply it to practical problems [5].

On the international stage, AI is already actively being integrated into educational practices: virtual assistants, smart classrooms, predictive analytics systems, as well as technologies capable of recognizing students' emotions and behaviors are being developed to improve the quality of education. Among the successful solutions are platforms such as ChatGPT (for content generation and explanation), Squirrel AI (adaptive learning with knowledge diagnostics), Coursera Labs (interactive practice with progress analysis), OpenEdX (a scalable online learning system), and Khan Academy, Duolingo, Carnegie Learning all of which utilize AI to varying degrees to enhance the effectiveness and personalization of education.

However, the global spread of AI is accompanied by several challenges: from ethical issues (such as data privacy and algorithmic bias) to organizational and financial ones (such as the shortage of specialists and the high cost of development and implementation). In Kazakhstan and other CIS countries, the integration of AI in education is still at an early stage. While certain elements are already in use, for example, in digital platforms like Bilimland, Kundelik, and automated assessment systems, the development is hindered by the lack of a clear national strategy, insufficient technical resources, and the low level of digital literacy among educators.

There is a clear need for a systemic approach: the development of educational infrastructure, the upskilling of teachers, the establishment of research centers in EdTech, and the creation of a regulatory framework governing the use of AI in education [6].

Given the above, the goal of our study is to determine the impact of artificial intelligence tools on the effectiveness of learning the topic «Electricity» in the physics course among students of technical majors.

Research objectives:

1. Conduct an experiment on the implementation of AI tools in the learning process on the topic «Electricity»;
2. Assess students' level of understanding and engagement;
3. Compare the results of the experimental and control groups.
4. Identify students' perception of AI as a learning assistant.

Object of the study: the educational process in technical universities in Kazakhstan.
Subject of the study: the impact of artificial intelligence tools on the study of the topic «Electricity» in the physics course.

Thus, the development and integration of intelligent educational systems, especially in such critically important disciplines as physics, open up promising pathways for modernizing engineering education. The use of AI not only improves academic performance and student motivation but also contributes to the formation of flexible and resilient technical competencies that are in high demand in the digital economy.

2. Methodology

To achieve the stated goals and address the research objectives, a comprehensive methodology was developed, incorporating both quantitative and qualitative methods of data collection and analysis. The approach aims to identify the impact of using artificial intelligence (AI) tools on students' mastery of the topic "Electricity" within the physics course. The following methods were employed in the study (see Figure 1):

- Surveys conducted among students and faculty of technical universities to assess their awareness of AI technologies, the extent of their use in the educational process, and subjective evaluations of their effectiveness;
- Case analysis involved examining practical examples of AI tool implementation in the educational process, both in international and local contexts.
- Interviews conducted with physics instructors and educational IT specialists to gather expert opinions on the potential and limitations of AI in teaching natural science disciplines;
- Pedagogical experiment, the core component of the research, in which an AI-based system of assistants and digital simulators was implemented in one student group, while another group followed a traditional instructional model. The results were compared based on academic performance, engagement, and perception of the learning process.

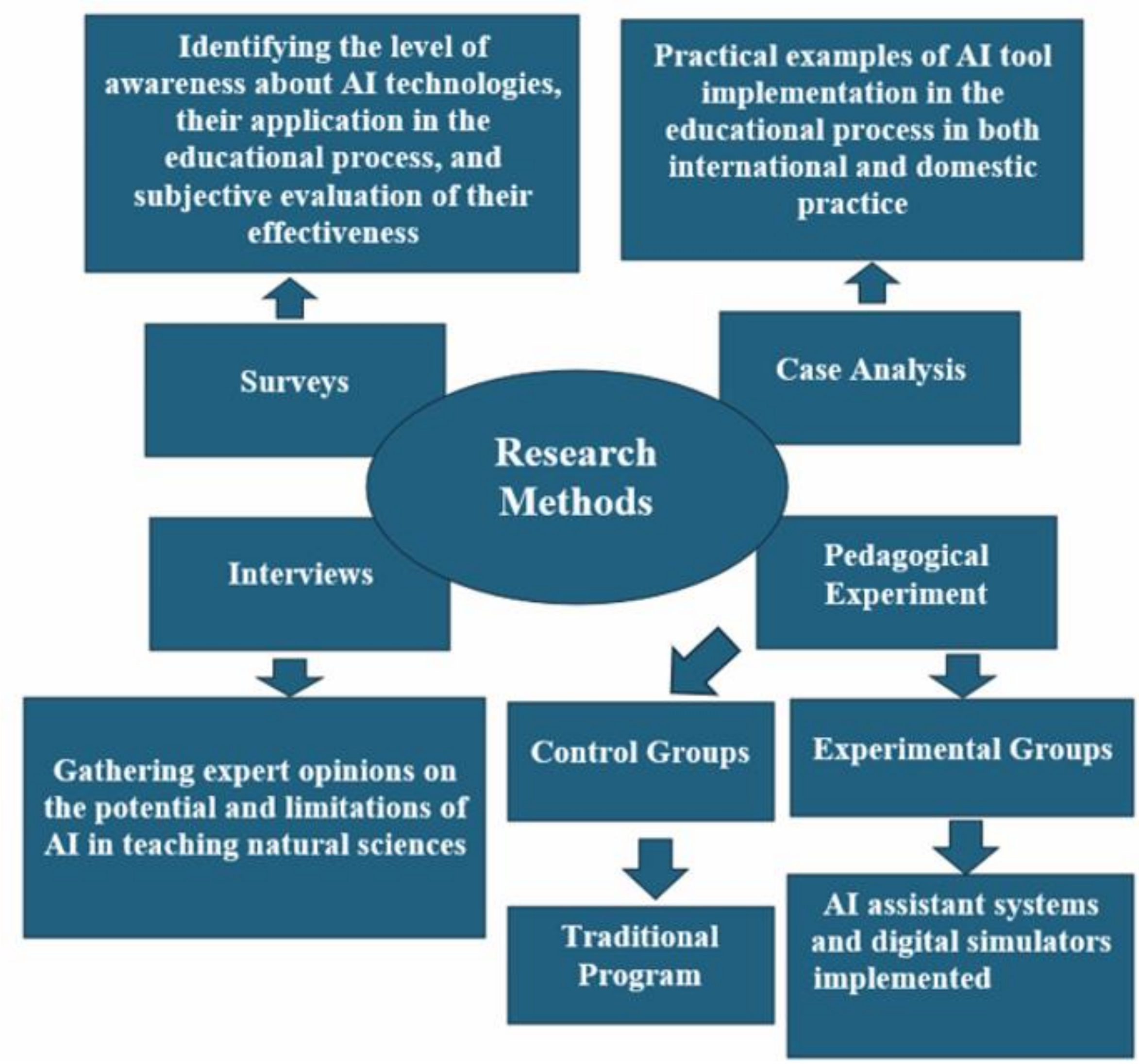

Figure 1.
Applied research methods.

The following AI solutions were selected as tools for integration into the educational process (Figure 2):

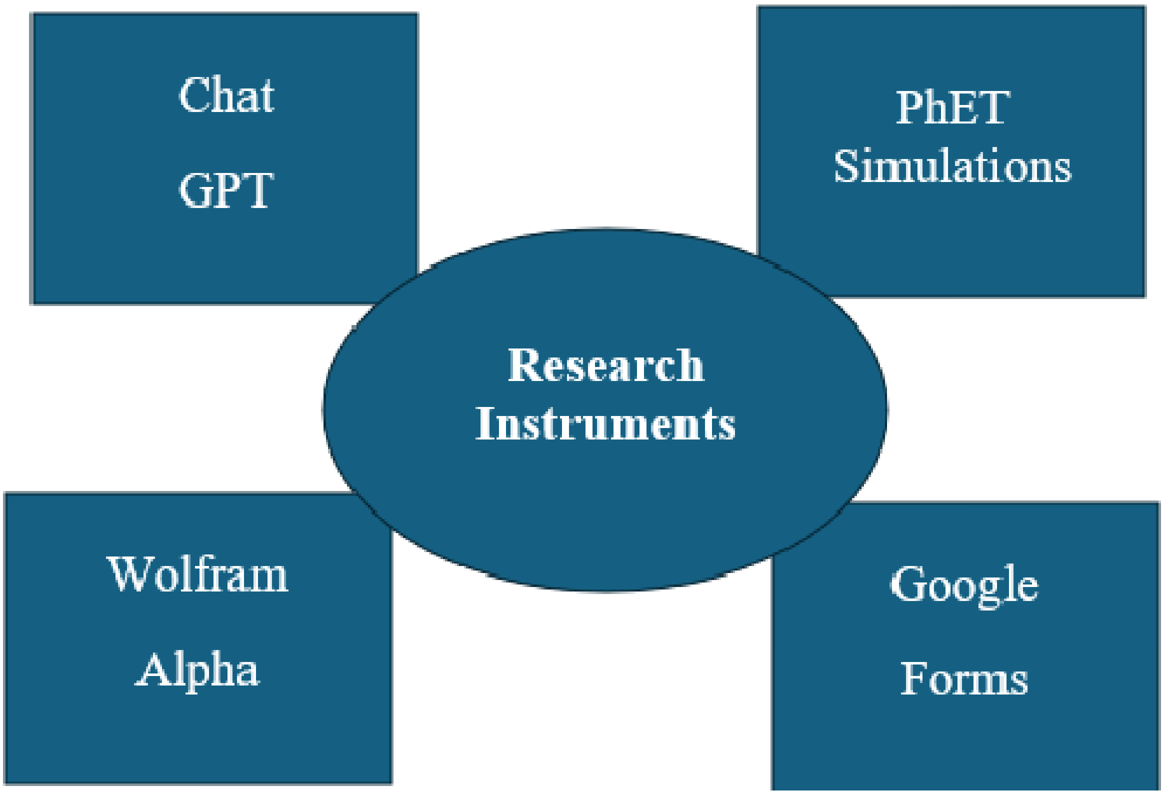

Figure 2.
Pedagogical Research Tools.

ChatGPT (OpenAI) was used as a virtual assistant for explaining complex concepts, assisting with problem-solving, generating quizzes, and answering students' questions on the topic of «Electricity». Students could interact with it during independent study. For example, a student might ask: *«What is the difference between alternating and direct current?»* ChatGPT provides an explanation with examples and diagrams. Another example: test generation *«Create 5 multiple-choice questions on Ohm's law»* the model generates an interactive quiz. Students could also input a physics problem, and ChatGPT would break down the solution step by step, emphasizing the application of physical laws.

PhET Simulations (University of Colorado Boulder) - interactive simulations of physical processes that allow students to model and visualize phenomena related to current, voltage, and resistance. These tools are particularly useful in topics where visual representation is important. For example, in the «Circuit Construction Kit: DC» simulation, students assemble an electric circuit using resistors, power sources, and ammeters, observing how current changes when resistance is varied. Another example is a virtual lab titled «Measuring Resistance Using Ohm's Law», where students simulate a circuit and plot the voltage-current graph.

Wolfram Alpha, a computational intelligence system used for performing calculations, plotting graphs, and analyzing formulas from the physics course, particularly on the topic of «Electricity». For example, a student enters the query: *«Solve $U = I * R$ for I, if $U = 12V$, $R = 4$ Ohms»*. Wolfram Alpha automatically substitutes the values and returns the result: $I = 3$ *A*. Another example is visualization: plotting the power-resistance dependency using the formula $P = U^2 / R$ with $U = 10V$. The system is also used to verify and simplify complex formulas, such as for RC circuits. The student receives both the final answer and a step-by-step explanation. This is especially convenient for students, enabling quick equation solving, value substitution, and graph visualization.

Google Forms + automatic analytics, used to conduct surveys and collect feedback on the perception of AI tools. A questionnaire and a 10-question quiz were developed with automatic grading, result export to spreadsheets, and generation of performance charts.

3. Discussion of Results

The topic «Direct Current Circuits» was selected for the experiment. First-year engineering students participated in the study (two groups of 20 students each were formed from participating universities). The control group followed a traditional learning method: lectures, textbooks, and standard problems. The experimental group, in addition to traditional materials, used AI tools (see Figure 2).

The experiment consisted of several stages (see Figure 3):

1. Pre-test — to determine the initial level of knowledge;
2. Main learning phase (2 weeks), each group studied using its assigned method;
3. Post-test — similar in difficulty to the pre-test;
4. Survey — to assess students' attitudes toward using AI in the learning process.

The results were analyzed by comparing the pre- and post-test scores, along with the survey responses provided by the students.

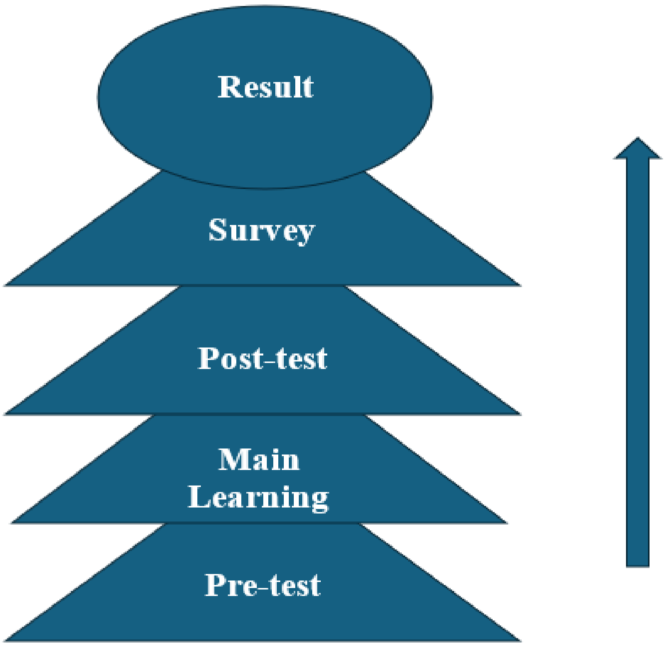

Figure 3.
Stages of the Pedagogical Experiment.

Subsequently, after a two-week period of using AI tools by students in the experimental group, data from the final assessment and student survey were collected and subjected to comprehensive analysis.

The final test included important questions covering the core topics of the section on «Electricity», designed to evaluate students' knowledge retention and conceptual understanding after the instructional period. In parallel, the survey aimed to assess students' subjective experiences and attitudes toward the use of AI-assisted learning. The questionnaire comprised the following items:

1. Self-assessed level of understanding after completing the lessons (very good; good; average; bad).
2. Impact of AI tools on understanding the material (yes, partially; no).
3. Types of AI features students found most useful (theoretical explanations; problem-solving assistance; simulations; other: specify).
4. Perceived convenience and usability of AI tools (very convenient; convenient; not convenient).
5. Intentions for future use of AI in physics learning (yes; maybe; no).
6. Students' personal comments and suggestions (open-ended response).
7. Clarity and comprehensibility of AI-generated explanations (always clear; mostly clear; sometimes unclear; completely unclear).
8. Frequency of AI usage during the study (daily; several times a week; once or twice; not used at all).
9. Most appreciated aspects of AI tools (quick responses; personalized support; clear explanations; process visualization).
10. Influence of AI on motivation to learn (significantly increased; slightly increased; unchanged; decreased).
11. Perceptions of AI as a potential replacement for tutors (yes; partially; no).
12. Trust in the accuracy of AI-generated information (fully trust; trust with verification; somewhat skeptical; do not trust).
13. Challenges encountered while using AI tools (language barrier; difficulty phrasing questions; incomplete/inaccurate answers; no difficulties).
14. Most helpful AI platform (ChatGPT; Wolfram Alpha; PhET simulations; other: specify).
15. Overall contribution of AI to understanding the topic (very high; high; moderate; low).
16. Willingness to use AI in other physics topics (definitely yes; possibly; no, prefer traditional methods).
17. Comparison of understanding before and after using AI (significantly better; slightly better; no change; worse).
18. Preferred formats of AI-based explanations (text-based explanations; graphs and images; videos or simulations; worked examples).
19. Preferred communication style of AI platforms (detailed explanations; concise and to the point; step-by-step instructions; question-answer format).
20. Interest in AI-integrated physics modules or courses (yes, definitely; maybe, if interesting; no, prefer standard curriculum).

Below is a breakdown of student responses to each of the 20 survey items regarding the use of AI tools in learning about the topic. These results are based on survey data from 20 students in the experimental group.

1. Self-assessed level of understanding after completing the lessons
- very good: 83%
- good: 8%
- average: 9%
- bad: 0%
2. Did AI tools help you better understand the material?
- yes: 87%
- partially: 13%
- no: 0%
3. What was most useful about using AI tools?
- theoretical explanations: 35%
- problem-solving assistance: 30%
- simulations: 32%
- other: 3%
4. How convenient was AI in your learning process?
- very convenient: 71%
- convenient: 24%
- not convenient: 5%
5. Do you plan to use AI for learning physics in the future?
- yes: 69%
- maybe: 26%
- no: 5%
6. Comments and suggestions
- 78% left written feedback, mostly positive with constructive suggestions.
7. How clear were the AI's answers to your questions?
- always clear: 41%
- mostly clear: 47%
- sometimes unclear: 12%
- completely unclear: 0%
8. How often did you use AI while studying this topic?
- daily: 53%
- several times a week: 29%
- once or twice: 13%
- not used at all: 5%
9. What did you like most about using AI?
- quick responses: 21%
- personalized support: 34%
- clear explanations: 28%
- process visualization: 17%
10. Did AI increase your motivation to learn?
- significantly increased: 48%
- slightly increased: 37%
- no change: 15%
- decreased: 0%
11. Do you believe AI could replace a tutor or instructor in some topics?
- yes: 36%
- partially: 51%
- no: 13%
12. How do you assess the reliability of AI-generated information?
- fully trust: 21%
- trust with verification: 62%
- somewhat skeptical: 17%
- do not trust: 0%
13. What difficulties did you face when using AI?
- language issues: 19%
- difficulty phrasing questions: 33%
- incomplete answers: 24%
- no difficulties: 24%
14. Which AI tool was most helpful?
- ChatGPT: 46%
- Wolfram Alpha: 21%
- Phet Simulations: 30%
- other: 3%

15. How would you rate the overall contribution of AI to your understanding?
- very high: 41%
- high: 38%
- moderate: 17%
- low: 4%

16. Would you like to use AI for other physics topics?
- definitely yes: 57%
- possibly: 38%
- no: 5%

17. Compare your understanding before and after using AI
- significantly better: 53%
- slightly better: 42%
- no change: 5%
- worse: 0%

18. Which formats of AI explanations were most useful?
- text explanations: 24%
- graphs/images: 31%
- videos/animations: 28%
- worked examples: 17%

19. Preferred AI response style
- detailed explanations: 33%
- concise: 25%
- step-by-step: 29%
- question-answer format: 13%

20. Would you be interested in an AI-integrated physics module?
- yes, definitely: 61%
- maybe: 34%
- no: 5%.

Subsequently, after two weeks of using AI tools by students in the experimental group, data from the final testing and the survey were collected and analyzed.

A comparison of test results in percentages (Figure 4) shows the following: in the control group, the average pre-test score was 61.2, and the post-test score was 68.5 (*+7.3*); in the experimental group, the average pre-test score was 60.8, and the post-test score was 78.9 (*+18.1*). The score improvement in the experimental group was almost 2.5 times higher than in the control group. Participants in the experimental group performed especially well on tasks involving the application of Kirchhoff's laws and the analysis of complex circuits.

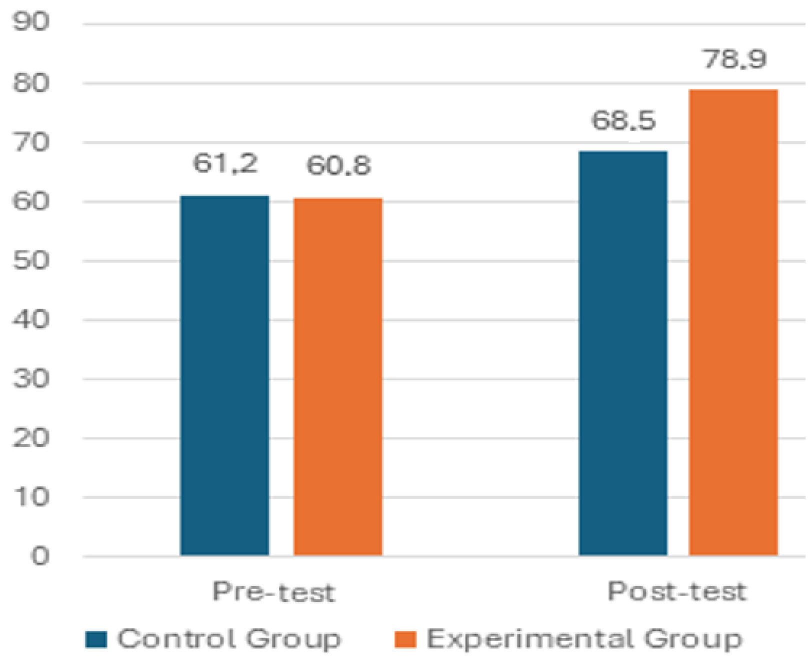

Figure 4.
Comparison of Results (in percentages): Control vs. Experimental Group.

According to the survey results, 85% of respondents stated that AI helped them better understand the theory; 78% reported that it helped them solve problems more quickly; 70% noted that it increased their confidence in their knowledge.

4. Conclusion and Recommendations

The use of AI tools in studying the topic «Direct Current Circuits» demonstrated significant potential in improving students' academic performance, engagement, and independence. The experimental data showed that the integration of digital intelligent tools positively affects both the objective learning outcomes (score improvement) and the subjective perception of the learning process.

AI tools performed various functions within the educational environment:

- ChatGPT provided personalized support, helping students understand complex topics, formulate solutions, and receive interactive explanations;
- Wolfram Alpha served as an accurate and reliable tool for performing calculations, generating graphs, and conducting algebraic analysis;
- PhET simulations offered visualization of abstract physical phenomena, contributing to the development of strong conceptual understanding.

At the same time, certain limitations were identified. Some students experienced difficulties in formulating effective queries and noted occasional ambiguity or incompleteness in AI-generated responses. This highlights the importance of pedagogical guidance, which helps direct and refine students' interactions with digital tools.

Overall, the method proved to be highly effective when properly integrated into the educational process as a complement to traditional teaching methods, rather than a replacement.

Thus, based on the findings, the authors recommend using AI tools as auxiliary resources in the study of physics and other subjects, aimed at individualizing learning and expanding opportunities for independent work [7-9]. It is also essential to conduct training sessions for students on how to formulate clear and effective prompts and how to critically evaluate AI-generated answers.

The authors intend to continue experimental research on the use of AI in education by applying it to other topics in the physics course [10, 11] in order to gain a broader understanding of its effectiveness and to identify best practices.

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