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Problematic Situations in Teaching Physics and The Methodology for Creating Them

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Abstract: This article scientifically analyzes the types of problematic situations in physics education and the methodology for creating them effectively. The main objective of the study is to improve the quality of students' learning, foster independent thinking, encourage creative approaches, and develop practical skills by utilizing problematic situations in the educational process. The article employs pedagogical experiments, observation, and analytical methods. Observation results show that in lessons based on problematic situations, students' cognitive activity, question-and-answer engagement, and independent research indicators significantly increase compared to traditional lessons. In conclusion, the article emphasizes that the implementation of problem-based learning technologies not only ensures a deep understanding of theoretical knowledge but also contributes to shaping individuals capable of solving practical problems. These findings offer recommendations aimed at improving the quality of education in both general secondary and higher education institutions.

Keywords: Problem situation, methodology, educational technologies, physics, teaching, creativity, inquiry, independent thinking.

Introduction: Nowadays, there is a growing demand for innovative approaches in the educational process. While traditional teaching methods serve primarily to deliver ready-made knowledge to students, modern pedagogical technologies encourage independent thinking, inquiry, communication, and creative approaches. From this perspective, problem-based learning technologies hold particular importance.

Currently, improving the quality of education in general secondary schools is closely linked with the implementation of innovative pedagogical technologies. In particular, problem-based learning technologies (PBLT) play a significant role in developing students' cognitive activity, independent thinking, problem-solving abilities, and creative potential.

International studies have shown that the PBLT model is an effective tool in physics education for reinforcing students' conceptual understanding, increasing motivation, and developing critical thinking skills [1; 2]. For instance, a systematic review conducted by Tain and colleagues (2024) analyzing 32 studies from 2014–2022 revealed that PBLT significantly enhanced students' conceptual understanding and motivation in general education schools (DOI: 10.1063/5.0210273). Karmila et al. (2021) also confirmed that a PBLT model integrated with Google Classroom was effective in improving students' scientific literacy (DOI: 10.2991/assehr.k.210326.064).

In Uzbekistan, research is being conducted on problem-based learning technologies. For example, Kamil Normamatovich Kholov and Nodirbek Kholturayevich Bobilov (2024) in their studies highlighted the theoretical and practical foundations of creating problematic situations in physics education, and proposed methodological recommendations aimed at developing students' independent thinking, engagement in laboratory activities, and social competencies [3].

However, there is still a lack of systematic implementation of PBLT methodology in general education schools, particularly in the context of physics lessons, and insufficient scientific evaluation of its effectiveness. This issue is considered relevant from both theoretical and practical perspectives.

Main Part (Materials and Methods)

The central component of problem-based learning technologies is the problematic situation. It arises when a student consciously feels the need to learn, finds existing knowledge insufficient, and acquires new knowledge in the process of resolving the issue [6; 9; 17]. Problematic situations in the learning process encourage students to think actively, conduct research, and seek alternative solutions [10].

A problematic situation is a condition that presents something new to the student—one that cannot be fully resolved with existing knowledge, but which can be solved through logical inquiry [5; 8]. An example from the topic "Oscillations and Waves" can illustrate this. For instance, if a student has previously learned the formula and properties of harmonic oscillation

$x = A \cdot \sin(\omega t)$,

as a problematic situation, a student may be asked a question about the superposition of complex oscillations: "If two oscillations with different frequencies simultaneously act on an object, how will it move?"

To answer this question, the student's existing foundational knowledge is insufficient, yet it prompts the start of inquiry based on that prior understanding. The emergence of a problematic situation is ensured by the following conditions:

- The presence of foundational knowledge related to the topic;
- The appearance of a new problem (a gap in knowledge);
- The student's internal need to learn;
- The teacher's active guiding role;
- Tasks directed toward independent inquiry [4; 13].

Table 1. Conditions for Creating a Problematic Situation

Condition	Description (based on "Oscillations and Waves")
Reliance on prior knowledge	The student already knows the formula for harmonic oscillation: $x = A \cdot \sin(\omega t)$.
Lack of sufficient knowledge	Existing knowledge is not enough to explain the result of the superposition of two oscillations with different frequencies.
Intrinsic motivation	The student becomes curious to understand the reason behind the unusual resulting motion.
Teacher's guiding role	The teacher guides the student toward understanding the problem by asking targeted questions.
Need for active thinking	The student starts thinking about linear combinations and frequency differences to interpret the phenomenon.

In pedagogical literature, the following main types of problematic situations are identified [7; 12; 16]:

1. A problem that arises from a conflict of knowledge
2. A problem that arises from the need to explain a new phenomenon
3. A problem that arises during the process of solving a practical task
4. A problem that arises from the necessity to choose between alternative viewpoints
5. A problem that arises from the refutation of a misconception

The first type, a problematic situation arising from a conflict of knowledge, occurs when previously acquired knowledge held by students contradicts itself. This situation arises when a student draws two different conclusions from their prior knowledge simultaneously and cannot determine which one is correct, thus creating a cognitive conflict [7; 8; 12].

Example from the "Oscillations and Waves" topic:

Students have been taught that the total energy of a harmonically oscillating body remains constant. They know the formula for the energy of harmonic oscillation is:

$$E = \frac{1}{2}kA^2.$$

However, the student is asked the following question:

"If two harmonic oscillations act simultaneously in opposite directions with equal amplitudes, what happens to the energy of the resulting motion?"

In this case, the student might assume that the energies add up, since two independent sources are acting on the object. However, from a physical standpoint, if two harmonic oscillations are in opposite directions and have equal amplitudes, their phase difference is 180°, resulting in destructive interference.

As a result, the overall oscillation becomes zero:

$$x(t) = A \cdot \sin(\omega t) + A \cdot \sin(-\omega t) = A \cdot \sin(\omega t) - A \cdot \sin(\omega t) = 0$$

Thus, the object exhibits no displacement, which means its kinetic energy is also zero. The total energy is not retained in the object in the form of kinetic or potential energy; instead, due to the interference of the oscillations, it is completely canceled out. In this case, the system's energy may have been transferred to the external environment — for instance, in the form of heat or another type of energy.

As a result, it may appear that the energy has "disappeared," but in reality, it is simply not visible in the object's oscillation. This situation leads the student to form two contradictory interpretations:

Energy increases (since two sources are acting simultaneously);

Energy disappears (because no motion is observed due to destructive interference).

This cognitive conflict motivates the student to conduct deeper analysis and grasp new concepts such as phase difference, constructive, and destructive interference [10; 14].

The following figure illustrates the graphical representation of this problematic situation:

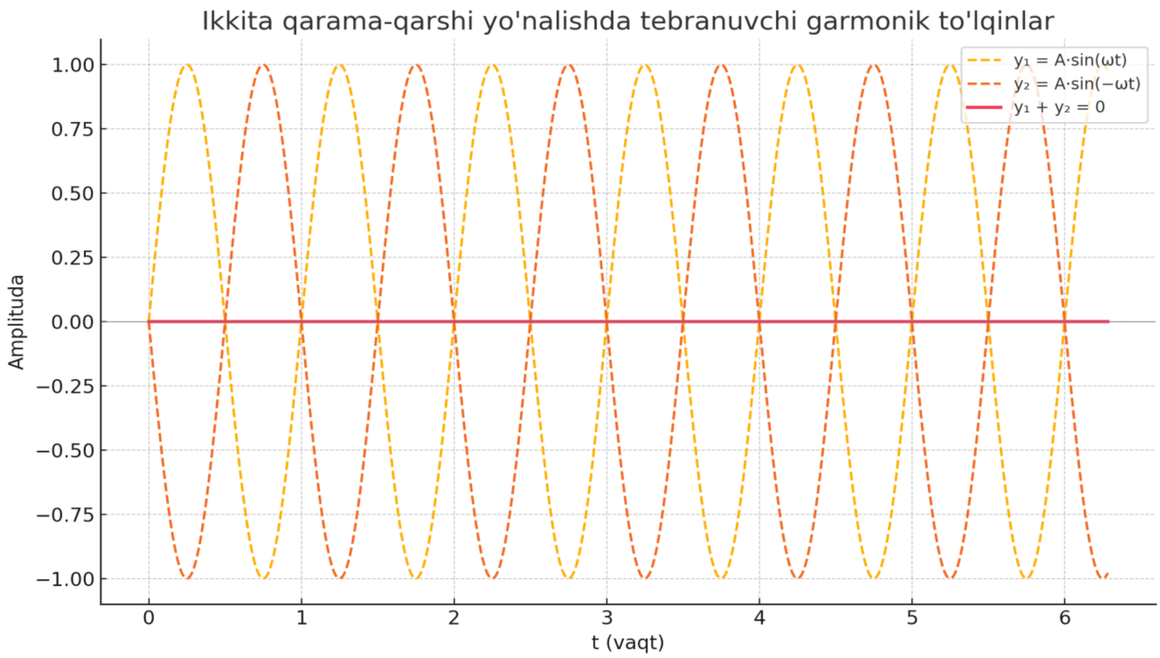

Figure 1. Harmonic Oscillations Acting in Opposite Directions with Equal Amplitudes

In this graph:

- $y_1 = A \cdot \sin(\omega t)$ (yellow line),
- $y_2 = A \cdot \sin(-\omega t)$ (red line),
- Their sum $y_1 + y_2 = 0$ is shown as a flat line (no oscillation).

This illustrates that the two harmonic motions cancel each other out completely due to their opposite directions and equal amplitudes, resulting in destructive interference.

The second type of problematic situation — a problem arising from the need to explain a new phenomenon —

occurs when a student's previously acquired theoretical knowledge proves insufficient to explain a real-world event. The student encounters a new situation and attempts to interpret it using existing knowledge, but the attempt fails. As a result, the student is compelled to seek new knowledge through observation, experimentation, or by studying additional theory [6; 7; 12].

Example from the topic "Oscillations and Waves":

In class, students have learned about oscillations and their propagation laws. The teacher then poses the following question:

Figure 2. "Why do you hear the voice of a person standing next to you instantly, but hear the sound of a distant object with a delay?"

This question presents a scenario in which students encounter a phenomenon they cannot fully explain using their existing knowledge. While they may already know basic facts about the nature and speed of sound, they may struggle to account for why sound waves reach the listener at different times depending on distance.

Through this problematic situation, students are encouraged to acquire the following new scientific concepts:

Sound waves propagate at a specific speed through an elastic medium;

The delay is explained by the formula speed = distance / time ($v = s/t$);

Air density and temperature affect the speed of sound;

Waves carry energy through the medium.

By analyzing this situation, the student gains a deeper understanding of physical principles behind real-life events. To resolve the problem, the student must observe, ask questions, perform calculations, and ultimately reach a conclusion [10; 15].

The third type of problematic situation — a problem arising during the process of solving a practical task — emerges when students need to apply theoretical knowledge in practice, especially in unconventional or complex situations. In such cases, the student recalls relevant formulas but may struggle to apply them correctly or interpret the outcome.

To solve the problem, the student is required not just to memorize formulas, but to analyze, understand cause-and-effect relationships, and use graphs or experiments to support their reasoning. This leads them to engage in research, make hypotheses based on experimentation, and develop solutions adapted to real-world contexts [7; 10; 15].

Example from the topic "Oscillations and Waves":

Imagine students are given the following task:

"To prevent a vibrating device (e.g., an electric generator) from affecting other equipment in the building, what kind of material should be used to build wave-absorbing walls?"

This situation is a practical problem, in which the student is required not only to apply physical formulas (e.g., oscillation velocity, wavelength, acoustic impedance) but also to consider material selection, properties of the medium, and to understand concepts such as the absorption coefficient.

Through this question, students grasp the following key ideas:

How sound waves are absorbed depending on the material;

The impact of frequency and energy variation on the functioning of devices;

Ways to prevent wave propagation;

Scientific approaches to solving real-world problems.

Thus, this type of problematic situation serves not only to reinforce theoretical knowledge but also to train students in applying it in real-life scenarios. Students develop a deeper understanding of the practical significance of physics and learn to justify their ideas and draw scientific conclusions [10; 15].

The fourth type of problematic situation — a problem arising from the need to choose between alternative viewpoints — occurs when a student is faced with multiple, seemingly valid but contradictory or subtly different ideas or solutions, and struggles to decide which one is correct. The existing knowledge appears sufficient for making a decision, but when applied to a specific case, a contradiction or ambiguity arises.

In this situation, the student must analyze each alternative both theoretically and practically, compare them, and draw a consistent conclusion. This cultivates critical thinking, logical reasoning, and evidence-based decision-making skills [6; 10; 15].

Example from the topic "Oscillations and Waves":

A student is asked:

"If two waves with the same frequency but different phases meet at a point, what will the resulting amplitude be?"

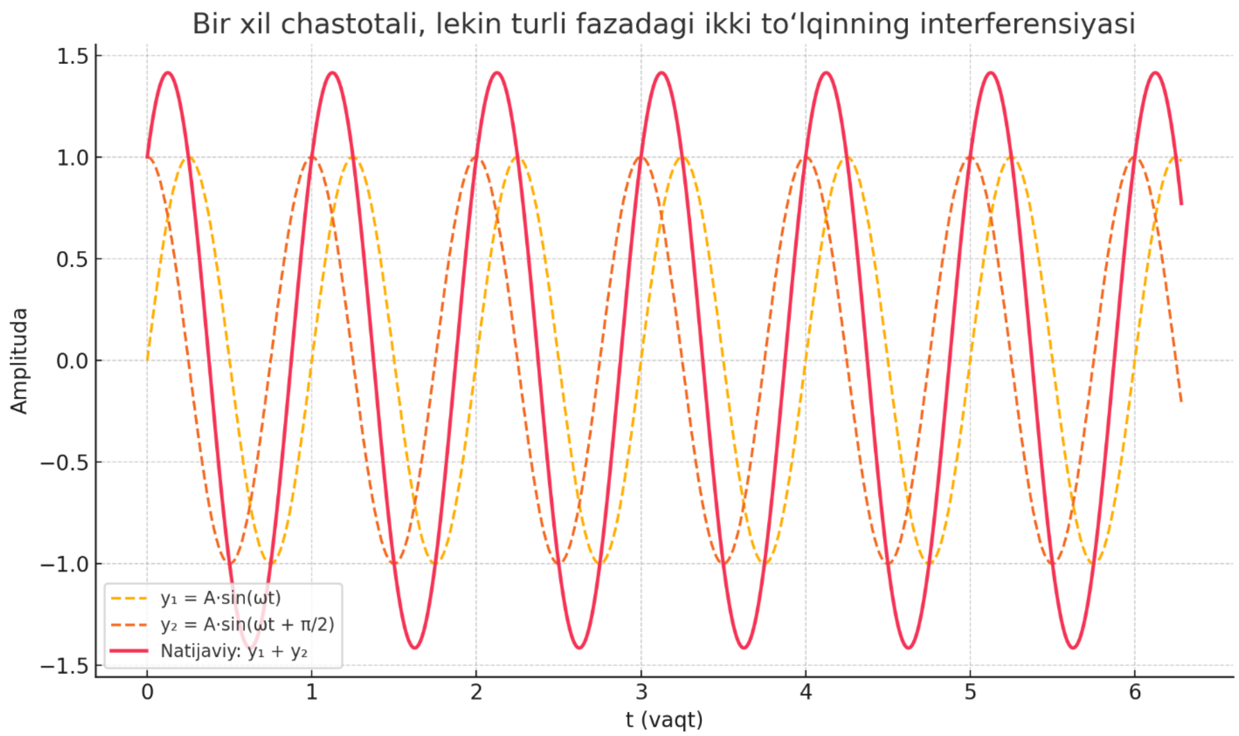

Figure 3. Interference of Two Waves with the Same Frequency but Different Phases

In this situation, the student is confronted with the following alternative viewpoints:

The amplitude doubles (if the waves are in phase);

The amplitude decreases or cancels out (if the waves are in opposite phase);

The amplitude remains unchanged (if the waves move independently).

To resolve this, the student must analyze in depth the concepts of interference, phase difference, and harmonicity. It is especially important to determine how the phase difference between two oscillations affects the resulting wave amplitude, which can be clarified through graphical analysis.

For example, the superposition of two waves with the same frequency but a phase difference of 90° ($\pi/2$) leads to a new wave, and its amplitude can be defined by the following expression:

$$y(t) = A\cdot\sin(\omega t) + A\cdot\sin(\omega t + \pi/2) = A\cdot\sin(\omega t) + A\cdot\cos(\omega t)$$

This is the sum of two orthogonal (perpendicular) waves, and results in a harmonic oscillation with an amplitude of $\sqrt{2}\cdot A$ and a phase shift of $\pi/4$:

$$y(t) = \sqrt{2}\cdot A\cdot\sin(\omega t + \pi/4)$$

Graphical analysis shows that the resulting oscillation in this case has an amplitude greater than each individual wave but is not the maximum possible. This scenario represents partial constructive interference.

Complete constructive interference only occurs when the phase difference is 0°, and destructive interference is observed at 180°.

Through this, the student forms generalized knowledge about constructive and destructive interference and is encouraged to apply mathematical modeling, graphical analysis, and experimental evidence to make the correct choice [7; 12; 16].

The fifth type of problematic situation — a problem arising from refuting a misconception — occurs when the student must scientifically reject an incorrect or overly simplified understanding. The student may have previously formed an incorrect conclusion based on earlier learning or everyday experience. In this case, a strong problematic situation is required to challenge and correct this misconception. The teacher deliberately confronts the student with a contradiction, prompting analysis based on scientific reasoning [6; 8; 10].

Example from the topic "Oscillations and Waves":

A common misconception among students is:

"Sound only travels through air and does not exist in other media."

Based on this belief, the teacher poses the following problematic question:

"If an explosion occurs in space, can it be heard?"

The student initially thinks that sound is always audible. However, through inquiry, they come to understand that sound is a mechanical wave that propagates only in elastic media. Since vacuum lacks such a medium, sound cannot travel in space.

Through this problematic situation, the student learns to:

Understand the mechanical nature of sound;

Realize the necessity of a medium for wave propagation;

Recognize that in a vacuum, energy can only be transmitted through electromagnetic waves.

By refuting the misconception, the student gains a proper understanding of fundamental physical concepts and develops a strong scientific foundation. Such situations help cultivate deep thinking in physics and broaden the student's scientific worldview [14].

Table 2. Types of Problematic Situations and General Examples

Type	Description	Example
Conflict of knowledge	Existing knowledge contradicts itself	The student explains the cause of a phenomenon in two different ways, but can't determine which is correct.
Explaining a new phenomenon	The phenomenon being studied cannot be explained using prior knowledge	"Why don't objects pulled with a rope move in the same way?"
Practical problem	Necessity to solve a real-life task	"How can we prevent a wire from heating up during electric current flow?"

Choosing between alternatives	Selecting the correct option from multiple possibilities	“Which experiment fully confirms Newton’s First Law?”
Refuting a misconception	The student’s misconception leads to a problem	Is the statement “Heat always flows only from hot to cold” always true?

Creating a Problematic Situation Requires a Planned, Step-by-Step Approach.

This process is based on encouraging students' active intellectual inquiry, stimulating engagement, and guiding them toward independently acquiring new knowledge. The following expanded methodological stages are described below [11; 15]:

1. Preparing the Problematic Question or Task.

A situation is selected that aligns with the lesson goal, builds on students' existing knowledge, but limits their ability to explain it simply. Example (on the topic of oscillations):

Question: “Why does a mass hanging on a spring slow down when more weight is added, and why does its oscillation frequency also change?”

This question cannot be explained through simple observation, as it involves complex mechanical concepts (mass, stiffness, natural frequency).

2. Presenting the Problematic Situation.

The problem is introduced to students in oral, written, or visual form.

Examples:

- Visual presentation: The teacher demonstrates the oscillation of a spring with and without a mass, draws a graph, or uses a video.
- Written task: “If two waves move in opposite directions, what will happen as a result?”
- The main goal at this stage is to spark interest and capture students’ attention.

3. Encouraging Inquiry.

Students are prompted with guiding questions to stimulate investigation:

Examples:

- “If the stiffness of the spring is doubled, how will the oscillation period change?”
- “When waves combine, does amplification always occur, or can cancellation happen too?”
- Students work in small groups to explore answers, design experiments, solve problems, or share personal hypotheses.

4. Developing Alternative Solutions.

Students generate multiple hypothetical solutions:

Example: One group explains resonance mechanically, another from the standpoint of energy transfer.

They may propose and test an experimental design in class or use simulation software.

5. Drawing Conclusions and Generalizing New Knowledge.

The teacher summarizes the discussion and highlights the key concepts:

Example: “The oscillation period of a spring depends on the mass and is inversely proportional to the stiffness. When waves interfere, both amplification and cancellation may occur.”

Together with the students, general conclusions are drawn using formulas, graphs, or experimental results.

Key Considerations When Creating a Problematic Situation:

- The situation should be interesting but not overly complex.
- It should connect with existing knowledge, while raising new questions.
- It should be reinforced through practical experience or visual explanation.

Through this approach, students not only gain knowledge, but also develop an interest in learning, and enhance their critical and creative thinking skills.

Applying various forms of problematic situations in education activates students’ intellectual processes. They not only acquire knowledge, but also learn the principles of scientific inquiry. This is especially important in physics, where observation, experimentation, analysis, and drawing conclusions are fundamental learning processes [12; 16; 17].

RESULTS AND DISCUSSIONS

The study was conducted with 10th-grade students in several general education schools in Uzbekistan. In the experimental group, lessons on the "Oscillations and Waves" unit were organized using Problem-Based Learning Technologies (PBLT), while the control group was taught using traditional explanatory-methodical approaches.

In the lessons, problematic situations were created around topics such as spring oscillators, wave interference, and resonance. Students were assigned tasks to find solutions through independent inquiry and practical experiments in small groups.

Table 3. Experimental Results of Problem-Based Learning Technologies

№	Indicator	Experimental Group	Control Group
1	Average test score (pre/post-test)	79,3	64,7
2	Independent problem-solving performance (%)	22%	10%
3	Participation in laboratory activities (%)	17%	8%
4	Students who showed interest in the lesson (%)	87%	54%

The students' knowledge and skill indicators were assessed through tests conducted before and after the lessons, practical tasks, and questionnaires. The results obtained are summarized in the table below (see Table 3).

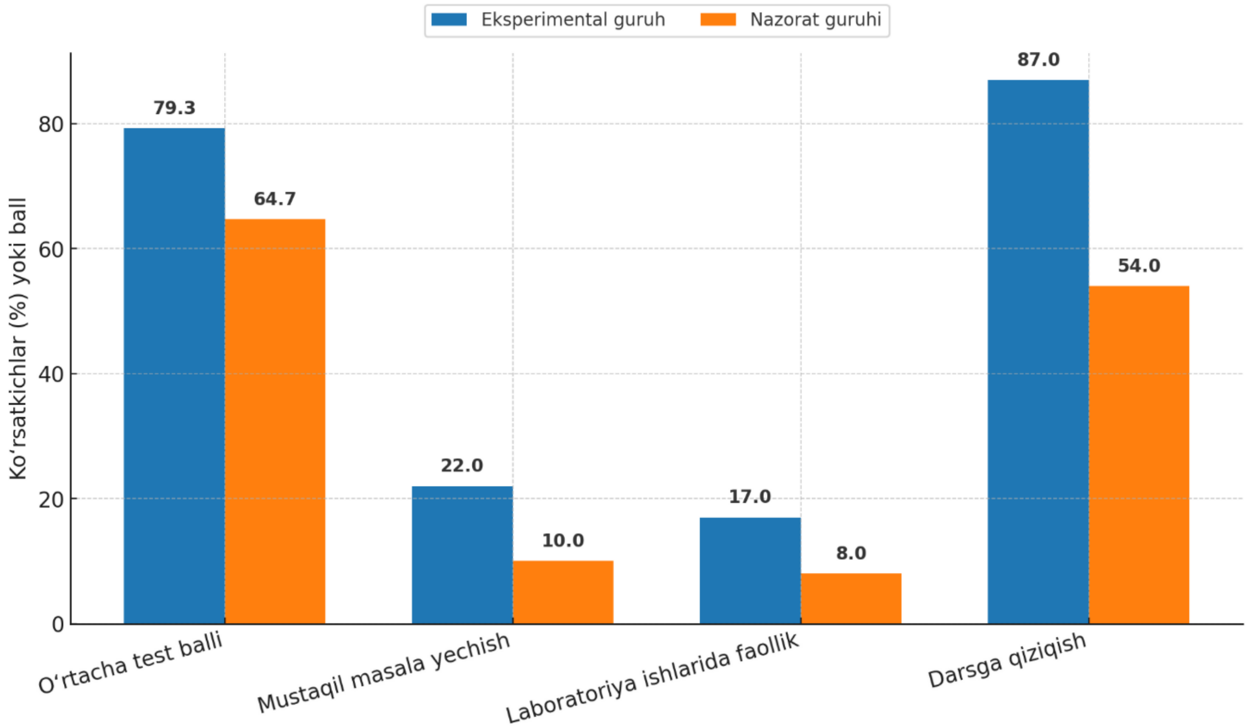

Figure 4. Comparative Diagram of Experimental and Control Group Results

The results of the study showed that the implementation of problem-based learning technologies (PBLT) significantly improves students' comprehension, inquiry skills, and interest in physics lessons. The higher average test scores and increased activity in practical tasks observed in the experimental group confirm that this approach fosters not only knowledge acquisition but also the development of creative and analytical thinking.

These findings align with both international and national research. For instance, Tain et al. (2024) demonstrated that the PBL model deepens conceptual understanding [https://doi.org/10.1063/5.0210273]; Karmila et al. (2021) reported its positive impact on scientific literacy [https://doi.org/10.2991/assehr.k.210326.064]; and Kholov and Bobilov (2024) found that it enhances communication and collaboration skills in Uzbek general education schools [3].

However, several practical limitations were identified during the study: insufficient methodological preparation of teachers, limited lesson time, and the lack of experimental tools in some schools, which prevented the full effectiveness of the results from being realized. In the future, specific measures should be taken to eliminate these limitations.

CONCLUSION

The results of the conducted research show that the integration of problem-based learning technologies (PBLT) into the physics curriculum is an effective tool for developing students' independent thinking, practical skills, research interest, and overall motivation.

Significant positive changes observed in the experimental group — such as increased average test scores, higher levels of engagement in problem-solving and laboratory tasks, and enhanced interest in lessons — clearly confirm the advantages of this methodology.

Compared to the control group, students taught through PBLT not only developed a deeper understanding of theoretical concepts, but also demonstrated more active and confident performance in solving practical problems. These outcomes are in line with findings from international and national studies by Tain et al. (2024), Karmila et al. (2021), and Kholov & Bobilov (2024), all of which confirmed the positive effects of PBL models on students' learning quality, critical and creative thinking, and collaborative skills.

Overall, the results of this study provide a scientific foundation for the wider implementation of PBL technologies in the practice of general education schools in Uzbekistan. In the future, it will be important to test this methodology in other physics domains — such as electromagnetism, optics, and thermodynamics — and to develop methodological manuals and organize special training sessions for teachers. These steps will contribute to improving the quality of the educational process and help cultivate 21st-century competencies in students.

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