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Scientific and methodological methods for solving Olympiad problems in physics and their role in shaping the research competencies of future teachers

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Abstract

The purpose of this study is to evaluate the impact of systematically including physics Olympiad problems on the development of research competencies in prospective physics teachers. A quasi-experimental design was implemented between 2020 and 2024 with experimental and control groups, supported by a 2023 survey of 141 participants. The research emphasized advanced tasks such as extremum problems, applications of conservation laws, and graphical analysis, with particular attention to the depth of reasoning. Ethical standards were fully observed. Findings show that students in the experimental group demonstrated a steady increase in success rates compared to the control group, producing more well-reasoned solutions and making fewer methodological errors. Qualitative improvements were also observed: participants more often formulated hypotheses, selected models deliberately, and provided grounded interpretations. Survey data confirmed enhanced intrinsic motivation for research-oriented tasks. The novelty of the study lies in clarifying methodological foundations for applying Olympiad problems to research skills formation, and in justifying a gradual shift from standard to non-standard tasks, strengthened by interdisciplinary links and reflection. Practical significance is expressed in integrating this methodology into courses and electives, with guidance for task selection, organization, and assessment. Limitations relate to design, sample, and time frame. Future directions include larger samples, wider testing across physics domains, refined diagnostics, and digital or distance-learning adaptations.

Keywords: Graphical method, Physics Olympiad problems, Problem-solving methodology, Prospective physics teacher training, Research competencies, Universal problem-solving approaches.

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1. Introduction

The ongoing transformation of higher pedagogical education underscores the necessity of developing new approaches to the professional preparation of future physics teachers. A particularly urgent challenge lies in fostering students' research competencies, which not only ensure the effective acquisition of disciplinary content but also cultivate the capacity for independent analysis, information retrieval, and the interpretation of data essential for addressing professional tasks. Within this framework, the integration of physics Olympiad problems deserves special attention, as they are distinguished by their high level of complexity and the demand for non-standard reasoning combined with a research-oriented approach.

The problem of developing research competencies in prospective physics teachers has been widely addressed in both national and international pedagogical literature.

The formation of design and research competencies within the framework of STEAM education was examined in a recent study [1]. Their findings demonstrate that the integration of science, technology, engineering, arts, and mathematics fosters students' ability to conduct research, engage in project-based activities, and apply interdisciplinary approaches.

International studies by Wen and Korsun [2] highlight that systematic engagement with physics tasks, particularly in the general physics course "Optics," contributes significantly to the development of research competency. The authors emphasize the importance of hypothesis formulation, justification, testing, and interpretation as core components of independent student work.

In the Kazakhstani context, Sarybayeva, et al. [3] focus on the development of methodological competence in prospective physics teachers, underscoring the role of interactive methods and specially designed tasks that strengthen professional readiness. Similar perspectives on the role of research-oriented learning activities as a factor in the foundations of teacher education are reflected in the works of Abylkasymova, Taubaeva, and Khmel.

Olympiad problems, in particular, have been recognized as a powerful tool for enhancing analytical and creative skills. Olympiad winners were shown to outperform regular students in solving challenging dynamics problems due to stronger logical reasoning and deeper analytical strategies [4]. Olympiad problems have been identified as a means of profession-oriented training for future physics teachers, demonstrating growth in professional and creative skills [5]. Methodological features of organizing student Olympiads in distance formats were investigated, with advantages such as accessibility and broader participation, and challenges such as objective assessment [6]. Other studies have addressed organizational and content aspects of Olympiads. Assessment systems in physics Olympiads were analyzed with attention to the complexity of physics and mathematics [7]. The role of Olympiad tasks in fostering students' cognitive independence has been highlighted [8, 9]. The high level of mathematical demands in German Olympiads has been discussed, which may reduce students' motivation for physics [10].

Recent research has also explored the integration of advanced technologies. The use of artificial intelligence and open science tools (e.g., ChatGPT, SageMath, Jupyter AI) in enhancing physics competitions has been considered, noting their potential to broaden the scope of research-based tasks [11]. Similarly, the applications of ChatGPT in physics education have been evaluated, demonstrating its capacity to generate, solve, and explain problems, as well as to design new research tasks [12].

Overall, the literature review indicates that the research competence of prospective physics teachers is studied across diverse contexts—from STEAM-based approaches and project activities to Olympiad-oriented training. However, the systematic development and implementation of scientific and methodological approaches to solving Olympiad problems as a component of teacher education remains insufficiently explored, which underscores the relevance of the present study.

The review of contemporary literature demonstrates that the problem of developing research competencies in prospective physics teachers has been approached from multiple perspectives: the integration of STEAM education, the use of inquiry-oriented tasks in general physics courses, and the application of interactive teaching methods. A number of studies highlight the potential of Olympiad problems, which demand non-standard reasoning, hypothesis formulation and testing, as well as the application of interdisciplinary knowledge. However, despite their recognized pedagogical value, the systematic integration of Olympiad problems into teacher education curricula remains insufficiently explored and methodologically underdeveloped. This gap highlights the necessity of designing a comprehensive scientific and methodological framework that positions Olympiad problems not merely as tools for competition preparation but as effective instruments for cultivating the research competencies of future physics teachers.

It is hypothesized that the systematic inclusion of Olympiad problems of varying levels of complexity in the educational process of pedagogical universities, accompanied by the development and implementation of scientific and methodological approaches to their solution, will more effectively foster the research competencies of prospective physics teachers, enhance their analytical and critical thinking, and strengthen their ability to independently formulate and test hypotheses.

The aim of this study is to develop and test scientific and methodological approaches to solving physics Olympiad problems in order to foster the research competencies of prospective physics teachers.

2. Materials and Methods

To achieve this goal, the available educational programs of Sarsen Amanzholov East Kazakhstan University and Khoja Ahmed Yasawi International Kazakh-Turkish University were used as the basis for the study. A survey was conducted among 2nd–4th year students, master's and doctoral students of the Physics Department, as well as among school students and physics teachers of the Regional Specialized Boarding School for Gifted Children in Ust-Kamenogorsk.
The qualification study employed the following classical research methods [13]:

- Theoretical methods: analysis of literature on Olympiad problems and teaching methodology;

- Practical methods: questionnaire survey;
- Methods of data processing and interpretation.

At this stage, the leading research method was the questionnaire survey, which made it possible to assess the level of knowledge, skills, and competencies of each participant in the study (students, teachers, and school teachers) with a certain degree of reliability. This method provided an opportunity to collect both quantitative and qualitative data that could be used to analyze the current state of training of future physics teachers and to evaluate the potential of using Olympiad problems in the educational process.

3. Results

A total of 141 participants participated in the survey in 2023 (see Table 1). The questionnaire was administered online via Google Forms and distributed through a link shared on social networks (https://docs.google.com/forms).

Table 1.
Participants of the survey.

Institution	Educational program	Level of study	Number of participants
Sarsen Amanzholov East Kazakhstan University	6B01502 – Physics	Bachelor's degree	20
	7M01502 – Physics	Master's degree	28
	8D01502 – Physics	Doctoral program (PhD)	6
Khoja Ahmed Yasawi International Kazakh-Turkish University	6B01502 – Physics	Bachelor's degree	50
	7M01502 – Physics	Master's degree	25
	8D01502 – Physics	Doctoral program (PhD)	6
Regional Specialized Boarding School-Lyceum for Gifted Children in Mathematics, Physics, and Computer Science, EKR Department of Education	"Physics" subject	Teachers and students	28

Before conducting the survey, the participants were informed about the goals and objectives of the study and provided written consent to participate in the pedagogical experiment.

The questionnaire included 10 questions aimed at assessing the formation of practical skills, the level of research competence in solving physics Olympiad problems, and the awareness of information necessary for their future professional activities. In some questions, along with choosing from the suggested answers, participants were given the opportunity to express their own opinions. Multiple-choice answers were also allowed. The table presents the percentage distribution of responses selected by the survey participants.

Table 2.
Summary of the questionnaire results on the use of Olympiad problems in physics.

№	Positive aspects	Negative aspects
1	Olympiad problems develop non-standard thinking and a creative approach to problem-solving.	Insufficient mastery of concepts related to Olympiad problems (e.g., "non-standard problem," "physical modeling").
2	Solving Olympiad problems increases interest in in-depth study of physics.	Lack of sufficient time for solving Olympiad problems within the educational process.
3	Olympiad problems help to better understand the fundamental laws of physics and their application.	Insufficient development of teaching methods for solving Olympiad problems.
4	They develop skills of analysis, logical reasoning, and application of physical laws.	Insufficient mastery of the mathematical apparatus required to solve Olympiad problems.
5	Participation in Olympiads increases motivation for studying physics and engaging in scientific activities.	Lack of sufficient methodological manuals and teaching materials on Olympiad problems.
6	Olympiad problems foster the development of independent work and research skills.	Difficulties in assessing the knowledge and skills acquired through solving Olympiad problems.
7	Teachers preparing students for Olympiads deepen their own professional skills and knowledge.	Insufficient teacher training for teaching the solution of Olympiad problems.
8	Olympiad problems develop physical intuition and the ability to apply knowledge in new situations.	Insufficient attention to Olympiad problems in the school curriculum.
9	Solving Olympiad problems helps students prepare better for exams and further studies.	Solving Olympiad problems helps students prepare better for exams and further studies.
10	Olympiad problems contribute to the development of scientific thinking and interest in research.	Lack of sufficient support and motivation from schools and parents for participation in Olympiads.

Based on the survey results, we identified both positive and negative aspects of using Olympiad problems in teaching physics (see Table 2).

The analysis of the results shows that Olympiad problems foster non-standard thinking, motivation, and the professional skills of teachers. However, the lack of time, methodological support, and educational materials, as well as difficulties in applying the necessary mathematical and physical apparatus, create challenges for both students and teachers.

Particular attention should be paid to the types of problems that most often cause difficulties for students—namely, tasks involving the determination of minimum and maximum values. Such problems are quite common in the Unified State Exam in physics, within the section of tasks of increased complexity.

Scientific and methodological approaches to solving Olympiad problems in physics represent a set of techniques aimed not only at obtaining the correct answer but also at developing students' research skills. These approaches are grounded in analytical and logical reasoning, which makes it possible to decompose a complex condition into simpler elements and construct a coherent chain of arguments. Mathematical modeling plays a crucial role, as it translates real situations into the language of equations and functions, enabling the use of algebraic, analytical, and geometric methods. Alongside this, graphical methods are applied: building diagrams and graphs makes the task more visual and helps to reveal hidden dependencies. Equally important are energy-based and variational methods, founded on conservation laws and principles of symmetry, as well as the use of limiting transitions and estimation techniques, which allow the problem to be investigated in boundary cases and the order of magnitude to be determined.

An important place is occupied by the experimental research approach, which includes thought experiments and practical tests, as well as a heuristic method based on hypotheses, the use of analogies and intuitive guesses. Interdisciplinary integration and the use of digital technologies are increasingly being applied, which expand the possibilities of analysis and modeling. Thus, the combination of these methods allows not only to successfully solve Olympiad tasks, but also to form students' critical and creative thinking, research culture and professional competencies.

In the process of solving Olympic problems, various methods are used. The main place belongs to the analytical method, since it provides for the analysis of the problem based on physical laws and the construction of a system of equations. In order to visually represent the relationships between the laws of motion and quantities, graphical approaches are effectively used. In the process of adapting known solutions to new conditions, methods of comparison and analogy are of particular importance. In cases where optimization is required, the extremum method is used, and the energy approach is used to draw conclusions based on the conservation of energy types. In addition, in solving complex problems, methods such as geometric constructions and Vector diagrams, finding symmetry and invariants of the system also increase productivity [14, 15]. In some cases, it becomes possible to make a forecast and check it or find a solution using approximate numerical methods.

Methodological approaches to solving various types of non-standard problems in the "Dynamics" section of school physics were examined, with emphasis on the importance of applying diversified strategies to enhance students' problem-solving abilities [16]. This perspective aligns with the focus of the present study, since Olympiad problems in dynamics often require a combination of analytical, energy-based, geometrical, and extremum methods. Such approaches are particularly significant in tasks where the complexity of motion laws and conservation principles demands flexible reasoning and the integration of multiple methodological tools.

The law of conservation of momentum in the problems of collisions of bodies

In problems for collisions of bodies, usually the initial momentum of the system (before the collision) can be likened to the momentum after the collision because the bodies are not affected by external forces at the moment of the collision, or can be ignored by the momentum of these forces because the collision time is very short.

Task 1. A particle with a mass of m_1 has a velocity of υ, hits a body with a mass of m_2 at rest and bounces back from it at u speed at a right angle to the direction of the first movement. What will be the speed of a body of mass m_2?

Problem solving: We denote the initial velocity vector of the particle as $\vec{v}$ the final velocity vector $\overrightarrow{u}$, and the final velocity vector of the body as $\vec{w}$. According to the law of conservation of momentum:

$m_1\vec{v}=m_1\overrightarrow{u}+m_2\vec{w}$, from the $\vec{w}$,$=\frac{m_1}{m_2}(\vec{v}-\overrightarrow{u})$.

By convention, the final velocity of the particle forms a right angle with the initial one, so we find the modulus of the vector of $\vec{v}$, - $\overrightarrow{u}$, by the Pythagorean theorem:

$w=\frac{m_1}{m_2}\sqrt{v^2+u^2}$

Force momentum. If the mechanical system is affected by external forces, then its momentum changes. This change is equal to the sum momentum of these forces, that is, equal to the Integral of the force of equal effect over time. When solving some problems, the method of finding force pulses is very convenient.

Task 2. A small body is thrown in a horizontal direction from a very high height with a mass of m, the initial speed of which is v_0. If the force of air resistance is proportional to the speed, i.e. $Fc = kv$, then at what distance L will the body fall from the starting point?

Problem solving: consider the movement of the body in horizontal X-growth. The projection of the initial velocity is: v_{0x}=v_0, the projection of gravity is zero, the projection of air resistance is:$-kv_x$, where v_x is the horizontal speed of the body at the current time. Since it is thrown from a very large height, the horizontal projection of the final velocity can be taken as zero.

We find the projection of the force momentum in a small Δt time interval:

$\Delta p(F_x) = F_x\Delta t = -kv_x\Delta t = -k\Delta x,$

where Δx is the displacement in the horizontal direction at this time. Therefore, the full displacement (i.e. L) is proportional to the momentum of the air resistance force:

$$L = -\frac{\Delta p(F_x)}{k} = \frac{0 - mv_0}{k} = \frac{mv_0}{k}$$

Task 3. The sandbox with a total mass of M lies on a horizontal surface, and the coefficient of friction μ. At an angle of α in a vertical direction, a mass of m pulley, the speed of which can be reached in the box, immediately rushes into the sand. What is the speed of the crate after the pulya is touched? [17].

Problem solving: in this problem, the law of conservation of momentum during pulley imposition cannot be applied, since the box is affected by the supporting reaction force (normal reaction force N and sliding friction force μN). Although the condition states that the pulya is impaled very quickly, at this point the modulus of the reaction force can reach a large value, so the momentum of this force cannot be ignored.

The normal force "removes" all the vertical momentum of the pulley, that is, this momentum:

$$mv\ cos\alpha$$

Accordingly, the momentum of the sliding friction force:

$\mu mv\ cos\alpha$

Now we find the horizontal speed of the box after the pulya is stuck in the sand (the vertical speed is zero):

$$(M + m)u - mv\ sin\alpha = -\mu mv\ cos\alpha,$$

from this:

$$u = \frac{mv}{M = m}(\sin\alpha - \mu\cos\alpha).$$

Note: If $\tan\alpha \leq \mu$, the box does not move at all.

Application of the concept of center of mass. From the definition of the center of masses of a system of material points, it follows that the total momentum of a mechanical system is equal to the speed of its center of masses multiplied by the total mass of all material points included in the system. In particular, if the total momentum of the system is zero, then the center of mass of the system remains stationary, and individual parts of the system can change their position. The use of these properties forms the basis of the method of solving problems through the concept of the center of mass.

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Task 4. On a flat horizontal surface lies a circle with mass M and radius R. Above the circle is a beetle with a mass of m. If the beetle begins to move along the circle, along what trajectories does the Beetle and the center of the circle move? [18].

Problem solving: The sum of all external forces acting on the circle and the beetle is zero at any given moment. Therefore, the full momentum of the circle and Beetle system remains constant (and equal to zero), so the center of mass of the system does not move.

The center of masses is located along the segment connecting the Beetle and the center of the circle. It is located at a distance $r_1 = \frac{mR}{M+\bar{m}}$ from the beetle and at a distance $r_2 = \frac{mR}{M+\bar{m}}$ from the center of the circle. Since the distance between the Beetle and the center of the circle remains constant at R during movement, both the Beetle and the center of the circle move in circular paths around the center of mass:

- Beetle moves along a circle with a radius of r_1;
- Circle moves along a circle with a radius of r_2.
- Application of the laws of conservation and transformation of mechanical energy
- In inertial reference systems, the change in the mechanical energy of the system is equal to the sum of the work performed by internal non-conservative forces and external forces. If there are no internal non-conservative and external forces, or their sum work is zero, then the complete mechanical energy of the system is preserved.
- Applying the law of conservation of mechanical energy is a powerful method for solving problems. However, it should not be forgotten that when using it, energy can change in a leaps and bounds during the rapid processes of impact, thrust, etc.in the system.
- Body movement in the field of gravity
- In the field of gravity, a body with any mass will have potential energy. If the acceleration of gravity g is taken to be the same at all points in space (the field is homogeneous), then the change in the potential energy of the body is written in a very simple way:

$$\Delta U = mg\Delta h,$$

where m is the mass of the body, Δh is the change in the height of the body (in the direction of action of gravity).

Task 5. In the Atwood machine (Figure 1), the masses of the load are equal to m_1 and m_2 . The weight of the block and thread is negligible; there is no friction. Initially, the heavier load m_2 is held at a height h above the horizontal plane, while the m_1 load is held on this plane. The sections of the thread not on the block are vertical. The loads are released from rest.

Considering that the thread is flexible, inelastic and practically massless, what is the maximum height to which the m_1 load rises after a fully inelastic collision? Acceleration due to gravity is g, and the block is located sufficiently far from the loads.

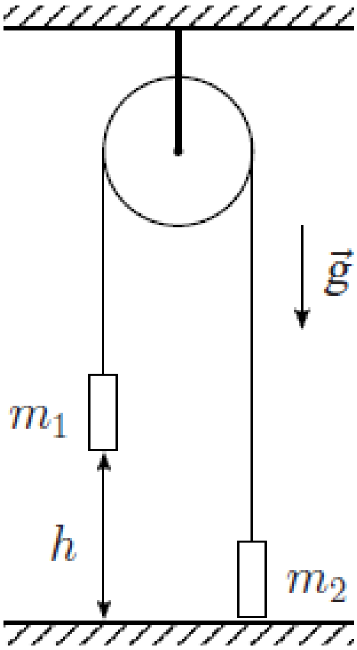

Figure 1.
Atwood machine.

Problem solving: Since the loads are connected by a practically non-stretchable thread, at the initial stage of movement, the magnitude of their velocities are equal during the initial stage of movement. Let v be the magnitude of the loads' velocity just before impact.

Until the impact, the total mechanical energy of the system is conserved:

$$m_1gh = m_2gh + \frac{(m_1 + m_2)v^2}{2}$$

From this, we solve for the value of v:

$v = \sqrt{\frac{2(m_1 - m_2)}{m_1+m_2}gh}$.

After the impact, the load of mass m_1 stops, and the load of mass m_2 moves upward with velocity v like a body thrown vertically upward, as the thread becomes slack. After rising to a certain height, the load begins to descend. The moment it returns to a height h above the horizontal plane, its speed will again be v. At this point, the thread becomes taut again, and the impulse from the tension sets the loads in motion.

The law of conservation of mechanical energy does not apply to this shaking process, but the law of conservation of momentum applies. Since the thread does not stretch, the magnitudes of the load speeds after the shake will be equal:

$m_2\upsilon = (m_1 + m_2)v_1$

where v_1 is the common speed of the loads after the impact. Now we find h_1, the highest height at which the m_1 load rises. To do this, we use the law of conservation of mechanical energy:

$\frac{(m_1+m_2)v_1^2}{2} + m_2 = m_1gh_1 + m_2g(h - h_1).$

Final Formula:

$$h_1 = \frac{m_2}{m_2} \cdot \frac{v^2}{2g} + h.$$

Oscillatory (Spring) Motion.

If the deformation of the spring obeys Hooke's law, then the potential energy is given by:

$U = \frac{kx^2}{2}$,

where k is the spring stiffness coefficient, and x is the displacement of the spring from its equilibrium position (either elongation or compression).

In systems where a massive object is suspended on a light vertical spring, there are two types of potential energy to consider:

1. The elastic potential energy of the spring;
2. The gravitational potential energy of the load.

In such problems, the spring's displacement x is often used as the variable. In this case the total potential energy of the system can be expressed as:

$$U = \frac{kx^2}{2} - mgx.$$

Here, as the zero level of potential energy, the state of the spring is taken as undeformed, and the coordinate axis x is directed downwards.

If we say that as a variable we take the deviation of the load from the equilibrium state:

$$y = x - \frac{mg}{k},$$

in it, Potential Energy has the following easy form:

$U = \frac{ky^2}{2}$.

Here, the equilibrium position of the load is taken as the initial level of energy. In most cases, it will be more convenient to use such a variable.

A situation in which the work of non-conservative forces is taken into account.

If a system is affected by non-conservative forces, it is necessary to calculate the work done by those forces to find the change in the mechanical energy of the system.

In the problems encountered in the school physics course, you often have to find the work of the friction force. To solve such problems, there are the following methodological recommendations:

1. The friction force changes direction if the direction of movement of the body changes. Therefore, when calculating the work of the friction force — the modulus of the force must be multiplied by the path, and not by the displacement.
2. To find the total work of the friction forces within the system, only the relative displacement of the two friction surfaces should be taken into account.

The following Example Best explains the meaning of this second statement:

Task 6. A board of mass M and length L lies on a horizontal, flat surface. The coefficient of friction between the board and the surface is zero (i.e., the surface under the board is smooth). A small block of mass *m* is placed at the rest on one end of the board. The coefficient of friction between the block and the board is μ. As a result, The block slides along the board. A certain amount of heat Q is released due to friction as the block moves relative to the board [19].

Question: You need to find out with what acceleration the board moved.

Problem solving: There are two friction forces in the system:

- One force acts on the block;
- The second force acts on the board.

According to Newton's third law, these forces are equal in magnitude and opposite in direction.

We introduce the following notation:

- The axis is directed in the direction of the force acting on the X — beam;
- x_1 is the coordinate of the block;
- x_2 is the coordinate of the board;
- F is the magnitude of the friction force.

Sum of elementary works done by the friction forces is:

$$dA = dA_1 + dA_2 = -Fdx_1 + Fdx_2 = -F(dx_1 - dx_2) = -dQ,$$

where dQ is the amount of heat dissipated in this interval.

Conclusion: The heat dissipated depends only on the relative displacement of the block and the board.

Since the total relative displacement of the block with respect to the board is equal to L:

$$Q = FL.$$

The friction force is the only horizontal force acting on the board, so we can write Newton's second law for it:

$$F = Ma$$

From this, the acceleration ɑ of the board is:

$$a = \frac{Q}{ML}.$$

Answer:

Board acceleration:

$a = \frac{Q}{ML}$.

Finally, it should be noted that both the amount of heat released and the relative displacement of bodies are invariant quantities, meaning they are independent of the choice of an inertial reference frame. This idea can also be useful for solving problems.

Circular motion. If a body makes a rotational motion and it is necessary to apply the law of conservation of mechanical energy, then Koenig's theorem is used to calculate the kinetic energy of such a body:

Koenig's theorem: The kinetic energy of a mechanical system is equal to the sum of the kinetic energy of its center of mass and the kinetic energy of the movement of the system relative to the center of mass.

Task 7. A thread is wound on a thin-walled cylinder. The other end of the thread is attached to the support. The cylinder is sliding down the inclined plane, and the thread remains parallel to the plane (see Figure 2).

What will be the speed of the cylinder's axis when it, initially at rest, has traveled the distance l?

Given:

- Angle of inclination— α,
- The coefficient of friction between the plane and the cylinder is μ.

Problem Solving:

- The end of the thread is fixed, which means that the speed of all points along the thread is zero.
- Therefore, the speed of the cylinder at point A (where the thread is attached) is also zero.
- This point A is the instantaneous center of rotation (the center at the moment of rotation).
  Therefore:
- As the axis of the cylinder moves, the velocity of the cylinder's point of contact with the plane is twice the velocity of its axis.

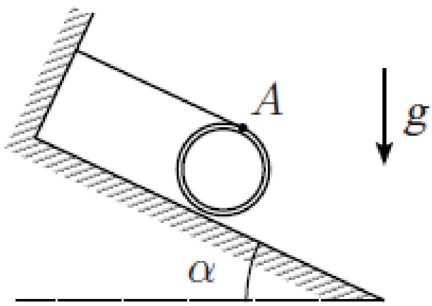

Figure 2.
A thin-walled cylinder sliding along a sloping plane.

Now, we construct an energy balance using work:

The work done by gravity is:

$$A_g = mg \sin(\alpha) \cdot l$$

Operation of the friction force:

The distance traveled by the point of contact is $2l$, because it moves 2 times more than the axis.

$$A = -\mu mg \cos(\alpha) \cdot 2l$$

Kinetic energy:

Total kinetic energy for a thin-walled cylinder:

$$T = \frac{1}{2}mv^2 + \frac{1}{2}Iw^2$$

Moment of inertia of a thin-walled cylinder:

$$I = mR^2$$

and since $\omega = \frac{v}{R}$:

$$T = \frac{1}{2}mv^2 + \frac{1}{2}mR^2(\frac{v}{R})^2 = \frac{1}{2}mv^2 + \frac{1}{2}mv^2 = mv^2$$

We apply the law of conservation of energy:

$$A_g + A_t = T$$

$Mg \sin\alpha \cdot l - \mu mg \cos\alpha \cdot 2l = mv^2$

From this:

$$v^2 = gl(\sin\alpha - 2\mu\cos\alpha)$$

Last answer:

$$v = \sqrt{gl(\sin \alpha - 2\mu \cos \alpha)}$$

Solving problems related to the topic" law of conservation of mechanical energy " using graphs.

One of the most commonly used methods in problems where you need to find the work of some force is to find the area under the graph of the dependence of the point of action of the force on the body on the displacement.

Task 8. If weights with masses m_1 and m_2 are hung from a spring one after the other, its length at equilibrium is L_1 and L_2, respectively.

What work must be done to stretch the spring from $L_1$to L_2?

Problem solving: When the spring length is L_1, the elastic force equals m_1g. When the lengths is L_2, the force equals m_2g.

We can plot a graph of the force versus the spring's length (Figure 3).
The work done is equal to the area of the shaded trapezoid:
$A = \frac{m_1g+m_2\,g}{2} \cdot \,(L_2 - L_1)$.

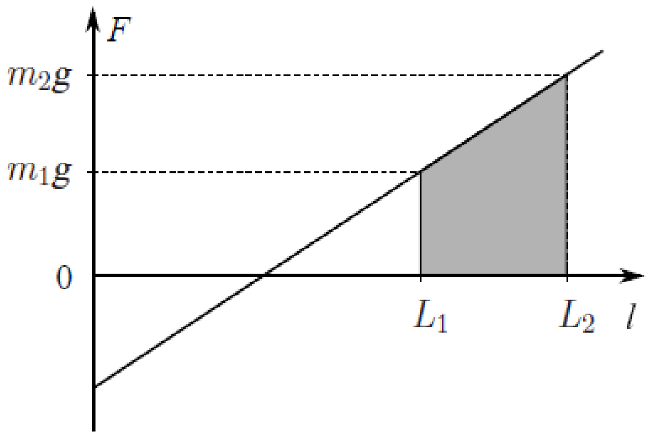

Figure 3.
Refers to the calculation to find the work that takes to stretch the spring.

Task 9. A horizontal platform with a mass of $M = 300$ g is suspended by a spring-like rubber thread AB (Figure 4). The thread passes through a hole in a load with a mass of $m = 100$ g. The system is in equilibrium. The cargo is then sent from the platform at height h without initial speed. At what smallest value of h for a thread break, the thread breaks if its greatest allowable elongation is $x_k = 8$ cm? How the force of attraction of the thread depends on its elongation is presented in the form of a graph (Figure 5). It is believed that the impact of the load on the platform is completely inelastic. Take the free fall acceleration as $g = 10\,m/s^2$ [20].

Problem solving: The thread is stretched to an initial one size before the ball hits the platform, and the force of the thread's pull is balanced by the weight of the platform:

$$F(x_N) = Mg = 3N$$

Based on the graph, we determine that $X_N = 3\,cm$.

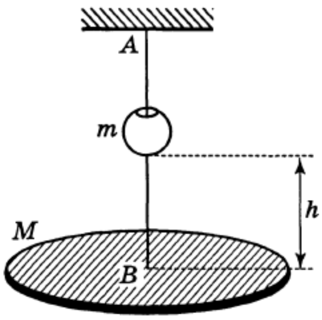

Figure 4.
Platform suspended on a thread.

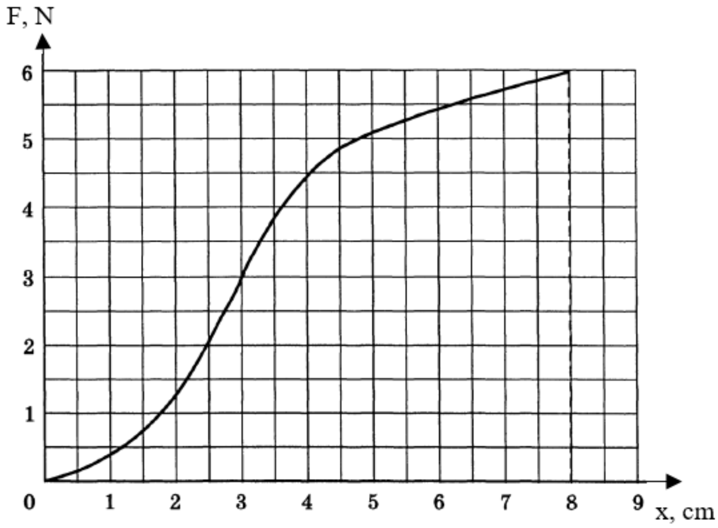

Figure 5.
Graph of the tension force due to the tension of the thread.

E_1 is the total kinetic energy of the platform and the load after the collision, A is the work that is spent on stretching the thread from the initial elongation x_N to the final elongation x_k. Considering the case when the load stops with the platform at the moment of the thread break, we use the law of conservation of mechanical energy to find the smallest height h:

$$E_1 - (M+m)gx_N = A - (M+m)gx_k, that\ is\ E_1 = A - (M+m)g(x_k - x_N)$$

We calculate the work A as the area under the graph: $A \approx 0.25\,J$. Then $E_1 \approx 0.05\,J$.
If we say that the speed of the platform and the load after the collision is u:
$E_1 = \frac{(M+m)\,u^2}{2}$.

From the law of conservation of momentum, the forward speed of the load from the collision:
$v = \frac{u(M+m)}{m}$.

Well, we determine the height of the load drop by the law of conservation of energy h:
$mgh = \frac{mv^2}{2} = \frac{M+m}{m} \cdot \frac{E_1}{2}$, then $h = \frac{(M+m)\cdot E_1}{mg} \approx 20\ cm$.

We systematized and analyzed the results of the control work in the experimental groups (Table 3) and in the control groups (Table 4) for 2021-2024.

Table 3.
The result of the control work in the experimental group.

№	Academic year	Course year	Number of students	Initial level	Final level	Average level
1	2020-2021	2	10	50%	64%	65%
2	2021-2022	3	10	50%	66%	65%
3	2022-2023	4	10	50%	63%	65%
4	2023-2024	5	10	50%	67%	65%

Table 4.
The result of the control work in the control group.

№.	Academic year	Course year	Number of students	Initial level	Final level	Average level
1	2020-2021	2	10	50%	60%	58%
2	2021-2022	3	10	50%	56%	58%
3	2022-2023	4	10	50%	57%	58%
4	2023-2024	5	10	50%	59%	58%

After analyzing the results of the experiment, we found that 60% of the students in the experimental group reached an average level of proficiency in solving extremum problems, and 70% reached a high level. In contrast, 42% of the students in the control group remained at the average level, while 58% demonstrated only a minimal level of this skill. These data indicate that the developed methodology helps students progress to a higher level, as evidenced by 60% increase in task success rates within the experimental group. No such change was recorded in the control group (Figure 5).

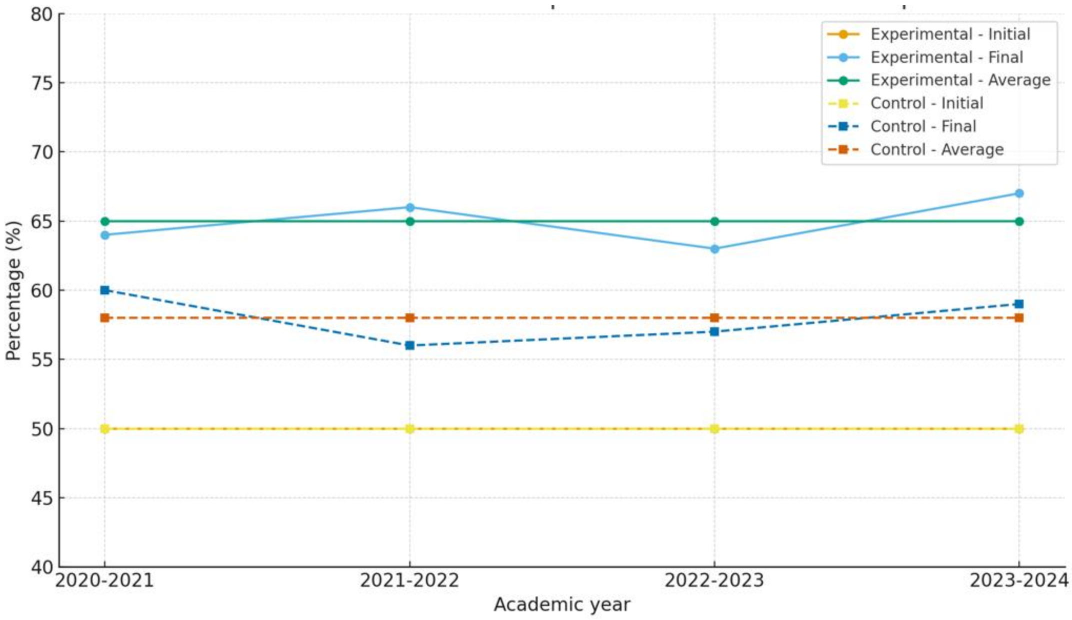

Figure 6.
Results of Control Work in Experimental and Control Groups.

Accordingly, if scientific and methodological approaches and methods of solving Olympiad problems of various levels of complexity are systematically introduced into the educational process of university disciplines, this will ensure a more effective formation of research competencies of future physics teachers. This approach will contribute to the development of students' analytical and critical thinking, the formation of skills to independently formulate and substantiate hypotheses, as well as to find solutions for non-standard tasks.

The results obtained convincingly confirm the hypothesis that the systematic inclusion of Olympiad tasks of increased complexity contributes to the formation of research competencies of future physics teachers. The post-testing data showed a steady increase in the success of solving extreme tasks, applying the laws of conservation of momentum and energy, as well as graphical analysis. At the same time, the proportion of well-founded decisions increased, the number of methodological errors and unfulfilled points of reasoning decreased, students began to formulate a hypothesis more often, choose an adequate model and interpret the results obtained. The survey confirmed the observations: interest in research tasks has become more stable and purposeful, and internal motivation to independently search for solutions has increased. A comparison with the control groups showed that the positive changes are precisely the effect of targeted pedagogical intervention, since no statistically significant dynamics were detected in the control groups. All this indicates the transition of students of experimental groups to a higher level of mastery of methods for solving non-standard tasks and proves the effectiveness of the proposed methodology for the development of research competencies.

4. Conclusion

The study confirmed that the systematic inclusion of scientific and methodological approaches to solving Olympiad problems of varying levels of complexity in the educational process of pedagogical universities is an effective tool for fostering the research competencies of prospective physics teachers. The developed and tested methodology proved its effectiveness: there was a recorded increase in the success rate of solving complex problems, a higher proportion of well-reasoned solutions, and a reduction in methodological errors.

In addition to the quantitative results, qualitative changes were also identified: students became more active in formulating and testing hypotheses, making deliberate choices of models and solution methods, providing reasoned interpretations of results, and demonstrating stable intrinsic motivation for research activities. This indicates the development of their analytical and critical thinking, as well as their ability to independently search for solutions in non-standard situations.

Thus, the aim of the study—namely, the development and investigation of scientific and methodological approaches to solving Olympiad problems oriented toward the formation of research competencies in future physics teachers—has been achieved. The results obtained have both theoretical and practical significance, open perspectives for further improvement of teacher training, and can be recommended for integration into educational programs for the preparation of physics teachers.

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