

DEVELOPING ACADEMIC LYCEUM STUDENTS' PHYSICS PROBLEM-SOLVING SKILLS THROUGH PROBLEM-BASED LEARNING

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Abstract. This article examines the theoretical and methodological aspects of developing academic lyceum students' physics problem-solving skills through problem-based learning. The study aims to develop an instructional model that guides students in analysing problem statements, constructing physical models, selecting appropriate physical laws, justifying solutions, and verifying results. The methods employed include theoretical analysis, comparison, pedagogical modelling, and the instructional redesign of problems. The study proposes an instructional sequence integrating a problem situation, hypothesis formulation, modelling, solution development, verification, and reflection. Its application is illustrated through problems involving mechanics and electrical circuits. Criteria for assessing students' problem-solving performance are also proposed. The article is theoretical and methodological in nature; determining the effectiveness of the proposed approach requires a separate empirical educational study.

Keywords: academic lyceum, physics education, problem-based learning, physics problem, problem situation, hypothesis, physical modelling, independent thinking, reflection.

INTRODUCTION.

One of the important objectives of physics education is to explain the laws of nature and teach students how to apply these laws when analysing practical situations. In academic lyceums, this objective is pursued through a more detailed study of physical phenomena, the integration of mathematical knowledge with physical concepts, and the organisation of independent problem-solving activities. Consequently, the assessment of physics learning outcomes should extend beyond students' ability to recall formulas. Their understanding of the conditions under which a formula applies, their ability to justify the selected method, and their interpretation of the result are equally important.

Resolution No. PQ–5032 of the President of the Republic of Uzbekistan, dated 19 March 2021, aims to improve the quality of education and develop scientific research in physics [1]. This policy direction highlights the need to improve both the content of physics instruction and the methods used to organise students' cognitive activities.

One issue requiring instructional attention is students' tendency to search for a formula matching the given quantities instead of analysing the physical meaning of a problem. This approach may produce

an answer in straightforward calculation tasks. However, reliance on a previously demonstrated solution becomes insufficient when the problem conditions change, irrelevant information is introduced, or a phenomenon requires analysis in several stages.

Uzbek-language publications addressing the methodological foundations of physics education include *Theory and Methods of Teaching Physics and Astronomy* by M. Jo‘rayev and B. Sattarova and *Methods of Teaching Physics* by D. A. Begmatova and co-authors [2; 3]. These publications form part of the national methodological literature relevant to the research topic.

N. Turdiyev’s methodological guide identifies independent physics problem solving, observation of phenomena, analysis of experimental results, and formulation of conclusions as educational objectives [4, p. 4]. These objectives support an approach in which calculation, observation, and explanation are interconnected within problem-solving activities.

In this article, **problem-based learning** is understood as confronting students with a learning situation that cannot be resolved immediately using their existing knowledge, but can be addressed through inquiry, and organising their efforts to develop a justified solution. A problem does not necessarily involve complex calculations. It may also arise from a discrepancy between an initial prediction and a physical law, uncertainty about model selection, or the need to explain a result.

The aim of the study is to develop an instructional sequence and assessment criteria for fostering academic lyceum students’ physics problem-solving skills through problem-based learning. The research question is formulated as follows: How can physics problem-solving activities be organised to guide students from applying ready-made formulas towards independent physical analysis and justified conclusions?

MATERIALS AND METHODS

The study adopted a theoretical and methodological design approach. Its source base comprised a policy document concerning physics education and Uzbek-language methodological publications [1–4]. The selection of literature considered its relevance to physics teaching methods, the verifiability of its bibliographic information, and its publication in Uzbek. A distinction was maintained between the guide examined in full and publications for which only bibliographic descriptions were verified.

The following methods were employed:

- **Theoretical analysis:** identifying the components of physics problem-solving activities.
- **Comparison:** comparing the instructional characteristics of solutions based on worked examples with those developed through problem-oriented inquiry.
- **Pedagogical modelling:** constructing a sequence that reflects the relationship between teacher support and student independence.
- **Instructional redesign:** transforming conventional physics problems into tasks requiring prediction, justification, and verification.

The unit of analysis was an individual learning action within physics problem solving: understanding the problem conditions, selecting a model, identifying the relevant physical law, performing mathematical operations, and evaluating the result.

The problems presented in the article were developed as instructional examples. No student experiments, surveys, or assessment measurements were conducted. Accordingly, the results section presents the proposed instructional arrangements rather than percentage increases in learning achievement.

RESULTS

Components of Physics Problem-Solving Skills

Within this study, physics problem-solving skills are defined as a system of interconnected actions enabling students to understand problem conditions, construct a physical model of a phenomenon, select appropriate laws, perform the mathematical solution, and verify the physical meaning of the result.

Based on this definition, five components were identified.

Table 1. Components of physics problem-solving skills

Component	Student action	Observable outcome
Conceptual analysis	Identifies known and unknown quantities and explains the phenomenon	Correct interpretation of the problem conditions
Modelling	Produces a diagram, schematic, or graph and identifies assumptions	A physical model appropriate to the phenomenon
Selection of physical laws	Selects the relevant law and explains its conditions of applicability	Justified equations
Mathematical execution	Solves equations and converts units as required	Consistent calculations
Verification and reflection	Evaluates the result, identifies errors, and generalises the method	A justified final conclusion

This structure enables teachers to identify errors more precisely. For example, an incorrect answer may result from an arithmetic error, an incorrectly constructed force diagram, or failure to consider the conditions under which a physical law applies. Each case requires a different form of instructional support.

An Instructional Sequence Based on Problem-Based Learning

A six-stage sequence is proposed for organising problem-solving activities.

Stage 1: Creating a problem situation. The teacher asks a question that reveals students' initial understanding. The question focuses on the physical meaning of the problem: "Which quantity

changes?”, “Is this conclusion always valid?”, or “Under what conditions would this formula no longer apply?”

Stage 2: Formulating a hypothesis. Before beginning calculations, students predict the expected result and write down their reasoning. Their initial prediction is retained for subsequent verification.

Stage 3: Constructing a physical model. Students define the system boundaries, relevant factors, and simplifying assumptions. For example, they explicitly state whether a body is treated as a point mass, whether air resistance is considered, or whether the electrical source is assumed to be ideal.

Stage 4: Developing the solution. Equations are formulated using the relevant physical laws. Wherever possible, a general expression is derived before numerical values are substituted.

Stage 5: Verifying the result. Students check units, signs, approximate magnitudes, and limiting cases. The calculated result is compared with the initial hypothesis.

Stage 6: Reflection and transfer. Students explain which predictions were confirmed, where errors occurred, and how the solution method could be applied to another problem.

Throughout this sequence, teacher support is provided according to students’ needs. The recommended progression begins with a general question, followed by guidance on constructing a diagram, and, only when necessary, the provision of part of an equation.

A Problem-Based Task in Mechanics

Problem. A student with a mass of 60 kg is standing on a scale inside an elevator. The elevator is moving upward. Will the scale always read 600 N? Determine the scale reading when the elevator accelerates upward at and when it moves upward while slowing 2 m/s^2 down. In the second case, the magnitude of the acceleration is also Assume

Guiding 2 m/s^2 question: Is the $g = 10 \text{ m/s}^2$ scale reading determined by the direction of motion or by the direction of acceleration?

Students are first asked to make a prediction without performing calculations. They then draw the forces acting on the student: the downward gravitational force (mg) and the upward normal reaction force (N) . The scale is assumed to display force in newtons.

Taking upward as the positive direction:

$$N - mg = ma_y.$$

When the elevator accelerates upward, $a_y = 2 \text{ m/s}^2$:

$$N = m(g + a) = 60(10 + 2) = 720 \text{ N}.$$

When the elevator moves upward while slowing down, its acceleration is directed downward, so :

$$a_y = -2 \text{ m/s}^2: \quad N = m(g - a) = 60(10 - 2) = 480 \text{ N}.$$

When the elevator moves at a constant velocity:

$$a = 0, \quad N = mg = 600 \text{ N}.$$

Instructional conclusion. Upward motion does not necessarily increase the scale reading. The reading depends on the vertical component of acceleration. The problem guides students towards distinguishing between velocity and acceleration.

For reflection, students are asked: “What will the scale read if the elevator moves downward while slowing down?” Students should transfer the previous solution to this new situation and identify that the acceleration is directed upward.

A Problem-Based Task on Electrical Circuits

Problem. A source with an electromotive force of $\mathcal{E}=12\text{V}$ and an internal resistance of $r=1 \Omega$. is initially connected to a single resistor of resistance $R=6\Omega$. An identical second resistor is then connected in parallel with the first. Does the voltage across the first resistor change?

Guiding question: Does the rule that “the voltage is the same across parallel branches” mean that the voltage remains unchanged before and after the second resistor is connected?

Initially, the current in the circuit is:

$$I_1 = \frac{\mathcal{E}}{R + r} = \frac{12}{7} \text{ A}.$$

The voltage across the first resistor is:

$$U_1 = I_1 R = \frac{72}{7} \approx 10.29 \text{ V}.$$

After the second resistor is connected in parallel, the equivalent resistance of the external circuit becomes:

$$R_{\text{eq}} = \frac{R}{2} = 3 \Omega.$$

The total current supplied by the source is:

$$I_2 = \frac{12}{3 + 1} = 3 \text{ A}.$$

The terminal voltage of the source, and therefore the voltage across each parallel branch, is:

$$U_2 = \mathcal{E} - I_2 r = 12 - 3 = 9 \text{ V}.$$

Thus:

$$U_2 < U_1.$$

Instructional conclusion. The voltages across parallel branches are equal to one another at a given time. However, this rule does not mean that the source's terminal voltage remains unchanged when the circuit is reconfigured. Because of the internal resistance, an increase in the total current produces a greater voltage drop within the source.

Finally, students analyse an ideal source with $(r=0)$. Under this condition, the voltage across the external circuit remains equal to $(\mathcal{E})$. The main learning objective is therefore to identify the limits of applicability of a physical model.

Organisation of the Lesson

The proposed approach can be incorporated into an 80-minute practical lesson as follows.

Table 2. Sample structure of a problem-based problem-solving lesson

Stage	Time	Main activity
Initial diagnostic assessment	10 minutes	A short conceptual question and individual response
Problem situation	10 minutes	Identification of conflicting predictions
Hypothesis and model	15 minutes	Recording a prediction and constructing a diagram or schematic
Solution development	20 minutes	Formulating equations and performing calculations
Verification and discussion	15 minutes	Comparing solutions and explaining errors
Individual transfer and reflection	10 minutes	Solving a modified problem and writing a conclusion
Total	80 minutes	

It is important to provide an individual task after group work. A correct group solution does not automatically demonstrate that every student has independently understood the problem.

Assessment Criteria

Assessment should consider both the final answer and the justification of the solution.

Table 3. Criteria for assessing problem-solving performance

Criterion	0 points	1 point	2 points
Analysis of the problem conditions	The phenomenon is interpreted incorrectly	Some important conditions are identified	All important conditions are correctly identified

Physical model	The model is absent or incorrect	The model is partly appropriate	The model and assumptions are justified
Selection of physical laws	No appropriate law is selected	The law is correct, but the explanation is insufficient	The law and its conditions of applicability are explained
Mathematical solution	The solution is absent or contains a major error	The method is correct, but some calculation errors occur	Calculations and units are correct
Verification and reflection	No verification is provided	The result is partially verified	The result is verified and the conclusion is justified

The maximum score is 10 points. These criteria constitute an instructional proposal, and their inter-rater agreement and practical usability should be examined during empirical testing. Consequently, the scores should not be treated as an established diagnostic standard.

DISCUSSION

The proposed instructional approach places students' thinking processes at the centre of physics problem solving. Its main feature is that students make predictions before beginning calculations and subsequently test those predictions using physical laws. This enables teachers to analyse both students' written solutions and their initial conceptions.

In the elevator problem, the learning difficulty arises from distinguishing the direction of motion from the direction of acceleration rather than from the complexity of the force equation. In the electrical circuit example, students must understand the precise meaning of the parallel connection rule and distinguish an ideal source model from a real source. Thus, creating a problem situation does not always require advanced mathematics. A question that clarifies the relationship between physical concepts can itself provide a basis for inquiry.

Students' prior knowledge must be considered when applying the instructional model. If a student does not know the relevant physical law or a basic mathematical operation, an open-ended problem may not lead to productive inquiry. In such cases, a brief explanation, part of a worked example, or guiding questions may be necessary. Instructional support should gradually decrease as students develop greater competence.

Task complexity should also increase progressively. It is advisable to begin with problems containing all the necessary information, proceed to problems requiring model selection, and then introduce tasks with insufficient information or multiple solutions. This sequence is expected to support the gradual development of learner independence.

A limitation of the study is that the proposed model has not been empirically tested in academic lyceums. Therefore, no firm conclusions are drawn regarding its effects on achievement, time efficiency, or superiority over other methods.

In a subsequent empirical study, the experimental and comparison groups should be made as comparable as possible in terms of prior knowledge, instructional time, and subject content. Assessment tasks should require the application of similar physical principles in new situations rather than reproduce the problems used during instruction. In analysing the results, changes in modelling, justification, and verification should be examined separately alongside the total score.

CONCLUSION

Based on theoretical and methodological analysis, an instructional sequence was proposed to develop academic lyceum students' physics problem-solving skills. The sequence integrates the creation of a problem situation, hypothesis formulation, physical modelling, solution development, result verification, and reflection.

The examples involving mechanics and electrical circuits illustrate the relationship between knowing a physical law and understanding its conditions of applicability. The practical value of the approach lies in requiring students to explain each major decision and enabling teachers to analyse errors according to specific components of problem-solving performance.

The proposed assessment criteria cover activities ranging from understanding the problem conditions to final reflection. The effectiveness of these criteria and the instructional sequence should be examined through empirical educational research in academic lyceums.

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