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DEVELOPING STUDENTS' INDEPENDENT THINKING AND PROBLEM-SOLVING COMPETENCIES THROUGH DIGITAL EDUCATIONAL RESOURCES IN PHYSICS INSTRUCTION

Dilobar Ruzimurotovna Arashova
Independent Researcher, Bukhara State University
arashovadilobar088@gmail.com
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Abstract: This article examines the scientific and methodological foundations of using digital educational resources to develop independent thinking and problem-solving competencies among academic lyceum students in physics instruction. Drawing on an analysis of research by scholars in Uzbekistan on digital pedagogy, virtual laboratories, and interactive simulations, the article proposes a six-stage instructional model: problem, hypothesis, digital experiment, evidence, solution, and reflection. The model is illustrated through lessons investigating motion on an inclined plane, examining buoyancy through virtual and physical experiments, and modeling the law of conservation of energy. Assessment criteria are proposed for students' ability to formulate predictions, control variables, analyze data in tables and graphs, and substantiate conclusions with evidence. The study is theoretical and methodological in nature and does not claim to report findings from an empirical educational intervention.

Keywords: physics education; digital educational resources; academic lyceum; independent thinking; problem solving; inclined plane; buoyant force; conservation of energy; virtual laboratory; formative assessment.

Introduction

Digitalization is accelerating the transition in education from transmitting ready-made knowledge toward organizing students' active engagement in learning. In physics, the ability to model phenomena that are difficult to observe, rapidly modify experimental conditions, and display measurements graphically is particularly valuable. Nevertheless, access to digital tools does not automatically ensure better learning outcomes: a student may watch an animation without understanding the physical mechanism it depicts. The pedagogical value of a tool must therefore be judged by the questions students ask, the hypotheses they formulate, the evidence they collect, and their ability to defend their conclusions.

Students in academic lyceums encounter complex concepts in mechanics, molecular physics, electricity, and optics. Common conceptual difficulties include confusing force with velocity, treating electric current and voltage as interchangeable, and intuitively assuming that energy simply disappears.

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In such situations, a digital experiment organized around a problem-based question can enable students to test and revise their initial assumptions.

Recent research in Uzbekistan on the digitalization of physics education has emphasized virtual laboratories, mobile devices, software-based modeling, and competency-based approaches. Karshiboev Sh (2023) addresses the organization of virtual laboratory activities using PhET [1]. Farmonov (2023) examines the advantages of virtual laboratories for visualizing physical experiments [2]. Akhmedov Yo.O (2024) explores the theoretical and didactic foundations of developing physics-related competencies through information technology [3]. These studies provide an important national research foundation for the approach advanced here.

The aim of this article is to develop a logically coherent, assessable, and classroom-applicable instructional model for strengthening independent thinking and problem-solving competencies through digital educational resources in academic lyceum physics lessons. The objectives are to examine approaches reported in national research, operationalize the constituent elements of these competencies, establish criteria for selecting digital resources, and propose sample assignments and assessment rubrics.

2. Literature Review and Research Methods

This article is a theoretical and methodological study. Open-access scholarly publications by researchers in Uzbekistan from 2023 to 2026 were examined through thematic analysis, comparison, conceptual synthesis, and instructional modeling. Sources were selected for their direct relevance to physics instruction, virtual laboratories, digital technologies, and competency development. The proposed lesson sequences constitute the author's instructional design and should not be interpreted as empirically demonstrated improvements in learning outcomes.

Karshiboev Sh (2023) discusses software tools for virtual laboratories and the organization of physics experiments using those tools [1]. Karshiboev Sh., Rahmonova X., Davirova pp. , Hazratqulova Z. (2024) describe methodological approaches to organizing and conducting physics laboratory sessions with digital technologies [4]. Together, these contributions reinforce the view that teachers' responsibilities extend beyond displaying a resource to designing experimental procedures, sequences of tasks, and guiding questions.

Qorjobova M., and Turayev Y (2023) discuss the potential of a virtual laboratory website and mobile application for physics teachers and school students [5]. Ganiev A.A (2024) examines virtual laboratories and mobile laboratory stands as instructional technologies [6]. This line of research supports combining digital experimentation with physical measurement: virtual environments provide controllable, idealized conditions, whereas physical laboratories help develop an understanding of measurement uncertainty, instrument limitations, and laboratory safety.

Nurmatova M (2024) analyzes the pedagogical and psychological foundations of using emerging information technologies in physics instruction [7]. Choriyeva G. (2026) investigates the development of students' scientific competence through digital technologies [8]. Saidova Sh.A. and Kamolov J.J.

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(2026) describe a model for systematically improving physics teaching methodology in digital learning environments [9]. Collectively, these studies suggest that selecting digital resources should not be limited to enhancing motivation or visualizing physical phenomena; rather, resource selection should be explicitly aligned with independent reasoning, analysis, inference, and evaluation.

Bozorov H. and Ismatova M. (2026) consider opportunities to teach the laws of conservation of energy and momentum through PhET and other digital applications [10]. Tilovova T. (2026) emphasizes integrating modeling, experimentation, and independent analysis through virtual laboratories [11]. Thus, although the national literature extensively discusses the didactic advantages of digital resources, a coherent classroom sequence connecting each learning activity to observable indicators of independent thinking and problem-solving competence remains of practical importance.

3. Key Concepts and Components of Competence

Independent thinking competence refers to a student's ability to interpret a physical situation without relying on a ready-made answer, ask justified questions, formulate hypotheses, critically evaluate information sources, compare alternative explanations, and reach evidence-based conclusions. It does not simply mean working alone: defending a reasoned personal position in group discussions is also part of this competence.

Problem-solving competence is the ability to translate an unfamiliar or ambiguous situation into a physical model, identify relevant laws and constraints, select a solution strategy, perform calculations or experiments, assess the outcome, and revise the strategy when necessary. Memorizing a formula may be necessary but is not sufficient; explaining why that formula is appropriate to the particular situation is decisive.

The knowledge component of competence comprises laws and concepts; the performance component concerns experimentation and calculation; and the metacognitive component involves recognizing the strengths and weaknesses of one's own decisions. For example, a student may know Newton's second law but still fail to apply it to a problem if unable to predict how a cart's acceleration changes as the angle of an inclined plane increases.

Component	Observable performance	Assessment evidence
Understanding the problem	Identifies known quantities, unknowns, and constraints	Statement of the problem
Hypothesis	Develops a testable causal prediction	Written prediction and justification
Planning	Selects variables and control conditions	Experimental plan

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Analysis	Identifies relationships in tables and graphs	Graph, calculations, explanation
Checking the solution	Checks units, limiting cases, and errors	Verification record
Reflection	Explains how the initial hypothesis has changed	Brief reflective statement

4. Didactic Criteria for Selecting Digital Resources

Selection of a digital resource should begin with the learning objective. If the aim is to understand a phenomenon qualitatively, an interactive simulation with clearly adjustable parameters is appropriate. If the aim is to establish quantitative relationships, an environment that provides numerical measurements together with a spreadsheet may be more useful. Quiz platforms can support diagnostic assessment; discussion boards can make contrasting views visible; and shared document environments may facilitate collaborative reporting.

A high-quality resource should be scientifically accurate, age-appropriate, technically reliable, and conducive to active student engagement. Its interface should avoid distracting animations, display measurement units clearly, and distinguish adjustable parameters. Privacy, advertising, and offline functionality should also be considered. Providing a paper-based calculation task or physical laboratory alternative for each digital lesson can help reduce inequities in access to technology.

A resource should not become a tool that automatically produces answers for students. Before launching a simulation, the teacher asks students to record predictions; during the experiment, students change only one independent variable at a time; and when an unexpected result occurs, they are required to explain it. In this way, visualization becomes a means of moving from passive reception toward evidence-based decision-making.

Resource type	**Didactic purpose**	**Student output**
PhET-type simulation	Test parameter–outcome relationships	Hypothesis and data table
Spreadsheet	Process measurements and construct graphs	Graph and error analysis
Digital quiz	Diagnose prior understanding	Justified answer
Video analysis	Compare motion trajectories and time	Graph and physical model
Virtual+physical laboratory	Identify differences between ideal models and physical measurements	Comparative report

5. Proposed Six-Stage Instructional Model

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Stage 1. Presenting a problem situation. The teacher introduces a realistic context and a question with a potentially unexpected result, such as: "Why do conductors with different resistances carry different currents when connected to the same voltage?" Students restate the problem in their own words and identify missing information. A genuine problem-based question should require a choice or causal justification rather than simple recall.

Stage 2. Formulating a hypothesis and prediction. Students express a testable proposition in the form "If ... , then ... , because ... ." The teacher records competing ideas without revealing the correct answer before the experiment. A hypothesis is testable when it identifies both a measurable outcome and a parameter to be varied.

Stage 3. Designing a digital experiment. Students distinguish independent, dependent, and controlled variables in the simulation, choose four to six measurement points, and prepare a data-recording table. The teacher provides brief instructions on technical operation while leaving the scientific decisions to the students.

Stage 4. Collecting and interpreting evidence. Students record measurements in a table, construct graphs where appropriate, and explain observed trends. Random errors, measurement precision, and the limitations of idealized models are discussed. Rather than merely observing that a graph "increases," students explain under which conditions it increases, by what relationship, and why.

Stage 5. Solution and transfer. Students solve the original problem and explain their reasoning to a peer. They then address a modified task—for example, replacing a parallel circuit with a series circuit or varying voltage rather than resistance. Applying knowledge under altered conditions indicates whether it has become functional and transferable.

Stage 6. Reflection and formative assessment. Students write brief responses to questions such as "What did I initially think?", "Which evidence changed my mind?", and "Which real-world factor is excluded from the model?" The teacher provides rubric-based feedback. Digital assessment results are used primarily to plan subsequent individualized learning activities, rather than merely to rank students.

6. Practical Activity 1: Digital Investigation of Motion on an Inclined Plane

Objective: to develop students' capacity to analyze forces, predict the effects of changing parameters, and independently justify changes in acceleration. Materials: an inclined-plane or force-and-motion simulation, a spreadsheet, and a protractor; if available, a cart and a physical ramp. Problem question: "Why does the same cart move faster as the ramp becomes steeper?"

The investigation begins with an ideal frictionless model, for which acceleration along the plane is $a = g \sin \alpha$. Students predict acceleration at $\alpha = 10°$, $20°$, $30°$, and $40°$. They then vary only the angle in the simulation and construct an $a(\alpha)$ graph. The tabulated values are theoretical examples calculated using $g = 9.81\ m/s^2$; they are not observations from an actual classroom experiment. Students explain the increase in the component of gravitational force parallel to the inclined plane.

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Extension task: calculate the cart's frictionless acceleration at an inclination of 30°, then enable friction and compare the outcomes. Explain the conditions under which $a = g(\sin \alpha - \mu \cos \alpha)$ applies (when the body slides down the slope). Answer the question "Would doubling the cart's mass also increase its acceleration?" using both a prediction and digital evidence.

Assessment considers not only the numerical answer but also a force diagram, identification of controlled variables, interpretation of the graph, and recognition of the idealized model's limitations in a real situation involving friction. The activity integrates prediction, measurement, calculation, and scientific argumentation into a coherent inquiry.

α, degrees	g, m/s²	a = g sin α, m/s²
10	9.81	1.70
20	9.81	3.36
30	9.81	4.91
40	9.81	6.31

7. Practical Activity 2: Investigating Buoyant Force Through Virtual and Physical Experiments

Objective: to observe the buoyant force acting on an immersed object, identify the factors on which it depends, and verify these relationships through a physical experiment. Problem question: "Why does an object of the same volume experience different buoyant forces in water and in another liquid?" Students formulate testable hypotheses about the effects of fluid density and submerged volume using $F_a = \rho g V$.

In the digital environment, an object of constant volume is fully submerged while fluid density is varied between 800, 900, 1,000, and 1,100 kg/m³. Buoyant force is calculated theoretically for $V = 0.0005$ m³ and $g = 9.81$ m/s². The following values are illustrative calculations rather than measurements obtained in a conducted experiment. Students construct an $F_a(\rho)$ graph and identify the linear relationship when other factors remain constant.

Follow-up question: how does the force change if the object is submerged only halfway? Students account for displaced volume and explain the result using $F_a = \rho g V_{submerged}$. If a dynamometer and container of water are available, they measure the difference between the object's apparent weight in air and in water and compare it with the ideal prediction. Measurement discrepancies are discussed in relation to string tension, contact with container walls, the meniscus, and instrument precision.

In this activity, independent thinking is demonstrated by students' ability to distinguish liquid density and object volume as independent variables, control the degree of immersion, infer relationships from graphs, and provide a scientific explanation for why a steel ship can float.

ρ, kg/m³	Vsubmerged, m³	$F_a = \rho g V$, N
800	0.0005	3.924

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900	0.0005	4.415
1000	0.0005	4.905
1100	0.0005	5.396

8. Practical Activity 3: The Law of Conservation of Energy

Problem question: "Why does the speed of a cart change as it travels downhill, and where does the energy go when the cart stops?" Students hypothesize about the interconversion of potential and kinetic energy. For a frictionless model, they examine $E_p = mgh$, $E_k = mv^2/2$, and the conservation of total mechanical energy, $E = E_p + E_k$. In the simulation, initial height and mass are varied separately, and the relationships shown by energy bars or graphs are compared.

Friction is then introduced. Students explain why the statements "mechanical energy decreases" and "total energy is conserved" are not contradictory: some mechanical energy is converted into thermal energy. A reasoning question follows: "Why cannot the simulation results be transferred directly to the motion of a real bicycle?" A satisfactory answer should consider air resistance, deformation, the energy of rotating components, and measurement errors.

As a final design task, students conceptualize a safe playground track or roller-coaster profile and justify its design in terms of energy. The task connects theoretical equations, digital experimentation, problem-based reasoning, and real-world application.

9. Formative Assessment and Diagnostic Criteria

Competence cannot be assessed solely by the proportion of correct answers on a test. Independent thinking becomes visible in the fit between hypotheses and evidence, the depth of analysis, and the coherence of decisions. Teachers may therefore use a diagnostic set of pre- and post-lesson tasks of comparable difficulty, an observation checklist, and written reflections.

Each criterion in the following rubric is scored from 0 to 3:

0 — the behavior was not observed;

1 — partially completed with assistance;

2 — completed largely independently, with minor shortcomings;

3 — completed independently, accurately, and with supporting evidence.

The maximum total is 18 points. Indicative proficiency bands may be interpreted as 0–6 points (emerging), 7–12 points (developing), and 13–18 points (established).

Criterion (0–3 points each)	**Evidence required for 3 points**
Problem formulation	Comprehensively identifies known quantities, unknowns, and constraints
Hypothesis	Provides a testable prediction and physical justification
Experimental planning	Controls relevant variables systematically
Data analysis	Interprets graphs and evidence correctly

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Justification of solution	Defends the result through calculation and physical explanation
Reflection and transfer	Recognizes limitations and applies knowledge in a new situation

Sample diagnostic task: If the angle of an inclined plane increases, how does the frictionless acceleration of the same object change? Justify the answer using a force diagram, outline a plan to test it in a simulation, and identify which assumption you would reconsider if the results differed from your prediction. This task assesses the capacity to formulate and test a hypothesis rather than the memorization of a conclusion.

Another diagnostic task: the same object is fully submerged first in water and then in a liquid of lower density. Predict how the buoyant force changes and design a virtual experiment in which all variables except liquid density are held constant. The teacher evaluates both tasks using the same rubric.

If an empirical evaluation is planned, the content validity of the diagnostic instrument should first be reviewed by experts, task difficulty should be made comparable, baseline group characteristics should be examined, and changes in performance should be analyzed using appropriate statistical methods. In an illustrative research design, the intervention group would be taught using problem-centered digital modeling, while the comparison group would follow conventional instruction; instructional time, content, and assessment conditions would be kept as similar as possible. This article does not claim that such an experiment has been conducted.

10. Results and Discussion: A Theoretical and Methodological Synthesis

The first methodological insight emerging from the literature synthesis and proposed lesson design is that the effectiveness of a digital resource depends less on technical sophistication than on the sequence of intellectual activities performed by learners. An attractive animation may generate temporary interest; without questions, hypotheses, testing, and evaluation, however, it provides insufficient evidence of independent problem-solving competence.

The second insight is that idealized digital models and physical experiments should be understood as complementary learning environments rather than competing approaches. Idealized models allow precise control of variables, repeated trials, and safe experimentation. Physical experiments expose learners to measurement uncertainty, instrument limitations, environmental influences, and responsibility for safe physical practice. Comparing the two encourages students to test how well models represent the real world.

Third, formative assessment cannot be delegated entirely to digital tools. Automated platforms often identify whether an answer is correct but cannot consistently diagnose the reasoning that produced an error. Teachers should therefore consider data tables, graphs, written hypotheses, and reflective explanations together. This provides a broader view of competence than test scores alone.

Fourth, the method must remain adaptable to the conditions of academic lyceums. Where computers and internet access are sufficient, students can conduct virtual investigations independently.

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When devices are limited, teachers can organize rotating group experiments, shared prediction tests using a projector, or activities with prepared screenshots and paper-based data tables. The essential pedagogical requirement is that students retain the opportunity to revise their hypotheses in response to evidence.

The model also has limitations. Outcomes may be influenced by students' prior mathematical knowledge, teachers' digital competence, language barriers, access to devices, and differences in motivation. The model's actual effectiveness, optimal duration, and suitability across physics topics require independent empirical investigation. Consequently, the propositions advanced here should be regarded as practical recommendations and testable hypotheses, rather than established empirical findings.

11. Practical Recommendations for Teachers

First, digital lessons should be designed around a competency indicator and a problem-based question rather than the name of a software application. Second, students should write their predictions before a simulation begins. Third, experimental protocols should distinguish manipulated, observed, and controlled quantities. Fourth, each activity should include at least one unexpected finding or transfer task. Fifth, students should analyze at least one graph or table rather than merely operate on-screen controls. Sixth, calculated or simulated data must not be presented as measurements from physical experiments. Seventh, rubrics should reward learning from errors, independently generated hypotheses, and consideration of alternative explanations. Eighth, a technical contingency plan and digital safety provisions should be established in advance.

A shared repository of digital educational resources is recommended at the subject-department level. Each entry should specify the topic, learning objective, competency indicator, platform, instructional stage, estimated duration, required device, offline alternative, and assessment method. Such a catalogue would enable teachers to use pedagogically reviewed activities and discuss experimental findings with colleagues.

12. Conclusion

Purposeful pedagogical use of digital educational resources in physics instruction provides a methodological basis for developing students' independent thinking and problem-solving competencies. The critical factor is not the interactive tool itself, but the learner's engagement in identifying a problem, formulating a hypothesis, conducting a digital experiment, interpreting evidence, justifying a solution, and reflecting on the process.

The proposed six-stage model has been illustrated through practical activities on motion along an inclined plane, buoyant force, and conservation of energy. The analytic rubric assesses not only final test performance but also observable products of students' reasoning. Previous national research provides a theoretical and methodological rationale for this approach; however, empirical intervention studies are needed to determine its effectiveness.

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Further studies should test the model across different topics, academic levels, and degrees of digital infrastructure; establish the validity of tasks and inter-rater agreement; and investigate the long-term retention of students' competencies.

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