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INTEGRATING DIGITAL SIMULATIONS AND COMPETENCY-BASED TASKS TO DEVELOP CORE PHYSICS COMPETENCIES AMONG ACADEMIC LYCEUM STUDENTS

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Abstract: This article develops a five-stage didactic model that integrates digital simulations with competency-based tasks and analyzes the pre-test and post-test scores of two groups. The experimental group comprised 23 students and the control group 22. Initially, the mean scores were 52.65 and 52.18 points, respectively; by the end of the intervention, they had reached 79.22 and 65.95 points. The average gains were 26.57 and 13.77 points, yielding a between-group gain difference of 12.79 points. The findings suggest the potential of the integrated approach, while the limitations of the quasi-experimental design preclude an unequivocal causal interpretation.

Keywords: digital simulation; physics education; core competence; academic lyceum; competency-based task; formative assessment; quasi-experiment.

1. Introduction and Research Problem

The outcomes of physics education cannot be assessed solely by a student's ability to recall formulas or solve problems using prescribed algorithms. Students must be able to explain physical phenomena, formulate experimental questions, examine relationships among variables, and draw evidence-based conclusions. Digital environments can support these activities; however, merely watching an animation on a screen does not in itself demonstrate the development of competence.

In academic lyceums, the theoretical complexity of the subject matter, unequal access to laboratory equipment and instructional time, and differences in students' prior preparation require methodological adaptation. Interactive simulations enable parameters to be adjusted quickly and safely, experiments to be repeated, and alternative representations of the same phenomenon to be compared. Nevertheless, without a clearly defined research question, assessment criteria, and reflective activities, a simulation remains little more than a demonstration.

Accordingly, the central research problem is as follows: how can working with digital simulations be transformed into a reproducible instructional cycle targeting measurable physics competencies? The proposed solution lies not in the digital resource itself but in its pedagogical integration with a sequence of tasks and diagnostic assessment.

Research Aim and Questions

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The aim is to develop a methodological model, a sample task, and an assessment system for integrating digital simulations and competency-based tasks in academic lyceum physics lessons, and to establish a procedure for empirically evaluating the approach.

1. Which observable competency-related actions does the integrated cycle activate in students?

2. How does the pre-test-to-post-test change in the group receiving this intervention compare with that of the comparison group?

3. Which elements of the tasks help identify and correct conceptual errors?

Hypothesis: when the same content is taught over an equivalent period, instruction combining simulation-based inquiry tasks, evidence-based explanations, and formative feedback positively affects students' corresponding competency indicators. This hypothesis must be tested against empirical evidence.

2. Theoretical Framework and Literature Review

Banda and Nzabahimana (2021) reviewed 31 quasi-experimental or experimental studies and synthesized positive findings concerning the contribution of PhET simulations to students' understanding of physics concepts. Their review demonstrates the potential of digital resources, although effectiveness must be interpreted in relation to lesson design and student engagement [1].

The research-based design principles of the PhET project emphasize encouraging scientific inquiry, visualizing otherwise invisible processes, connecting multiple representations, and enabling interactive control [2]. Thus, from a methodological perspective, the questions "What hypothesis did the student formulate?", "What variable did the student change?", and "How did the student explain the result?" matter more than "Which button did the student press?"

Lichtenberger and Hofer (2024) investigated formative assessment in secondary-school physics using a cluster-randomized research design. Their work demonstrates the need to connect conceptual understanding with diagnostic questions, feedback, and assessment during instruction [3]. In the present study, formative assessment is regarded not as an optional final addition to the simulation cycle, but as a regulatory mechanism embedded at every stage.

Comparative Analysis of Research by Uzbek Scholars

Saidova and Kamolov (2026) conceptualize digital education as an integrated pedagogical system comprising virtual laboratories, simulations, electronic resources, and digital assessment [7]. This perspective aligns with the systemic nature of the proposed model; our approach, however, places particular emphasis on aligning observable competency indicators with tasks and assessment evidence. Bozorov and Ismatova (2026) examine the possibilities of virtual experimentation with PhET and Crocodile Physics in teaching the conservation of energy and momentum [8]. Their work illustrates the methodological importance of selecting resources appropriate to specific physics content.

Shoyzakova (2025) emphasizes the need to develop prospective physics teachers' creative and intellectual competencies through digital tools and to provide specialized teacher preparation [9]. Sayidov (2025) examines the potential of simulations and virtual laboratories for visualizing physical concepts [10]. Muhammadova and Fayziyeva (2024) analyze both the possibilities and

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the limitations of using computer-based tools to solve physics problems [11]. Choriyeva (2026) explores the relationship between scientific competence and virtual laboratories in higher education [12]. Most of these studies concern other educational levels or the general use of resources. Examining the relationship between tasks, indicators, and scores in academic lyceums is a distinct focus of the present work.

Conceptual Distinctions

Term	Definition	Practical evidence
Digital simulation	A virtual environment for manipulating the parameters of a physical model	Changing parameters and observing outcomes
Competency-based task	Transforms knowledge into justified action in a new situation	Hypothesis, evidence, conclusion
Formative assessment	Diagnosis and feedback during learning	Rubric and corrective action
Core competence	The ability to transfer performance across multiple learning tasks	Completion of a transfer task

A comparison of national and international literature leads to a general conclusion: although the capabilities of digital tools are widely discussed, it is particularly important to demonstrate the competencies of academic lyceum students through explicitly defined indicators, inquiry tasks, and measurements. The contribution claimed here is therefore context-specific rather than absolute: the observed outcomes are linked to the educational setting and the criteria selected for assessing students' competencies.

3. Integrated Didactic Model

The model consists of five interconnected stages: a diagnostic problem, simulation-based inquiry, an evidence-based task, dialogue and reflection, and criterion-referenced assessment. At each stage, students produce a concrete output. This makes it possible to assess the physics content of their activity rather than merely their engagement with digital technology.

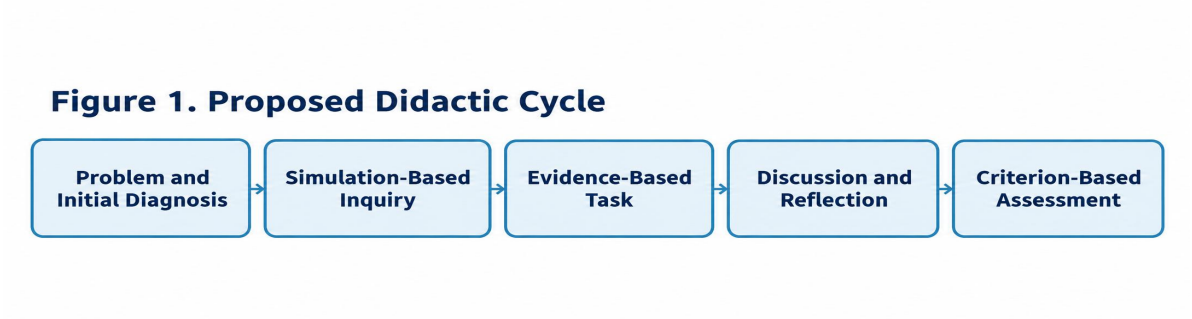


Figure 1. Integrated cycle of simulation and competency-based tasks

The Teacher's Role at Each Stage:

At the diagnostic-problem stage, students are presented with a question that challenges common intuition or with two competing predictions. During inquiry, students select the

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independent variable, identify controlled conditions, and run the simulation several times. At the evidence stage, they explain their observations using a table, graph, or relevant physical concepts.

During reflection, students compare their initial predictions with the results and explicitly identify the sources of errors. The assessment stage considers not only the correctness of the final response but also the experimental design, quality of evidence, and recognition of limitations. The teacher then checks whether students can transfer their learning to a new task.

The model can potentially be applied through a similar cycle to mechanics, electricity, waves, and optics. When selecting a simulation, teachers should also consider curriculum alignment, scientific accuracy, language, accessibility, device requirements, and the degree of instructional control.

4. Sample Lesson: Newton's Second Law

The relationship among force, mass, and acceleration was selected as the sample topic. Expected competence: the student explains the conditions under which the statement "acceleration increases as force increases" holds, conducts an investigation while controlling mass, and interprets the meaning of F = ma on the basis of a graph.

Stage / time	Student activity	Observable evidence
Problem / 5 min	Predicts what happens when an equal force acts on different masses	Written hypothesis
Investigation / 12 min	Keeps mass constant and tests three levels of force	Observation table
Second investigation / 8 min	Keeps force constant and changes mass	Comparative explanation
Interpretation / 10 min	Explains the graph or relationship	Evidence of cause and effect
Transfer / 7 min	Applies the concept to a real cart or transport situation	Response to a new situation
Reflection / 3 min	Records an error and a learning strategy	Exit ticket

Sample Task

"Two carts moving on identical horizontal surfaces are acted upon by the same net force. The mass of the first cart is twice that of the second. Which cart has the greater acceleration, and why? Verify your answer using at least three combinations of measurements in a simulation. Specify how friction is represented in the physical model."

Identifying the "twofold" ratio alone is insufficient. Students must also recognize that the force in question is the net force, explain how other parameters are controlled, and acknowledge the limitations of the model when applied to the real world. These requirements transform a routine calculation into a competency-based task.

5. Mapping Competencies to Performance Indicators

Before assessment, the notion of competence is broken down into observable actions. Recognizing theoretical knowledge, designing an experiment, working with a digital model,

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constructing evidence-based arguments, and defending findings through communication are mutually reinforcing activities.

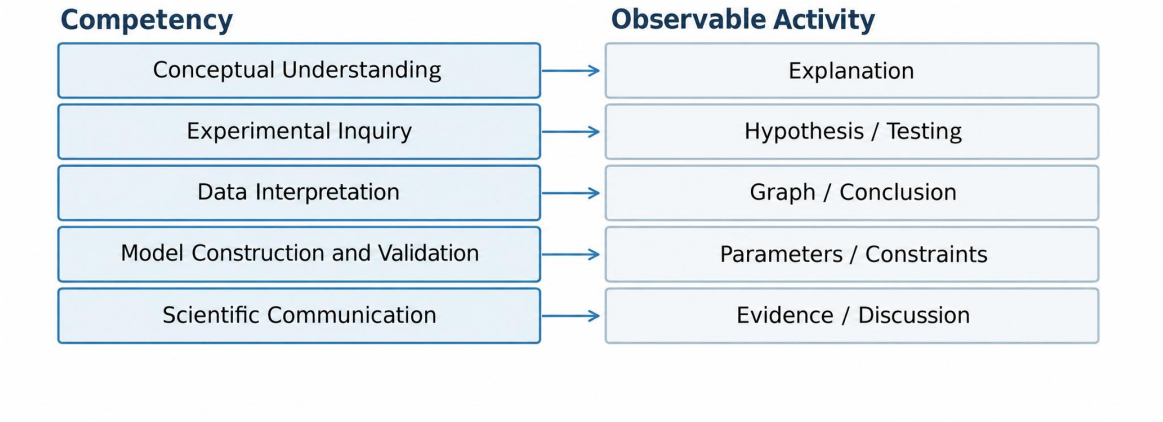


Figure 2. Alignment of competencies and assessed performance

Analytic Rubric by Performance Level

Criterion	0 - Beginning	1 - Developing	2 - Proficient	3 - Advanced
Hypothesis	Absent	Prediction without justification	Testable	Clear, conditional, and justified
Variables	Not identified	Partially identified	Key variables correct	Explains control of variables
Evidence	Absent	Observation only	Appropriate table/graph	Evaluates the quality of evidence
Physics explanation	Incorrect	Partial	Correct underlying law	Also explains limitations
Transfer	Unable to apply	With assistance	Applies to a new situation	Generalizes and justifies

The total score across the five criteria ranges from 0 to 15. If the rubric is used as an independent measure, its internal consistency, inter-rater reliability, and content validity must be empirically evaluated. These coefficients have not yet been calculated for the present project.

6. Research Methodology

The supplied dataset contains 45 paired observations for a quasi-experimental pre-test–post-test design with a control group: 23 students in the experimental group and 22 in the control group. Each participant has an initial and a final test score on a 100-point scale. Participants' ages, year of study, sampling method, intervention duration, and test validity still require supporting documentation.

Figure 3. Known group sizes and sequence of evaluation

Measurement Instruments

It is recommended to use equivalent pre-test and post-test tasks that measure the same construct while reducing the effects of memorizing test items: (1) conceptual questions, (2)

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interpretation of graphs and tables, (3) experimental design, and (4) transfer situations. Work assessed with the analytic rubric, simulation output tables, and teacher observations should be collected for triangulation.

The topic, lesson duration, instructional objectives, and assessment criteria should be kept as similar as possible across the two groups. The proposed cycle is applied in the experimental group. The instructional approach actually used in the comparison group must be described precisely; the term "traditional" should be used only if that description is supported by observation.

Requirements concerning student consent and personal data protection must be observed. Having assessors evaluate work without knowing the students' group assignments could improve methodological objectivity.

7. Empirical Findings and Statistical Analysis

Descriptive and inferential analyses were performed on all paired scores for the 23 and 22 students in the original dataset provided by the researcher. Scores were reported on a 100-point scale. The table below presents the means, sample standard deviations (SD), and individual gains.

Indicator	Experimental n = 23	Control n = 22
Pre-test, M ± SD	52.65 ± 6.38	52.18 ± 5.70
Post-test, M ± SD	79.22 ± 2.37	65.95 ± 3.32
Individual gain, M ± SD	26.57 ± 5.26	13.77 ± 5.05
Pre-test-to-post-test gain, points	26.57	13.77

Figure 4. Mean pre-test scores, post-test scores, and individual gains in both groups

On average, scores in the experimental group increased by 12.79 points more than those in the control group. Statistical analysis indicated that this difference was substantial and statistically significant.

8. Analysis of the Experimental Results

In the experimental group, the mean test score increased from 52.65 to 79.22 points, whereas in the control group it increased from 52.18 to 65.95 points. The difference between the groups was only 0.47 points at baseline, but reached 13.26 points by the end of the study.

These results indicate a markedly greater improvement in test performance among students in the experimental group, where digital simulations and competency-based tasks were used, compared with the control group.

Internal Evidence and Cautious Interpretation

Both groups showed positive gains; consequently, it would be inappropriate to rely solely on the pre-test–post-test difference within the experimental group. The primary comparison concerns the difference in individual gains between the two groups over the same period. The 95% confidence interval for this difference lies entirely above zero.

The standard deviations of post-test scores were 2.37 in the experimental group and 3.32 in the control group. Such limited dispersion may reflect test difficulty, a ceiling effect in the final scores, or relatively similar student performance.

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Further Competency-Specific Investigation

To substantiate claims about educational quality, test questions should be organized into subscales such as conceptual understanding, experimental design, graph interpretation, physical modeling, and transfer. A content map of test items and rubric results for each area would provide stronger evidence of precisely which competencies developed.

The current figure presents total test scores and score gains from the available dataset. If documentation on research procedures, diagnostic instruments, and inter-rater agreement becomes available, additional regression and sensitivity analyses could be used to assess the robustness of the findings.

9. Discussion

The scores of 45 students showed greater improvement in the group designated as receiving digital simulations and competency-based tasks than in the control group. However, an improvement in total test scores does not in itself fully establish growth in specific experimental or modeling competencies. Students' hypotheses, graphs, and written explanations must also be analyzed to examine how digital resources interact with the task structure.

An important feature of the model is its use of multiple representations. When students observe a phenomenon in an animation, record it in a table, depict it graphically, and generalize it using a formula, they can connect the physical meaning across different representations. Such connections do not arise automatically; teachers must pose bridging questions such as "What does the slope of the graph represent?"

A comparison with research from Uzbekistan supports this interpretation. The systemic digital-learning environment proposed by Saidova and Kamolov [7] provides a general framework for our didactic cycle, while Bozorov and Ismatova [8] offer an example of teaching particular physical laws through virtual experiments. Shoyzakova [9] stresses teachers' methodological preparation. However, the 45 aggregate test scores analyzed here do not measure each of these mechanisms separately; conclusions are limited to the overall differences in learning outcomes.

Assessment limited to a final test may conceal important difficulties. A more comprehensive evidence base should therefore include rubrics, students' explanations, and artifacts of digital activity. This approach is methodologically consistent with the conceptual questioning and formative feedback investigated by Lichtenberger and Hofer [3], although their results cannot be transferred directly to the local lyceum groups.

Scope of the Methodological Contribution

The five-stage cycle described here is a methodological framework proposed by the author for this article. It is not presented as an entirely new universal theory. Before publication, it should be made explicit which component was developed for the first time in the dissertation, how it differs from earlier publications, and how it was validated.

10. Practical Recommendations for Teachers

Each simulation-based lesson should begin with at least one testable question. Tasks should explicitly distinguish manipulated variables from controlled parameters. Students should produce explanations, tables, and transfer responses rather than merely screenshots. The assessment rubric

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should be introduced before the lesson, and the limitations of the model should be discussed at the end.

When technical resources are limited, students may work with simulations in pairs or small groups. Rotating the roles of operator, recorder, and interpreter helps ensure active participation by all learners. Where internet disruptions are possible, permitted offline resources and paper observation sheets should be prepared in advance.

Conclusion

Across the 45 paired test observations, the mean gain was 26.57 points in the experimental group and 13.77 points in the control group. The between-group gain difference was 12.79 points and differed from zero with a high degree of statistical confidence under the selected test. These observed findings are consistent with the potential effectiveness of the integrated instructional approach. At the same time, the method of group allocation, documentation of the intervention, and validity of the test instrument remain important limitations on causal interpretation. The five-stage model and analytic rubric provide a basis for examining distinct competencies in subsequent research.

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