DIGITAL TECHNOLOGY-BASED INDEPENDENT LEARNING IN PHYSICS FOR ENGINEERING STUDENTS

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Abstract. Under the credit-module system, independent study takes 50–60% of the total workload, yet in physics courses for engineering students it is often left unguided and unmonitored. This paper presents a methodological model for organizing independent learning in physics on the basis of digital technologies. The model has six components and is implemented through the author's web application "Learn Physics Independently" (fizika365.uz) and the HEMIS platform. The virtual laboratory content (43 works) was selected through a needs analysis of 45 engineers at three industrial enterprises. A five-stage didactic cycle for developing experimental skills and a three-level monitoring system are also described.

Keywords: independent learning, physics, engineering education, credit-module system, digital technologies, virtual laboratory, web application, HEMIS, needs analysis, experimental skills.

Introduction

The transition of Uzbek higher education to the credit-module system (Cabinet of Ministers Resolution No. 824, 2020) has shifted a large share of learning to students' independent work. For first-year engineering students, physics is a foundational course: in most programmes it carries 10 credits over two semesters, and 50–60% of these hours are assigned to independent study [1]. In practice, these hours are often given as scattered assignments with little guidance, weak individual monitoring and subjective assessment.

Research on self-regulated learning [2], formative feedback [3] and technology integration [4] shows that independent learning is effective only when it is structured, supported and continuously monitored. Virtual laboratories and interactive simulations improve students' conceptual understanding in physics [5, 6]. However, most existing digital tools (PhET, MOOC courses, LMS platforms) are designed for general physics teaching. They are not integrated into a single platform that combines theory, formulas, virtual experiments, an AI assistant and automated assessment for engineering students in the credit-module system. This paper addresses that gap.

Methods. The methodological model turns independent study hours into a guided, monitored learning cycle. It consists of six interrelated components:

1. **Target** — objectives of independent learning in the credit-module system: mastering physical laws, developing experimental skills and self-assessment.
2. **Content** — physics topics arranged in six modules (mechanics; molecular physics and thermodynamics; electrostatics; magnetism; optics; atomic and nuclear physics), from simple to complex.
3. **Technological** — the "Learn Physics Independently" web application and the HEMIS platform.
4. **Organizational** — guided sessions three days a week (2 hours each), step-by-step scaffolding and peer tutoring.
5. **Assessment** — automated testing and a certification system.
6. **Control-corrective** — three-level monitoring and corrective support for students who fall behind.

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The web application was built with HTML, CSS and JavaScript, has a responsive interface and is also available on Google Play. It unites six modules:

Module	Content
Library	8 textbooks and study guides, including the author's own
Formula database	145 formulas in 10 categories, with variables and units explained
Virtual laboratory	43 interactive experiments in 4 sections
AI assistant	Answers students' questions (Gemini API)
Testing	600+ questions; 6 sectional stages (15 random questions each) and a 7th final stage (25 random questions)
Certification	A certificate for a final score above 60%, verified by an individual QR code

Randomized questions discourage copying and encourage repeated attempts. A student who scores below 60% revises weak sections and retakes the final test after a set period.

Results. Needs-based laboratory content. The virtual laboratory works were selected through a needs analysis of 45 technical employees from three enterprises: AKFA Extrusions LLC, Hydrometallurgical Plant No. 6 and the Bukhara Regional Railway Junction. Of 92 candidate works, 43 were marked as necessary for professional activity by more than 60% of respondents. They cover mechanics (15), molecular physics (10), electricity and magnetism (11), and optics and waves (7). This links the laboratory content directly to students' future engineering work.

Five-stage cycle for experimental skills. Each virtual experiment follows the same didactic cycle:

1. Theoretical preparation — through the library and formula database.
2. Hypothesis and planning.
3. Independent execution of the virtual experiment.
4. Recording and processing data.
5. Analysis, conclusions and self-check — through the testing module.

For example, in the "Simple pendulum" work, the student studies $T = 2\pi\sqrt{(L/g)}$, predicts how the period depends on string length, varies L in the simulation, processes the data and determines the free-fall acceleration g. Support is reduced step by step. At the start of the year the teacher performs one experiment per session together with students; from the second semester students choose the number of experiments themselves.

Three-level monitoring. Level 1 is automatic data from the web application (logins and test results). Level 2 is direct observation during guided sessions (three days a week, 2 hours each). Level 3 is documented control through certificates. Students who do not reach the target receive corrective support: identifying the gap, redirecting to review, pairing with a high-achieving peer and a retake. Final results are entered into HEMIS as an official grade for independent study.

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Conclusion

The proposed six-component model turns the independent study hours of the credit-module system into a guided learning cycle with clear tasks, digital tools, regular monitoring and objective assessment. Its distinctive features are the needs-based selection of virtual laboratory content, the five-stage cycle for experimental skills and the integration of the web application with HEMIS.

The model has been implemented at Asia International University, Navoi State University of Mining and Technologies and the Yangiyer branch of the Tashkent Chemical-Technological Institute, with 299 first-year engineering students over two semesters. Further work will add a teacher analytics dashboard and AI-based adaptive learning paths, and adapt the application to other science and engineering courses.

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