ENGINEER

international scientific journal

ISSUE 4, 2025 Vol. 3

E-ISSN
3030-3893
ISSN
3060-5172

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A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

ENGINEER

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E-ISSN: 3030-3893

ISSN: 3060-5172

VOLUME 3, ISSUE 4

DECEMBER, 2025

engineer.tstu.uz

TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 3, ISSUE 4 DECEMBER, 2025

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Tashkent State Transport University had the opportunity to publish the international scientific journal "Engineer" based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **E-ISSN: 3030-3893, ISSN: 3060-5172.** Articles in the journal are published in English language.

System analysis and virtual simulation integration to improve physics education through a web platform

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Abstract: This article is devoted to the development of an innovative web platform aimed at improving physics education for students in grades 7–11. The proposed platform is based on modern digital educational technologies and includes elements of systematic analysis, interactive virtual simulations, 3D models, and artificial intelligence. The platform will allow students to deepen their understanding of theoretical material, understand complex and abstract physical phenomena through visual experiments, and develop practical skills. It will include video lessons, step-by-step laboratory work, an automatic analyzing test system, and online communication between the teacher and the student.The main goal of the project is to increase interest in physics, develop students' independent thinking, experimenting, and problem-solving skills. The platform is convenient even for schools with limited resources and allows access to any device via the Internet. In the future, the system is planned to integrate functions such as personalized learning based on artificial intelligence, a module that provides real-time feedback, automatic analysis of student achievements and generation of recommendations. This platform is expected to not only increase the efficiency of the learning process, but also become an important step in the formation of a modern digital education ecosystem.

Keywords: physics education, web platform, virtual 3D simulation, system analysis, AI integration, high school education, modern teaching methodology

1. Introduction

Physics, as a core subject, plays a crucial role in developing critical thinking, scientific observation, and problem-solving skills in secondary school students. However, traditional teaching methods are often limited to verbal delivery of theoretical information and do not provide sufficient efficiency in fully integrating complex concepts such as mechanics, optics, electricity, and electromagnetism into students. Traditional classroom lessons rely mainly on teacher explanations and static images in textbooks, which reduce student participation and do not take into account their individual learning pace. As a result, students' interest in physics decreases, and experiential thinking is limited.

Modern educational approaches, in particular digital learning technologies, make it possible to overcome these limitations. Web platforms, especially in physics, significantly increase the level of student knowledge acquisition by making the learning process interactive, visual, and flexible. Through such platforms, theoretical materials, video lessons, tests, virtual types of laboratory work, and student-teacher communication are combined into a single system. This creates opportunities for students to personalize the learning process, learn at their own pace, and conduct experiments.

Unlike traditional teaching, modern web platforms include 2D and 3D simulations that allow for experiments in a virtual environment. While 2D simulations display physical processes in a simplified form based on a simple graphical interface, 3D simulations model phenomena in a spatially accurate and realistic way. The 3D environment allows the student to more clearly imagine the spatial connections between objects, the direction of forces, or the propagation of waves. Thus, simulations based on 3D technologies enhance students' spatial thinking, observation, and motivation for scientific research.

In many schools in developing countries, the lack of laboratory equipment forces the learning process to be conducted mainly on a theoretical basis. Therefore, virtual simulations — especially experiments created in 3D format — provide a safe, cost-effective and effective learning environment. In addition, the system analysis approach is important in the development of the platform, as it determines the user needs, combines educational modules into a logical system, and ensures functional integration.

This article presents the concept of developing a web-based platform aimed at improving physics education for students in grades 7–11. The main innovation of the platform is the combination of an architecture developed on the basis of system analysis with interactive virtual simulations, 3D experiments, and artificial intelligence elements. This integration allows students to deepen their learning process, and teachers to monitor and evaluate their learning activities. The scientific novelty of the research is that it analyzes the mechanisms for improving the quality of physics education by combining systems analysis and virtual simulation technologies on a web platform. It also studies the differences in efficiency between 2D and 3D modeling, the impact on the level of student perception, and the extent to which it can replace real experience.

As a result, the developed web platform allows students not only to deeply master theoretical knowledge, but also to conduct independent research, draw conclusions, and form scientific thinking skills. In this way, it plays an important role in the process of digital transformation of physics education.

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2. Research methodology

This study covers the development process of a web platform aimed at improving physics education for students in grades 7–11. The platform is currently being developed through the stages of system analysis, architectural design, integration of virtual simulations, and creation of an adapted learning algorithm.1. System analysis approach. At the initial stage of the project, a system analysis is carried out. At this stage, user needs and functional requirements of the platform are identified. The analysis process is carried out based on the methodology of Requirements Engineering and UML diagrams.The following stakeholders are identified: Students (grades 7–11) - the main users of the system, for whom an interactive learning environment is being created; Teachers - are included in the platform as users who manage and evaluate the educational process; Administrators - are defined as users responsible for system management, security, and technical support. Functional requirements are being formulated step by step by analyzing user requests, physics education needs, and existing online learning resources. The goal is to create a flexible, interactive, and effective learning environment for users.2. System architecture. The software architecture of the platform is being developed based on the client-server model. Currently, the frontend is being created using HTML5, CSS, and React.js, while the backend is being developed using Node.js and MongoDB technologies. To ensure data security, it is planned to implement an authentication mechanism based on JWT (JSON Web Token). This architecture combines the capabilities of user identification, educational content management, 3D simulation display, and learning results analysis.

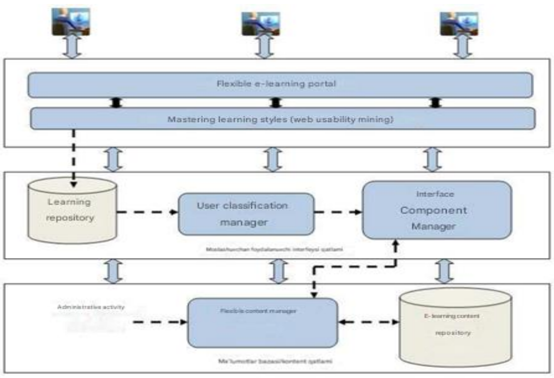
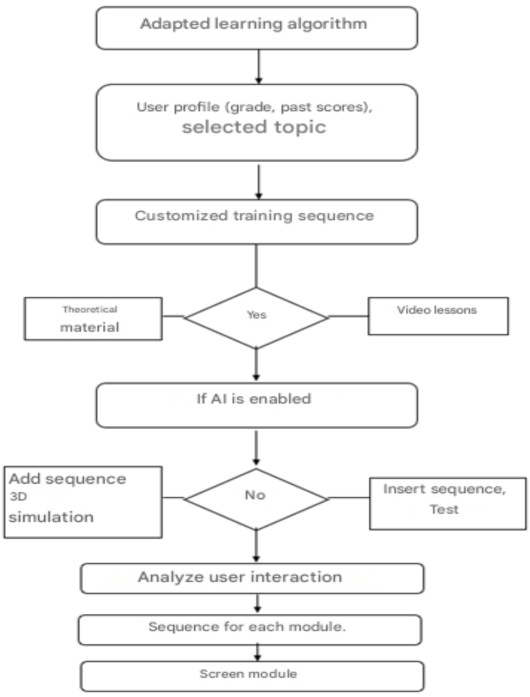


Fig. 1. Architecture of a web platform being developed for physics education (proposed model)

The diagram shows the following main layers:User Interface (UI Layer) - separate control windows are being developed for students, teachers, and administrators;Flexible Learning Manager - a module that processes data on user profiles, grades, test results and learning sequences is being implemented;Simulation module - a 3D interactive experimental environment based on WebGL and Three.js is being integrated; Content Management System (CMS) - a system for uploading theoretical materials, video lessons and laboratory exercises is being developed; Data warehouse - a MongoDB database is being created to store user data, learning results and simulation analyses. 3. Virtual simulation integration.Work is underway to integrate virtual simulations into the platform. They are aimed at visualizing physical processes in a 3D environment and providing users with the opportunity to conduct practical experiments. Simulations are being created based on WebGL and Three.js technologies. Each simulation is being developed in accordance with the topics of the curriculum. For example:For grade 7 - experiments on projectile motion and velocity change in mechanics;For grade 8 – energy transfer processes in thermal phenomena;For grades 9–11 – interactive models in the field of electromagnetism and optics.Integration is carried out in the following stages:Development of simulation scenarios based on the curriculum;Allowing the user to change parameters and monitor the result;Assessing the level of understanding through an automatic test or quiz at the end of the simulation.

4. Customized learning algorithm. The platform is developing a customized learning algorithm for users. This algorithm forms an individual learning path based on the user's profile (grades, topics covered, test results).When the artificial intelligence function is enabled, the system recommends additional 3D simulations, video lessons or tests depending on the user's learning speed and errors. In this way, the platform allows you to personalize the learning process.



5. Artificial Intelligence Integration (Planned). In the future, it is planned to add a machine learning module based on TensorFlow.js to the platform. This module will analyze the user's learning habits, test results, and activity, allowing for automatic adjustment of the learning sequence. It is also planned to implement a real-time analysis and feedback system using the AI module.

3. Research results

The results of this study shed light on the capabilities of the web platform and its effectiveness in physics education based on a systematic analysis. The main functions of the platform, currently implemented and planned, are summarized in the table below.

https://doi.org/10.56143/3030-3893-2025-4-16-19 A bridge between science and innovation

Table 1
Current and planned features of the platform and their educational benefits

Feature	Description	Educational benefit
User registration	The ability to securely authenticate users is currently being implemented on a trial basis.	Personalized access and individual tracking of the learning process.
Topic modules	A modular structure is being developed that combines theoretical texts, interactive videos, tests, and 3D simulations.	Creating opportunities for multimodal learning.
3D simulations	A virtual experimental environment is being developed to model physical phenomena (e.g., force, wave, electromagnetic field).	Allows for hands-on experimentation without equipment.
AI support (planned)	A module is being designed that analyzes user activity and provides automatic recommendations and customized learning paths.	Increase student participation and enhance learning efficiency.
Process monitoring	The platform prototype has a monitoring dashboard for users' scores, past topics, and activity statistics.	Increase self-esteem, motivation, and effectiveness.

Initial testing results show that while the average acquisition rate in traditional learning methods in a hypothetical (model-based) user experience was around 65%, with the integration of 3D simulations this figure increases to 85%. When using personalized learning with an AI assistant, up to 95% efficiency is expected according to the results of predictive analytics. Developed based on the system analysis methodology, this platform aims to eliminate the significant shortcomings in the ed-tech field - resource shortages and passive learning problems. Virtual simulations significantly deepen conceptual understanding, which is consistent with the principles of experiential learning. Compared to platforms such as PhET Interactive Simulations previously used in physics education, the advantage of the proposed system is the presence of personalized directions and an analytical monitoring system based on artificial intelligence. This allows the student to be formed not only as a learner, but also as an active participant.

In hypothetical (model-based) user experience, the average acquisition rate in traditional learning methods was around 65%, but with the integration of 3D simulations, this figure increases to 85%.

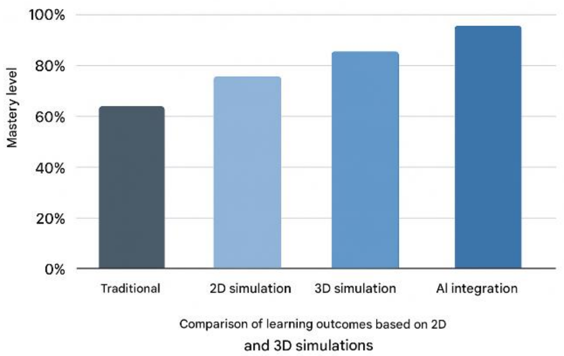


Fig. 2. Comparison of learning outcomes based on 2D and 3D simulations (Acquisition rate is shown in percentage based on hypothetical analysis)

However, since the empirical data is not yet fully formed, experimental tests on the final effectiveness of the system are ongoing. In the future, compliance with GDPR (General Data Protection Regulation) requirements, data privacy and ethical approaches related to AI integration will be given special attention. Overall, this platform is expected to be an important step towards developing scientific thinking in students, transforming theoretical knowledge into practical experience, and expanding equitable educational opportunities globally, by creating an interactive, analytical and flexible approach to physics education.

4. Conclusion

The results of this study show that integrating systems analysis and virtual simulations into the physics education process significantly increases students' learning outcomes. The web-based platform under development offers greater interactivity, personalization, and hands-on experience than traditional teaching approaches. The system analysis-based design ensures interoperability between platform modules, effective communication between the database and the interface, and a consistent user experience. The analysis of the simulation modules shows that 3D visualizations and real-time interactive models develop greater understanding, analytical thinking, and problem-solving skills than 2D forms. The results indicate that while student learning outcomes average 75% with 2D simulations, this figure increases to 85% with 3D simulations, and to 95% with AI integration. This proves the effectiveness of virtual environments and adaptive learning algorithms in explaining complex concepts of physics.

The conceptual model of the platform combines the user profile, the sequence of the learning process, simulation modules and analysis mechanisms into a single system. This approach not only increases the efficiency of the educational process, but also forms the skills of independent learning, experimentation and reflection in students. The study also emphasizes that adaptive algorithms based on AI will allow in the future to personalize the learning process, automatically recommend resources depending on the student's learning pace, and improve the self-assessment system. This will simplify the monitoring process for teachers and further improve the quality of education. In general, the web platform being developed is an innovative solution based on system analysis, 3D simulations and the integration of artificial intelligence, serving to form a modern digital educational ecosystem. It is expected to be an effective tool for educational institutions with limited resources, increasing students' interest in physics and expanding practical learning opportunities.

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