

## EXPANDING THE DIDACTIC POSSIBILITIES OF INTERDISCIPLINARY TEACHING BASED ON AN INTEGRATED DIGITAL-REAL LABORATORY ENVIRONMENT

Baymatova Nargiza Tuxtabayevna

Tashkent State Technical University Named After Islam Karimov

baymatovanargiz77@gmail.com

### ABSTRACT

This article analyzes, from a scientific and pedagogical perspective, the issue of improving the effectiveness of interdisciplinary teaching in technical education through the integration of digital and real laboratories. It is substantiated that, under conditions of digital transformation, the training of technical specialists requires students to possess not only theoretical knowledge but also solid practical skills in working with real devices, computer modeling, using IoT technologies, and developing competencies in remote monitoring and control.

**Keywords:** Digital laboratory, real laboratory, interdisciplinary integration, technical education, virtual and remote experimentation, IoT-based project, AR/VR technologies, integrated laboratory environment, technical competencies, smart irrigation system.

### INTRODUCTION

Nowadays, the digital transformation observed worldwide is also setting new tasks for the education system. In order to work with production processes based on digital technologies and modern devices connected to the Internet, graduates must possess deep theoretical knowledge, well-developed practical skills, and competencies for independent inquiry. Therefore, the contemporary model of teaching technical disciplines requires the implementation of activity-oriented, integrated, and creativity-enhancing technologies rather than traditional knowledge-transmission approaches.

In the process of technical education, alongside the formation of practical technical knowledge, there is a growing need to develop in students higher-order educational and cognitive competences such as independent thinking, solving problem situations, designing, conducting experiments, analyzing information, and modeling technological processes. These competences are among the key factors in training today's competitive, innovative-minded technical specialists.

At the same time, the increasing complexity of the content of technical disciplines, the high-tech nature of modern production, and the multifactor and systemic character of real technical processes require the integration of disciplines, computer modeling, harmonization of real and virtual laboratories, and the creation of an innovative laboratory environment in the teaching process. Through such approaches, the student not only masters a single subject but also comes to understand the intrinsic links between mathematics, physics, informatics, economics, and technology, and learns to approach complex technical problems in a systemic way [3].

The above-mentioned changes and needs necessitate a revision of the methodology for teaching technical disciplines on a new scientific basis. In particular, improving the teaching of technical disciplines through the integration of real and digital laboratories, forming high-

level technical competences in students, developing their independent research activity, and increasing the effectiveness of education are being raised as urgent scientific and pedagogical problems.

The article focuses in detail on enhancing the effectiveness of interdisciplinary teaching through the integration of digital and real laboratories as a key pedagogical requirement for modern instruction in technical disciplines.

**Integration with Physics, Mathematics and Informatics.** Interdisciplinary integration in the system of teaching technical disciplines is one of the leading didactic principles that serves to develop in students the ability to solve complex, systemic, problem situations using multifaceted approaches. At present, curricula, syllabi, and standards in the education system of Uzbekistan are being updated, with particular attention given to ensuring the coherence between disciplines taught in technical fields. Integration not only deepens students' theoretical knowledge but also enables them to perceive the physical, mathematical, economic, and technological foundations of complex technical processes in a holistic way [3].

**Integration with physics and mathematics.** The theoretical foundations of technical disciplines are, first and foremost, related to physics and mathematics. For example:

- In an electronics course, when studying Kirchhoff's laws, the student primarily relies on mathematical tools such as systems of linear equations and the basics of integral and differential calculus.
- The operating principle of light-emitting diodes (LEDs) is connected with the theory of semiconductors in physics, based on concepts such as energy bands and electron recombination.
- When studying generators and transformers, it is necessary to understand electromagnetic induction, magnetic field lines of force, and mathematical models of sinusoidal waves [4].

**Integration with informatics** modernizes technical education:

- The use of software tools such as Multisim, Proteus, and MATLAB/Simulink deepens mathematical modeling.
- Projects developed on Arduino and Raspberry Pi platforms are integrated forms of informatics, electronics, and automation.
- Processes such as circuit simulation, signal analysis, and plotting graphs using a computer are closely linked to informatics.

### **Integration with Information Technologies**

Integration with information technologies has become an integral part of technical education. Modern laboratories make it possible to:

- Safely, quickly, and accurately model real processes by means of virtual simulators (NI Multisim, LabVIEW, CircuitLab);
- Simplify complex experiments through the use of computer models;
- Exchange data between real devices and a computer through Data Acquisition (DAQ) systems;

- Conduct remote experiments using IoT devices;
- Create three-dimensional laboratory environments using AR/VR technologies.

### Integration with Economic and Technological Disciplines

A technical specialist must know not only how a device operates but also its economic efficiency and its relationship with technological processes in production. Therefore, integration is carried out in the following directions (Table 1).

Table 1 Directions of integration with economic and technological disciplines in technical education

Direction of integration	Content of integration and types of learning activity in this direction
Energy-efficient technologies	In calculating the economic efficiency of energy-efficient technologies, integration is achieved not only with physics and engineering but also with economics. Students learn to calculate indicators such as energy consumption, cost price, and payback period.
Design of electronic devices	When designing electronic devices, the selection of materials, determination of device cost, and assessment of technological expenses require integration between technological disciplines (materials science, production technology) and economic disciplines (economic analysis, management).
Automated production lines	When studying automated production lines, technological processes, economic efficiency (labor productivity, production cost, defect rate), as well as safety regulations are considered together. Students acquire the ability to analyze technical, economic, and safety requirements in an integrated way.

**Didactic Results of Integration.** Interdisciplinary integration prevents the fragmentation of knowledge in technical disciplines. On the contrary, it organizes the learning process in a holistic, logical, and systemic manner. As a result, students develop competences such as:

- the ability to analyze complex technical problems;
- the ability to apply knowledge from several disciplines simultaneously;
- the ability to integrate theoretical knowledge into practice;
- the ability to solve problems based on an innovative approach;
- design and modeling skills.

As an example, the interdisciplinary integration involved in designing an IoT-based smart irrigation system can be considered (Table 2).

Table 2 Designing an IoT-based “Smart Irrigation System”

Discipline	Elements of interdisciplinary integration
Physics	Soil moisture; water pressure; evaporation rate
Mathematics	Regression model based on soil moisture; optimization of water consumption; plotting graphs
Electronics	Moisture sensor; water pump; valves; connection of microcontroller (ESP32/Arduino)
Informatics	Remote monitoring; sending data to the cloud; control via Telegram bot
Technology	Design of the drip irrigation system; water supply mechanism

As can be seen from the example, teaching based on integrated laboratories develops a number of competences in students. An interdisciplinary approach serves to systematically develop the following competences [6]:

- Technical and professional competence – working with real circuits, taking measurements, adjusting and debugging, identifying faults, working with technical documentation;
- Information and communication competence – working with software packages, simulators, IoT platforms, cloud services, and presenting results in digital format;
- Research competence – identifying problem situations, formulating hypotheses, designing experiments, collecting data, performing statistical analysis, and drawing conclusions;
- Creative and innovative thinking competence – improving existing technical solutions, proposing ideas for new devices, and creating prototypes;
- Communicative and collaboration competence – working in teams, defending one's ideas, exchanging views with peers, and jointly implementing projects;
- Economic and technological competence – calculating project cost, assessing energy efficiency, and taking into account production technology and safety standards.

The introduction of an interdisciplinary approach based on the integration of digital and real laboratories elevates the quality of teaching technical disciplines to a new level. Such integration prevents technical knowledge from splitting into separate blocks and helps to master it in a systemic and holistic way. Students learn to analyze real technical processes from the perspectives of physics, mathematics, informatics, economics, and technology. As a result, they develop high-level professional and research competences such as applying theoretical knowledge in practice, solving complex technical problems through creative approaches, and independently organizing project and research work. In addition, the synergy of digital and real laboratories effectively integrates traditional, distance, and hybrid forms of education, making the learning process flexible, learner-centered, and innovative in content. Based on the results of this study, it is advisable to develop several scientific and practical directions in the future. First of all, it is necessary to design specialized integrated laboratory modules for various technical fields such as energy, automation, telecommunications, and mechatronics, and to introduce them into the educational process step by step. It is also important to pilot and test the concept of an “extended laboratory” that directly links AR/VR technologies with real laboratories, and to study in depth, through digital analytical platforms, factors influencing students' technical creativity and start-up activities. Furthermore, the development of unified competence-based criteria and diagnostic methods to assess the effectiveness of integrating digital and real laboratories, and their experimental implementation at the level of educational institutions, will contribute to the modernization of technical education. In this way, an integrated laboratory environment emerges as an important condition for training competitive, innovative-minded technical specialists.

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