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PEDAGOGICAL EFFECTIVENESS OF ORGANIZING LABORATORY SESSIONS FOR THE COURSE “COMPUTER NETWORKS” USING VIRTUAL LABORATORIES

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Abstract. This article analyzes the pedagogical effectiveness of organizing laboratory sessions for the "Computer Networks" course in higher education institutions using virtual laboratories (simulation and emulation software such as Cisco Packet Tracer, GNS3, and EVE-NG). The study presents a comparative analysis of learning outcomes, students' independent work skills, and their interest in the subject between experimental and control groups. The results demonstrated that the use of virtual laboratories significantly improves the quality of the educational process.

Keywords: virtual laboratory, computer networks, pedagogical effectiveness, simulation software, distance learning, Cisco Packet Tracer, GNS3, practical skills.

Introduction

The progress of modern society is unimaginable without digital technologies. The rapid development of information and communication technologies is shaping new pedagogical approaches within the education system. Today, enhancing teaching effectiveness and delivering knowledge through visual and interactive formats—by integrating virtual and digital technologies into the educational process—is a priority task.

In recent years, the rapid advancement of information and communication technologies has necessitated a fundamental overhaul of teaching methodologies in higher education. In technical fields—specifically in the teaching of the "computer networks" course—practical and laboratory sessions are crucial for a deep understanding of the subject matter. However, organizing traditional laboratory sessions presents several challenges: a shortage of expensive networking equipment (such as routers and switches), students' fear of making errors during equipment configuration, time and resource constraints, and—particularly in remote learning environments—the inability to physically access real laboratories.

To address these issues, virtual laboratories—tools that simulate or emulate network environments using software (such as Cisco Packet Tracer, GNS3, EVE-NG, Mininet, etc.)—are being widely adopted as an alternative solution. Such tools enable students to conduct experiments—in unlimited numbers, at any time, and from any location—without the risk of damaging actual hardware.

The aim of the study is to determine the impact of organizing "Computer Networks" laboratory sessions using virtual laboratories on students' knowledge quality, practical skills, and interest in the subject, as well as to substantiate the pedagogical effectiveness of this approach.

The research objectives are as follows:

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1) to develop a methodology for integrating virtual laboratories into the educational process;

2) to conduct a comparative study between experimental and control groups;

3) to perform a statistical analysis of the obtained results;

4) to formulate practical recommendations based on identifying the advantages and disadvantages of virtual laboratories.

Main part

Lessons organized using digital technologies elevate the educational process to a qualitatively new level. The use of computers, internet technologies, electronic whiteboards, and smart panels enables the presentation of educational materials in a visual and accessible manner. When virtual technologies are systematically integrated into the lesson process, students' comprehension of the subject matter and their retention of knowledge improve significantly.

Digital Technologies in Education

This article substantiates the didactic effectiveness of using virtual technologies in the educational process based on the author's approach. In particular, virtual laboratory sessions offer advantages over traditional laboratory work by ensuring safety, conserving material resources, and enabling the modeling of complex processes. These factors play a crucial role in developing students' practical skills. Furthermore, sessions based on virtual, digital, and internet technologies foster independent learning and the development of students' knowledge, skills, competencies, and experience. Through electronic tests, interactive assignments, and virtual projects, students cultivate the ability to independently acquire knowledge, analyze information, and draw conclusions. Such an approach increases students' interest in the subject and ensures their active participation in the learning process.

In this regard, as the President of our country, Shavkat Mirziyoyev, has emphasized, mastering digital knowledge and modern information technologies is essential for achieving progress. This offers us the opportunity to take the fastest path to advancement, given that information technologies are currently deeply penetrating every sector worldwide.

In the era of digital technologies, the primary focus is on enhancing the quality of education.

Consequently, whether the session involves a lecture, a practical exercise, or a laboratory class, there is a clear need to utilize digital technologies, computers, and modern pedagogical methods.

Does the integration of digital information technologies into the educational process actually impact the quality of instruction? Is it truly necessary to use computers during lessons? Must professors and teachers—who have long made effective use of traditional textbooks, study guides, and other teaching aids—now study and master these new pedagogical technologies?

It is evident today that the strategic development of the education system hinges on addressing the challenges of learner-centered education; ultimately, the core of this endeavor is the process of imparting knowledge. To effectively address emerging shortcomings in students through a rational and appropriate approach, a teacher must be able to make an accurate assessment—meaning it is essential

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to understand the students' characters as fully as possible. Accomplishing this and similar tasks is far more complex than traditional teaching methods, requiring a very high level of professional competence and skill from the teacher.

Using digital information technologies in the classroom is not merely an end in itself; rather, it is a way to connect with the world of young people, a means to provide more comprehensive information, an advanced approach to teaching and learning, and a method to broaden students' horizons and foster their active engagement in independent learning. We live in an era of rapid and intensive scientific and technological progress. Consequently, it is essential for educators to keep pace with the times and embrace these digital technologies.

Integrating computers into the lesson creates unique advantages for both teachers and students, particularly through the use of interactive educational resources. Linking computers with other modern digital tools—such as virtual laboratories, electronic whiteboards, and smart panels—enhances the volume of information conveyed through visual aids, thereby enabling teachers to make more efficient use of class time. Integrating elements of computer technology into the lesson process adds variety to the educational experience, saves students from boredom, elevates the quality of instruction to a new, higher level, ensures access to high-quality learning materials, fosters personal development, cultivates the creative potential and cognitive engagement of both students and teachers, and boosts their interest in learning and life. The use of computers in the classroom yields the most effective results in specific scenarios. In particular, observations and analyses indicate that students' knowledge retention is significantly higher in classes utilizing digital technologies compared to traditional lessons.

Explaining unfamiliar terms and concepts through visual aids when introducing new material enhances students' comprehension of the topic. Higher rates of topic mastery are observed in lessons that employ presentations and multimedia tools.

Utilizing electronic exercises and interactive tasks to reinforce theoretical knowledge positively impacts long-term retention. Such an approach also leads to a reduction in errors made by students.

Conducting virtual laboratory experiments during practical and laboratory sessions ensures safety while saving time and material resources. Groups utilizing virtual laboratories demonstrate higher rates of task completion.

The use of electronic educational resources in organizing independent study boosts students' engagement in self-directed learning. Many students report that digital educational tools heighten their interest in independent study.

Using computerized testing systems for knowledge assessment ensures transparency and speed in the evaluation process. Automated assessment significantly minimizes subjective errors.

The use of digital tools in projects and presentations fosters the development of students' analytical and creative thinking skills.

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The most important aspects here are the concise summary of the lecture and the use of visual aids. While displaying presentation slides, the instructor can show various images, formulas, and graphs, and have students take down notes that are brief and to the point. This allows students to visually see the concepts they are simultaneously hearing about. It is well known that a significant portion of information is acquired visually. Using computer-based electronic tests to summarize, reinforce, and thoroughly master the material helps students develop the necessary skills and proficiency in the subject. It also fosters an interest in new computer programs. Utilizing computers during ongoing, interim, and final assessments yields excellent results; for instance, test questions can be displayed on a monitor using multimedia elements, which sparks student interest in this method of assessment. Conducting virtual laboratory experiments prevents exposure to harmful or dangerous risks and helps save time. Computers also play a significant role in students' scientific research activities. For instance, as a project assignment, students might be tasked with developing an effective and engaging method for creating presentations on a specific topic or preparing virtual laboratory exercises. To do this, they must first study the subject in depth and gather relevant materials; subsequently, they synthesize this information, incorporate images, graphs, and tables, and enhance the presentation with various animations and effects. This process fosters the development of skills and techniques for interacting with computers.

Research methodology

The study was conducted during the 2025–2026 academic year involving second-year students majoring in "Computer Engineering" at a higher education institution. A total of 122 students participated and were randomly assigned to two groups: the experimental group (62 students), where laboratory sessions were conducted entirely using virtual laboratories (Cisco Packet Tracer and GNS3); and the control group (60 students), where sessions were held using traditional methods based on actual hardware and theoretical assignments.

The study was carried out in three stages. In the first stage, an identical entry test (diagnostic assessment) was administered to both groups to determine their initial level of knowledge. In the second stage, spanning a 12-week instructional period, the experimental group performed practical tasks—such as designing network topologies, configuring routing, and setting up VLANs and firewalls—within a virtual environment, while the control group studied the same topics using traditional methods. In the third stage, a final (exit) test was administered to compare the results of both groups, and a survey was conducted among the students in the experimental group.

Descriptive statistics (mean, standard deviation) and the Student's t-test for two independent samples were used for data analysis (significance level $p<0.05$). Survey results were collected using a 5-point Likert scale and expressed as percentages.

Results

No statistically significant difference was found between the two groups based on the results of the initial test (mean score of 58.4 in the experimental group and 57.9 in the control group; $p > 0.05$), confirming that the groups had an equivalent initial level of preparation. The results of the final test, conducted after 12 weeks of training, are presented in the table below.

Group	Number of students	Average score (entry)	Average score (exit)	Growth, %

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Experimental (VL)	62	58,4	84,1	+44,0
Control (traditional)	60	57,9	69,3	+19,7

Table 1. Pre-test and post-test results for the experimental and control groups

As shown in the table, the proficiency level increased by 44.0% in the experimental group and by 19.7% in the control group. The difference between the groups is statistically significant ($t=4.86$; $p<0.01$), confirming that the use of virtual laboratories had a positive impact on learning outcomes.

The results of a survey conducted among students in the experimental group revealed their attitudes toward virtual laboratories:

Indicator	**Satisfied, %**	**Dissatisfied, %**
Increased interest in the subject	87	13
Improved independent working skills	82	18
Opportunity to experiment without fear of making mistakes	91	9
Fully replaces working with real equipment	34	66

Table 2. Results of the student survey on virtual laboratories

According to the survey results, the majority of students (87%) report that virtual laboratories increased their interest in the subject, 82% note an improvement in their independent work skills, and 91% highly value the opportunity to conduct experiments freely without the fear of making mistakes. At the same time, only 34% of students believe that virtual laboratories can fully replace working with real equipment—indicating the need for a combined approach that integrates virtual and real environments.

Discussion.

The results indicate that virtual laboratories offer high pedagogical effectiveness in teaching the "Computer Networks" course. Several factors contribute to this: firstly, the virtual environment allows students to reconfigure routers and switches as often as they wish without the fear of making mistakes, thereby fostering the solid development of practical skills. Secondly, virtual laboratories are not constrained by time or location, enabling students to practice independently outside of scheduled classes, including remotely. Thirdly, given the high costs associated with purchasing and maintaining real network hardware, virtual laboratories are also economically advantageous for educational institutions.

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At the same time, the research findings revealed certain limitations of virtual laboratories. Specifically, one-third of the students noted that the virtual environment cannot fully replicate the experience of working with actual hardware; this is attributed to the fact that skills such as physical cabling, measuring signal levels, and troubleshooting real equipment malfunctions can only be developed in a real-world setting. Therefore, it is recommended to use virtual laboratories not as a complete substitute for real laboratory sessions, but rather as a complementary and preparatory stage; in other words, it is advisable to implement a blended approach based on the principle of "virtual first, then real."

These results align with the findings of other researchers: the use of simulation and emulation tools helps enhance students' cognitive engagement and motivation in technical education; however, to ensure the full development of practical technical skills, these tools must be used in conjunction with real-world practice.

Conclusion

The study confirmed that organizing laboratory sessions for the "Computer Networks" course using virtual laboratories yields high pedagogical effectiveness: the mastery level in the experimental group was significantly higher than in the control group, and students' interest in the subject and their independent work skills improved. Based on these findings, the following recommendations are proposed:

1. Systematically integrate virtual laboratory tools, such as Cisco Packet Tracer and GNS3, into the "Computer Networks" curriculum;

2. Implement a blended learning model that combines virtual and physical laboratory sessions;

3. Organize professional development courses and develop methodological guides for instructors on the use of virtual laboratory tools;

4. Expand the database of virtual laboratory assignments for independent student practice and ensure remote access capabilities.

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