Impact of Virtual Laboratories on the Development of Research Competence in Students of Technical Specialties

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Abstract: - The purpose of this study is to examine the peculiarities of the impact of virtual laboratories on the development of research competence in higher education students. The study employed a research experiment, testing, and expert assessment methods. Statistical analysis was performed using the Mann-Whitney U test, Pearson's coefficient, and correlation analysis. The reliability of the method was verified using Cronbach's alpha. In the control group (CG), a higher average score was observed for the application of scientific methods, and the ability to conduct experiments and process results, compared to the experimental group (EG). On average, in the CG, the application of scientific methods was assessed at 17 points, while in the EG – at 9 points. The CG also showed a higher assessment of teamwork compared to the EG. However, the average scores for this indicator were the same in both groups and amounted to 11. The results of the study show that the use of virtual laboratories significantly increases research competence. This is due to the creation of a favorable educational environment and the provision of modern working tools for students.

Key Words: - educational environment, professional competencies, skills, higher education, virtual laboratories, skills development, innovative technologies, technical specialties.

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1 Introduction

Virtual laboratories represent a new approach to learning, enabling students to conduct experiments and research within a simulated environment that would often be inaccessible or expensive in the real world. This innovation fosters critical thinking, practical skills, and problem-solving abilities in complex technical domains, all without risking expensive equipment or materials. Let's delve deeper into how virtual labs enhance the research capabilities of engineering students. Undoubtedly, education should prioritize fostering autonomy and self-actualization, with the ultimate goal of intellectual growth, including the ability to analyze, synthesize, and reflect.

Accordingly, the development of research skills and the ability to independently set and solve research tasks are becoming an important direction of modern education, [1]. In this regard, the methods of developing research competencies of future specialists are also changing, [2]. The introduction of virtualization and simulation elements into the educational process for the formation of research competencies of a specialist, which determine the essence of all types of professional activity, is becoming increasingly important, [3].

Laboratory classes in the process of forming research competencies of students are an integral part of the educational process, [4]. They provide practical experience that allows you to master the necessary skills when working with real equipment. Unfortunately, the equipment necessary for practical laboratory work is not always available. Therefore, the problem of training and improving the quality of students' knowledge is attracting more and more attention, [5]. One of the most effective and generally recognized methods of teaching students today is considered to be virtual laboratory complexes, consisting of modeled virtual components, [6].

Thus, the *relevance of this study* is the need to form research competence in students, which essentially helps to navigate research activities and achieve the set goals. The existing shortcomings are explained by the existence of objective contradictions: between the social demand for the training of a highly qualified specialist, who is ready to perceive the new, advanced, and independently determine their professional prospects, and traditional forms and methods of higher education that do not meet the new requirements for training specialists at a high level, [7].

Given the identified contradictions, the research problem was formulated to investigate the educational conditions that contribute to the development of research competence among higher education students. The need for a deeper theoretical and practical study of this problem, and the inadequacy of its solution determined the main focus of the study. Therefore, investigating how virtual laboratories influence the development of research skills among engineering students is a crucial step in enhancing the effectiveness of education and preparing competitive professionals for today's technologically advanced world.

The aim of this article is to explore how virtual laboratories influence the development of research competencies among engineering students in higher education institutions during the learning process.

1.1 Tasks/Questions

1. To analyze the formation of research competence.
2. To study the satisfaction of the educational environment.
3. To explore the correlation between the development of research competence and satisfaction with the educational environment in higher education institutions.

2 Literature Review

2.1 Definition of Research Competence in Scientific Literature

Before considering the problems of forming research competence in students, it is necessary to refer to the term "research competence". Having understood its essence and content, it is possible to make the necessary conclusions. During the analysis of psychological and pedagogical literature, it was found that there is no general and specific formulation of the concept of "research competence". The structure of research competence can be depicted as a complex combination of knowledge, skills, abilities, and personal qualities necessary for successful research (Figure 1).

Research competence, as defined by [8], is the propensity and skills related to studying and assessing scientific literature. Authors, [9], define research competence as the ability that characterizes the process and result of creative intellectual and research-project activity. The study by [10], notes that research competence is a personal quality, a complex ability to objectively assess problems, and transform them into specific tasks, based on the skills to conduct research work. In the understanding of [11], research competence should be understood as knowledge, ideas, programs of action, value systems, and relationships, which are then manifested in research competence in activity-based, actual manifestations. Researcher, [12], sees research competence as a personal quality, a set of knowledge, value orientations, needs, and experience of research activity, which is manifested in the readiness and ability to perform the functions of its subject.

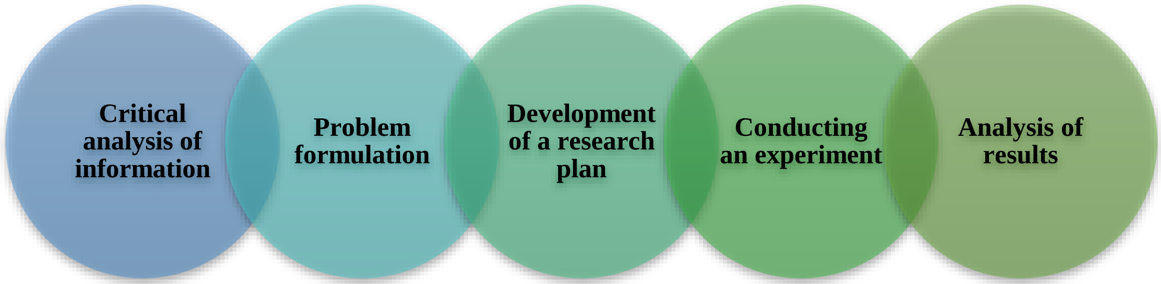

Fig. 1: Structure of Research Competence
Source: Created based on [8]

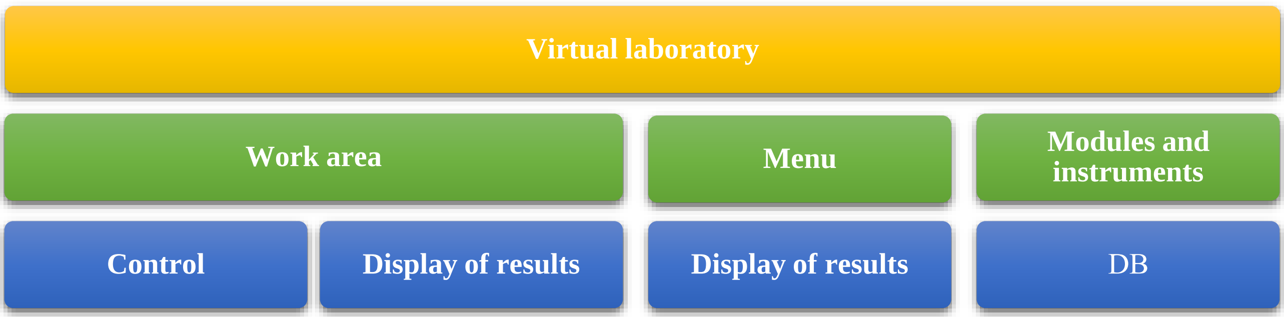

Fig. 2: Structure of a Virtual Laboratory
Source: Created based on [16]

Author, [13], understands research competence as a set of personal characteristics: value-semantic orientations, personal qualities, knowledge, research skills and abilities, and experience of well-known and creative ways of research activity in order to solve professional tasks.

2.2 Modern View of Virtual Laboratories

As noted, in [14], a virtual laboratory is a sophisticated program that enables experiments not feasible in a real laboratory environment. These virtual laboratories allow students to learn remotely at any time. Additionally, as mentioned, [15], this software reduces the costs of real laboratory resources and minimizes the risk of negative consequences associated with failed experiments or the improper use of materials, reagents, or instruments during training. In Figure 2, each block reflects the main components of a virtual educational laboratory, such as the user interface, workspace, modules and tools for experiments, display of results, as well as additional functions such as saving and settings.

A virtual laboratory can be defined as a computer-generated environment that allows users to engage in realistic experiments. This technology has numerous applications, particularly in the training and education of professionals, [17]. As noted, in [18], an optimal approach to teaching laboratory procedures combines didactic methods, including theoretical instruction, the use of virtual technologies, and subsequent reinforcement of acquired competencies and skills in authentic laboratory settings. This combined approach allows students to become familiar with theoretical material, procedures, and the specifics of conducting experiments on complex equipment in advance. Students of physics, mathematics, and engineering disciplines must be equipped with the necessary competencies to effectively fulfill their future roles. During their studies, students should develop an intuitive understanding of the physical and functional aspects of working with virtual laboratories. Based on this, virtual laboratories are an integral part of any technical discipline. Additionally, access to physical laboratories is often limited by cost and equipment availability.

2.3 Under-Researched Issues

Despite the widespread coverage of this issue in the scientific literature in recent years, the relevance of further research and clarification remains. One such issue is the study of the effectiveness of different methods of using virtual laboratories for the development of the research competence of students. While there is research on the impact of virtual laboratories on academic outcomes and student motivation, less attention has been paid to their impact on the development of specific research skills and critical thinking.

3 Methods

3.1 Design

The effectiveness of this study is evaluated using qualitative and quantitative indicators. During the observations, these indicators are measured, compared, and analyzed. Further research includes the interpretation of the obtained data. The research process went through several stages, which can be seen in Table 1.

Virtual laboratories were used in the study, the main tool of which was the MATLAB software package. It was implemented into the educational environment through the use of special teaching materials and textbooks with practical tasks, as well as through lectures and practical classes using this software. Students were given the opportunity to independently study and complete various tasks using MATLAB, which contributed to their professional development and deepened their understanding of the material.

3.2 Participants

The experimental research was carried out on the basis of the Department of Automation and Computer-Integrated Technologies of Cherkasy National University named after Bohdan Khmelnytsky, the Educational and Scientific Institute of Retraining and Advanced Training of the Mikhail Drahomanov National Pedagogical University, the Department of Technical and Technological Disciplines, Occupational Safety and Health of the Uman State Pedagogical University named after Pavlo Tychyna, the Department of Computer and Software Engineering of the Mikhail Drahomanov National Pedagogical University, the Department of Physics, Electrical Engineering and Power Engineering of the Faculty of Energy and Automation of the Ukrainian Engineering and Pedagogical Academy, Kharkiv, Ukraine. The study involved 398 students of the II-III courses. The sample was formed using stratified sampling using the method of randomized selection of students. The main criterion for inclusion/exclusion was voluntary consent to participate in the experiment.

The experimental work covered students of 22 academic groups, the age of students is from 18 to 21 years old, of whom 82% are men, and 18% are women. The number of each of the groups is from 20 to 25 people. The total general population was 519 people. 130 people did not agree to participate in the study. The selected respondents were divided into two groups: experimental (EG) and control (CG). The research was conducted in accordance with generally accepted ethical norms. Each respondent provided consent for the processing of their personal data and the publication of the research results. This sampling method ensures the reliability of the data obtained.

3.3 Instruments

The functionality of Google Forms was used to conduct the survey. The collected data was processed and analyzed using the software "Microsoft Excel" and "SPSS Statistics 18.0". All results are presented in relative terms (% of the total number of respondents). To organize virtual laboratory work, the MATLAB system was used - an interactive environment for numerical calculations and programming, which is widely used in scientific, technical, and engineering disciplines.

Table 1. Stages of Research on Gamification of the Formation of the Readiness of HES for Self-Realization

No	Phase	Duration	Research Phase Content
1	Stating Stage	February 2023	Defining the goals and objectives of the research. Forming the control and experimental groups from among the students. Selection of tools and research methods. Conducting initial testing.
2	Formative Stage	September 2023 – December 2023	Implementing pedagogical conditions for the introduction of virtual laboratories in the study of mathematical analysis, theoretical mechanics, applied mechanics, and general physics (for the experimental group) and traditional laboratories (for the control group). Studying the formation of research competence. Studying the satisfaction with the educational environment. *Conducting statistical processing of the obtained results.* Formulating conclusions based on the obtained results.
3	Final Stage	January 2024	Processing the research results. Summarizing the findings.

Source: Created by the authors

3.4 Data Collection

1. Research experiments in virtual and real laboratories. Participation in research in laboratory conditions is an important part of the development of research competencies of students. Conducting research in virtual or real laboratories allows you to identify: the application of scientific methods, the ability to conduct scientific research, data processing, and teamwork.

2. Educational Environment Trust Scale – (EETS). This test was developed by researchers at the University of Illinois. EETS consists of 18 statements that assess students' trust in their teachers, peers, and the educational environment as a whole, [19].

3. Expert assessment method. Thanks to the use of this method, it was possible to confirm the reliability of the obtained data. In addition, this approach facilitated a more detailed analysis of the effectiveness of using virtual laboratories in the educational process. The expert group was formed from among the teachers of the mentioned departments in the amount of 12 people. All experts have scientific degrees of Doctor of Science and work experience of more than 20 years.

3.5 Analysis of Data

1. The Alpha-Cronbach reliability coefficient characterizes the internal consistency of the test tasks. In studies examining the impact of virtual laboratories on the development of research skills in engineering students, it is crucial to evaluate the reliability of the instruments used for data collection. The Alpha-Cronbach coefficient is calculated using the formula:

$$\frac{N}{N-1}\left(\frac{\sigma_x^2-\sum_{i=1}^{N}\sigma_{Y_i}^2}{\sigma_x^2}\right), \quad (1)$$

σ_x^2 – the variance of the total test score;;
$\sigma_{Y_i}^2$ – the variance of element i.

2. Calculation of the Mann-Whitney U statistic is given by the formula, [20]:

$$U = (n_1 \times n_2) + (n_x \times (n_x+1)/2) - T_x; \quad (2)$$

n_1 – the number of respondents in the experimental group;
n_2 – the number of respondents in the control group;
T_x – the larger of the two rank sums;
n_x – the number of respondents in the group with the larger rank sum.

3. Correlation analysis. Correlation analysis is a method used to determine the degree of relationship between two or more variables. The main goal of correlation analysis is to determine how much a change in one variable can affect a change in another. The coefficient r is determined by Pearson's formula:

$$r = \frac{n(\sum XY)-(\sum X)(\sum Y)}{\sqrt{[n\sum X^2-(\sum X)^2][n\sum Y^2-(\sum Y)^2]}}, \quad (3)$$

N – the number of observations,
$\sum$ – the sum of all values,
X and Y – are the values of the two variables.

Correlation analysis is used to examine the relationships between two or more variables. It helps determine how changes in one variable are related to changes in another, especially when studying the impact of virtual laboratories on the development of research skills in engineering students. This approach allows us to draw conclusions about the presence and strength of relationships between different aspects of the studied process.

4 Results

To assess the reliability of the methodology, Cronbach's alpha coefficient will be used. This coefficient measures the internal consistency of the scale items. According to Table 2, a Cronbach's alpha value of 0.7-0.9 is considered reliable.

The results indicate that both methods (research experiments in virtual and real laboratories and the Educational Environment Trust Scale (EETS)) have high reliability, as the Cronbach's alpha coefficients for them are above 0.7. This means that the items of these methods are consistent and give similar results, which confirms their reliability for assessing students' research competencies.

Table 2. Reliability Assessment of Research Methods using Cronbach's Alpha Method

Method	Number of Items	Cronbach's Alpha Coefficient
Research experiments in virtual and real laboratories	4	0.82
Educational Environment Trust Scale (EETS)	18	0.88

Source: Compiled based on the research results

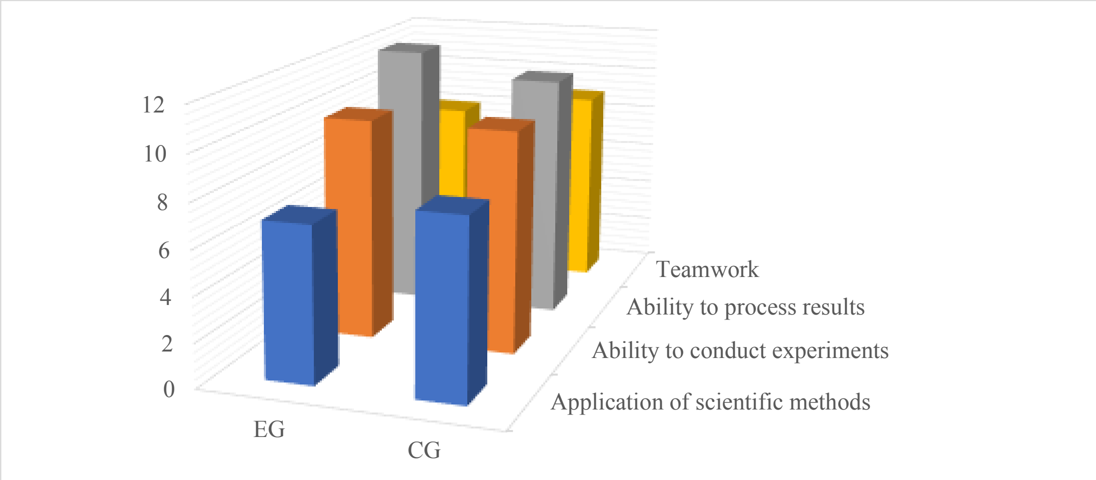

Fig. 3: Comparative Diagram of the Levels of Formation of Research Competence of Respondents of the CG and EG at the Beginning of the Experiment
Source: Compiled based on the research results

Table 3. Statistical Analysis of the Formation of Research Competence of Respondents of the CG and EG at the Beginning of the Experiment

Skill	p-value	Conclusion
Application of scientific methods	0.42	No statistical significance
Ability to conduct experiments	1.00	No statistical significance
Ability to process results	0.64	No statistical significance
Teamwork	0.56	No statistical significance

Source: Compiled based on the research results

Before the start of the study, at the diagnostic stage, a study of the formation of research competencies in students of both groups was conducted. The general results of the diagnostics of the formation of the block of research competencies at the beginning of the study are reflected in Figure 3.

Analyzing the diagram, it can be found that the average scores of the levels of development of digital competence in the respondents of both groups - EG and CG - are quite similar. In each of the four indicators (application of scientific methods, the ability to conduct scientific research, data processing, and teamwork), the average score in the CG group is almost or exactly the same as in the EG group. The comparative diagram confirms this similarity in the levels of competence between the two groups, which is proven by the statistical analysis presented in Table 3.

According to Table 3, no statistical differences were found, which indicates equal conditions at the beginning of the experiment. P-values for all four skills are above 0.05, indicating that there is a low probability that the observed differences are the result of anything other than chance. The same method was applied at the end of the pedagogical experiment. Its results are reflected in Figure 4.

As shown in the diagram, there are noticeable differences between the CG and EG indicators. The EG indicators have increased significantly due to the effective use of the virtual laboratory. The results indicate that, compared to traditional methods and procedures, the development of research competencies using modern educational technologies, particularly virtual laboratories, is more successful. Table 4 presents a statistical analysis. Based on the data provided in Table 4, it can be concluded that there are statistically significant differences in three of the four listed skills between the two groups (EG and CG). This may indicate the effectiveness of using virtual laboratories in the formation of research competencies.

Further research focused on analyzing the attitude of students from the EG and CG groups to the learning environment. The level of comfort that students feel was determined using the EETS. The results are presented in Table 5.

The analysis of the data presented in the table shows that the average values of most indicators (trust in peers, trust in teachers, perception of fairness of rules, sense of belonging, and perception of teacher support) are higher in the EG than in the CG.

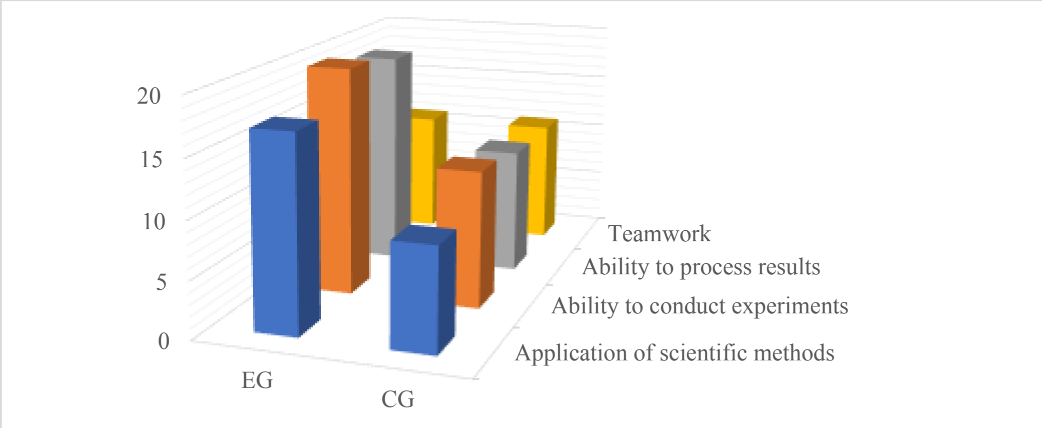

Fig. 4: Comparative Diagram of the Levels of Formation of Research Competence of Respondents of the CG and EG at the End of the Experiment.

Source: Compiled based on the research results

Table 4. Statistical Analysis of the Formation of Research Competence of Respondents of the CG and EG at the Beginning of the Experiment

Skill	p-value	Conclusion
Application of scientific methods	0.001	No statistical significance
Ability to conduct experiments	0.003	No statistical significance
Ability to process results	0.002	No statistical significance
Teamwork	1.00	No statistical significance

Source: Compiled based on the research results

Table 5. Results of the Analysis of the Attitude of Students from the EG and CG Groups to the Learning Environment

EETS Subscale	CG (200)	Mean Value	EG (198)	Mean Value	p-value (Mann-Whitney U coefficient)	p-value (Pearson's chi-squared test)
Trust in peers	50	3.2	50	3.6	0.03	0.02
Trust in teachers	50	3.8	50	4.1	0.01	0.01
Perception of the fairness of rules	50	3.4	50	3.7	0.02	0.01
Sense of belonging	50	3.5	50	3.8	0.01	0.01
Perception of support from teachers	50	3.7	50	4.0	0.01	0.01

Source: Compiled based on the research results

Table 6. Assessment of the Relationship between Attitude to the Learning Environment and Research Competencies

Mann-Whitney Skill	Control group (CG)	Experimental Group (EG)	Pearson Correlation Coefficient (CG)	Pearson Correlation Coefficient (EG)	p-value (CG)	p-value (EG)
Application of scientific methods	17	9	0.42	0.65	0.07	0.001
Ability to conduct experiments	20	12	0.38	0.72	0.09	0.001
Ability to process results	19	11	0.41	0.68	0.06	0.001
Teamwork	11	11	0.02	0.05	0.92	0.82

Source: Compiled based on the research results

Additionally, the statistical significance of the difference was demonstrated using both methods of assessing p-values (Mann-Whitney U test and Pearson's chi-squared test), emphasizing the importance of these differences between groups. For example, the p-value > 0.05 for all indicators indicates the statistical significance of the difference between the groups. This suggests that EG students have a more positive attitude towards the learning environment than CG students. To assess the relationship between attitudes towards the learning environment and research competencies, Pearson's correlation coefficient will be used. The results are presented in Table 6.

In the control group, there is a moderate positive correlation between attitude towards the learning environment and the application of scientific methods (Pearson correlation coefficient 0.42) with a p-value of 0.07, which is close to being statistically significant. In the experimental group, the correlation is stronger (0.65) and statistically significant (p=0.001), indicating a substantial positive influence of the learning environment on this competence. A similar situation is observed with the ability to conduct experiments: in the control group, the correlation is 0.38 (p=0.09), and in the experimental group, it is 0.72 (p=0.001), indicating a significant positive influence of virtual laboratories. The ability to process results showed a correlation of 0.41 in the control group (p=0.06) and 0.68 in the experimental group (p=0.001), again confirming the higher level of competencies in the experimental group. Teamwork did not show significant correlations in either group: in the control group, the correlation coefficient is 0.02 (p=0.92), and in the experimental group, it is 0.05 (p=0.82). This suggests that attitudes towards the learning environment do not have a significant impact on this competence.

Analyzing Table 6, the following conclusions can be drawn. Application of scientific methods and the ability to conduct experiments show a moderate positive correlation with the attitude to the learning environment for both the control and experimental groups. The Pearson correlation coefficients for the experimental group are higher, which indicates a stronger relationship between research competencies and attitude to the learning environment in this group. The ability to process results also shows a moderate positive correlation with the attitude to the learning environment, but the correlation coefficients for both groups are lower than in the case of scientific methods and experiments. As for teamwork, it can be seen that it has an insignificant, practically insignificant relationship with the attitude to the learning environment in both groups. The correlation coefficients for this skill are very low. The p-values for the experimental group are in most cases lower than for the control group, which confirms the statistical significance of the obtained correlation relationships in the experimental group.

5 Discussion

As this study shows, modern virtual laboratories are complex systems that are built on the basis of many information technologies (data transfer protocols, software, etc.). Along with the development of information technologies, virtual laboratories are also developing and improving. As noted, in [21], [22], an important stimulus for the development of virtual laboratories is the development of hardware capabilities. The increasing power of computers allows them to be loaded with a larger number of interacting software products, which in turn allows to reduce the number of computing machines required for the correct operation of the laboratory as a whole. It is the use of modern computing systems, as this study shows, that contributes to greater satisfaction with the educational environment, and, accordingly, to the growth of research competencies. This is noted in the works, [23], [24].

However, the discussion regarding the usefulness of virtual laboratories for developing research competencies remains unresolved. According to [25] and [26], the ultimate goal of a laboratory is to provide students with real-world practical experience that they can apply in the workplace.

In contrast, were emphasized the advantages of virtual laboratories in terms of their effectiveness, convenience, and cost but overlooked the main purpose of a laboratory: serving as an effective tool for transferring practical skills to students, [27], [28]. Moreover, [29], argues that during practical laboratory tasks, students may gain access to unplanned information, which was not initially included in the laboratory work. Another disadvantage of virtual laboratories is the lack of psychomotor development when using such tools. It is also noted that practical laboratories provide students with sensory and situational understanding that cannot be replicated in a virtual environment. Skeptics argue that the lack of real physical contact leads to a deficit in achieving key competencies necessary for working in real-world conditions.

Nevertheless, proponents argue that modern technologies contribute to the conceptualization of a virtual laboratory as a comprehensive replication of a real laboratory. Modeling is a dynamic representation of a natural or engineered system that allows students to interact with it, based on the implementation of mathematical or logical models in a computer environment using programming technologies. Virtual laboratories are, in essence, synthetic environments that promote interactivity and real-time feedback, as evidenced, by [30], [31]. These attributes make virtual laboratories an attractive option for any learning strategy involving practical skills training. Acquiring skills involves interaction with equipment and the working environment. Virtual laboratory work can be considered a form of practical training, as it provides students with the opportunity to either reinforce or acquire knowledge and skills through individual interaction.

The study has important theoretical significance, as it expands our knowledge in the field and reveals new relationships. In particular, it can identify gaps in existing theoretical models. Practically, the research results can be used to solve specific problems, improve processes, and make informed decisions in the real world. The research results can be used in the educational process of the research institutions in the creation of educational programs in technical disciplines aimed at the formation of high research competence in future specialists.

When conducting research, it is important to consider the following limitations that may affect its results and validity. It is important to consider the limitations of the scope of the study due to lack of time, money, and data availability. They can affect the results and make the study less complete or more complex. Sampling limitations are critical to consider, as they may affect the generalizability of findings and make them less accurate or representative of the wider population.

6 Conclusions

The relevance of the obtained data can be determined in view of the current state of education and technological progress. Knowledge of the effectiveness of these technologies becomes crucial given the growing use of virtual educational laboratories and their impact on the educational process. The obtained results demonstrate that virtual laboratories contribute to increased engagement in learning and the preparation of future specialists. They promote better visual perception of technical processes, reduce organizational costs, increase the scalability of the learning process, ensure objective assessment of performance, and facilitate collective teaching and methodological work. Therefore, virtual laboratories significantly contribute to the development of research competencies. Unlike the significant costs typically associated with creating real training laboratories, virtual laboratories offer increased flexibility and the ability to reproduce complex laboratory conditions.

The research results can be used to update and develop technical courses in higher education institutions. This will help prepare students for real challenges in the digital environment. In future research, it is worth considering the aspects of the impact of virtual laboratories on the formation of educational space.

The novelty of this research lies in its comprehensive analysis of the impact of virtual laboratories on the development of research competencies among engineering students within the context of modern education and technological advancements. Given the widespread use of virtual learning laboratories, this study provides new insights into their effectiveness and influence on the learning process, which is crucial for improving teaching methodologies.

The research findings not only confirm or refute the hypothesis about the benefits of virtual laboratories but also refine the methodology for their use and integration into the development of research competencies. These processes help to reduce organizational expenses, increase the scalability of the learning process, ensure objective performance evaluation, and facilitate collaborative teaching and methodological practices.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors utilized DeepL Write to enhance the readability and scientific accuracy of certain complex textual passages. The primary objective of this approach was to improve the text's comprehensibility and accessibility to a wider readership. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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