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Original Research

Virtual laboratories as a means of increasing accessibility of biological education in Ukraine

Volodymyr Sipii[1], Fedir Kurtiak [2], Ilona Mykhaliuk[3], Inna Hryhorchuk[4], Tetiana Zasiekina[5]

[1] Department of Biological, Chemical and Physical Education, Institute of Pedagogy of the National Academy of Educational Sciences of Ukraine, Kyiv, Ukraine

[2] Department of Zoology, Faculty of Biology, Uzhhorod National University, Uzhhorod, Ukraine

[3]Department of Biology, Ecology, and Methods of Teaching, Faculty of Physical Education and Biology, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy, Kremenets, Ukraine

[4]Department of Biology and Ecology, Faculty of Natural Sciences and Economics, Kamianets-Podilskyi Ivan Ohiienko National University, Kamianets-Podilskyi, Ukraine

[5]Institute of Pedagogy, National Academy of Educational Sciences of Ukraine, Kyiv, Ukraine

ABSTRACT

Research objective. The objective of the study was to investigate the impact of virtual laboratories on students' research skills while studying biology in a university environment. Applied research method. The research method used in the study was a research experiment in a virtual laboratory, the method of testing (EETS), and the method of expert evaluation. The statistical analysis was carried out using the Mann-Whitney criterion, Pearson's coefficient, and correlation analysis. The reliability of the method was tested by Cronbach's alpha. Main results. There is a positive correlation between the use of scientific methods and the ability to conduct experiments, as well as the attitude to the learning environment in both the experimental and control groups. The Pearson correlation coefficients were higher for the experimental group; this clearly indicates a stronger connection between their research skills and attitudes toward the learning environment. The ability to process results also has a small positive relationship with attitudes toward the learning environment. Major conclusions. The results of the study demonstrated the positive impact of using virtual laboratories in the study of biological disciplines.

Keywords: Biological education, simulation, augmented reality, innovative technologies, digitalisation.

Corresponding Author:

Volodymyr Sipii
Department of Biological, Chemical and Physical Education
Institute of Pedagogy of the National Academy of Educational Sciences of Ukraine
04053, Ukraine, Kyiv, st. Sichovyh Streltsiv, 52-D
E-mail: sipiy@ukr.net

1. Introduction

In today's world, the main aim of education should be to foster individual self-determination and establish an environment that encourages self-realization. This objective should be grounded in fostering intellectual development, particularly the ability to analyze, generalize, and reflect. These competencies are especially crucial in modern biological education. Thus, the cultivation of research skills and the capacity to independently identify and address research problems is emerging as a key focus in biological education in Ukraine [1-3]. In this regard, the methods of developing research competencies of future specialists are also changing [4]. It is extremely important to integrate virtualization and simulation into the educational process for the effective training of future biologists [5].

In the process of developing students' research skills, laboratory classes are an important part of their education. They offer hands-on experience that allows developing the skills necessary to work with real equipment. Unfortunately, the equipment needed to perform laboratory work in practice is not always available. Thus, the problem of improving the quality of students' knowledge is attracting increasing attention [6-8]. Virtual laboratory complexes consisting of modelled virtual components are currently designed to solve these issues [9].

For example, in the biological training of future professionals, the development of virtual laboratory practices for the study of rare species of animals and plants is crucial to ensure that these organisms are not removed from their natural habitats [10]. The use of ethical research methods is imperative when working with biological objects, and virtual laboratories serve as an invaluable tool in achieving this goal [11]. In the educational field, virtual laboratories offer unprecedented opportunities to study the fine structure of biological objects at an optimal scale for perception. They allow the use of computer animated models and improve emotional and cognitive understanding of complex processes and phenomena through visualization [12]. This approach makes it easier to study the material at the appropriate scale, making it easier for students to learn complex concepts.

Virtual laboratory workshops can be classified according to various criteria. The key factors in this classification are the development environment, the realism of virtual laboratories, the way of interacting with the model, the mathematical basis of modelling an object or phenomenon, and the availability of automatic verification of results [13]. It is worth mentioning the nature of the model, which plays an important role in determining how the laboratory is implemented:

a) A qualitative model characterizes phenomena or experiences that are difficult or impossible to reproduce in an educational institution, reproduced on the screen, allowing the user to control the experience [14].
b) The semi-quantitative model allows simulating the phenomenon in a virtual laboratory, where changes in certain characteristics (e.g., immunological tests) lead to changes in the results of the original laboratory tests [15].
c) Quantitative models provide the use of quantitatively specified parameters in the model to change the dependent characteristics or simulate phenomena [16].

A virtual laboratory workshop usually includes two types of hardware and software:

a) Laboratory setup with remote access.
b) Software that allows users to simulate laboratory experiments [17].

In the natural sciences, laboratory workshops are an integral part of the educational process. They combine theory and practice in a way that is only possible in the laboratory [18]. Without laboratory classes, students would not get the full benefit of the methodological knowledge they are supposed to acquire [19-21]. The virtual laboratory workshop is now seen as an innovative and effective way of teaching used by HEIs. It combines a distance learning format with laboratory classes. Virtual laboratory workshops can be classified according to a number of features, including the development environment, the realism of virtualization, the way of interacting with the model, and the availability of automatic verification of results [22-25]. The virtual laboratory workshop is methodically presented in the form of sections: theoretical part, description of the research work, methodology, laboratory setup, and report.

Virtual laboratories are being introduced as one of the STEM education technologies starting from school education. This has made it possible to ensure the development of practical skills in the field of biological science, especially in conditions of limited access to physical laboratories. In the context of the COVID-19 pandemic and martial law, biological research was conducted remotely, as students did not have access to educational institutions and their equipment due to security conditions. A virtual laboratory workshop can solve many problems. There is no need to buy expensive equipment and reagents. It offers enhanced safety, visualizes processes at the molecular or cellular level, conserves time and resources when recording results, and is suitable for distance learning. These virtual environments reduce the risks associated with handling hazardous chemicals and lower expenses related to reagents and equipment. Additionally, they enable students to perform essential experiments at their convenience.

The research problem is to study the effectiveness of the pedagogical conditions of the virtual laboratory in the context of the development of students' research competence in higher biological education. The authors' primary task was conducting a more comprehensive theoretical and practical analysis of the problem. The study will assess the impact of virtual laboratories on students' research competencies in the context of biological disciplines in higher education. The study had the following objectives:

1. To assess the research competence of students.
2. To study students' satisfaction with the educational environment.
3. Investigating the relationship between the development of research skills and the level of satisfaction with the university's academic atmosphere.

2. Research design

This study used several qualitative and quantitative indicators monitored, compared, and analyzed throughout the observation period. The research process took place in several stages. After defining the research objectives, students were randomly assigned to a control or experimental group. After selecting the research tools and procedures, preliminary testing was conducted in February 2023. The project, which lasted from September 2023 to May 2024, successfully created pedagogical conditions for integrating virtual laboratories into the biology curriculum for the experimental group, while the control group continued to use traditional laboratories. Subsequently, a statistical analysis was conducted to assess the growth of research competence and satisfaction with the educational environment based on the study results. By January 2024, the data were processed and conclusions were drawn at the end of the project.

2.1. Participants of the study

The experimental study involved 230 second- and third-year students. Students had experience using virtual laboratories during distance learning due to the COVID-19 pandemic in general secondary education institutions. These students were selected from 12 academic groups and divided into experimental and control groups. All participants provided consent for their data to be utilized, ensuring adherence to ethical guidelines for the study. To enhance the reliability of the research, a panel of six experts was assembled from the faculty members of the specified university.

2.2. Research methods

a) The research experiment involved conducting activities in both virtual and real laboratories, with students actively participating in the laboratory work. The aim of this research in either setting is to achieve several objectives: applying scientific methods, developing the ability to conduct research, processing results, and collaborating effectively as a team.
b) The Educational Environment Trust Scale (EETS), which measures respondents' attitudes toward the educational environment. This test was developed by researchers at the University of Illinois. The EETS consists of 18 statements that assess students' trust in teachers, peers, and the educational environment in general [26].
c) The method of expert assessments was used. This method confirmed the reliability of the data obtained. In addition, this approach allowed for a more comprehensive analysis of the effectiveness of using virtual laboratories in the educational process.

3. Analysis of the data obtained

Cronbach's alpha reliability coefficient is a definitive measure of the internal consistency of test items. It is calculated using the following formula:

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

Where N - total number of questions in the test;
σ^2_x is the variance of the entire test score;
σ^2_Y is the variance of the element i.

The Cronbach's alpha coefficient will be employed to evaluate the dependability of the methodologies. This coefficient represents a measure of the internal consistency of scale items. Values of Cronbach's alpha between 0.7 and 0.9 are deemed reliable (Table 1).

Table 1: Evaluation of the reliability of research methodologies using the Cronbach's alpha method

Method.	Number of points	Cronbach's alpha coefficient
Research experiments in virtual and real laboratories	4	0.72
Educational Environment Trust Scale - (EETS)	18	0.86

Source: Compiled based on the results of the study

The results demonstrate that the selected methods, including research experiments conducted in both virtual and real laboratories, as well as ETS, exhibit high reliability, as indicated by Cronbach's alpha coefficients exceeding 0.7. The formula for calculating the Mann-Whitney U test statistic is as follows:

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

Where n_1 this figure represents the number of respondents in the experimental group;
n_2 - the number of respondents in the control group is indicated below;
T_x - this is the larger of the two-ranked sums.;
n_x - the number of respondents in the group with the higher sum of ranks is as follows:

A correlation analysis was conducted. Correlation analysis is a method used to ascertain the strength of the relationship between two or more variables. The principal objective of correlation analysis is to ascertain the extent to which a modification in one variable can influence a modification in another. The r coefficient is calculated using the Pearson formula.

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

Where n is the number of observations,
∑ is the sum of all values,
X and Y are the values of two variables,
n - number of observations.

4. Results

Prior to the commencement of the ascertaining phase of the study, students from both groups underwent an assessment of their research skills. The overall results of evaluating the development of the research competency block at the study's outset are illustrated in Figure 1.

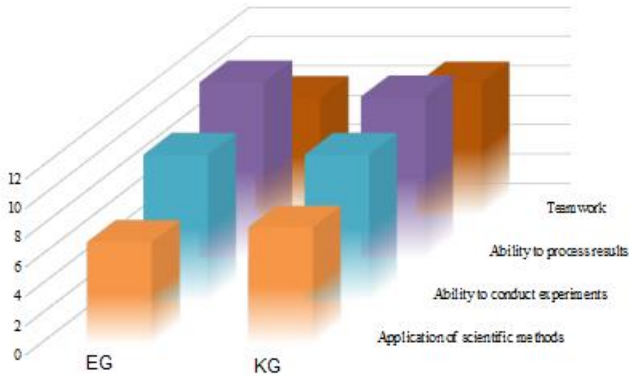

Figure 1. Comparative diagram of the levels of research competence of CG and EG respondents at the beginning of the experiment.

The analysis of the diagram revealed that the average scores of digital competence development levels of EG and CG respondents were approximately the same. In the CG group, the average score for each of the four indicators (application of scientific methods, ability to conduct scientific research, processing of results, and teamwork) was almost or the same as in the EG group. This similarity between the two groups is confirmed by Table 2, which contains the results of the statistical analysis.

Table 2. Statistical analysis of the research competence of CG and EG respondents at the beginning of the experiment

Skill	p-value	Conclusion
Application of scientific methods	0.44	No statistical significance
Ability to conduct experiments	1.00	No statistical significance
Ability to process results	0.63	No statistical significance
Teamwork	0.51	No statistical significance

Table 2 demonstrates that no statistical differences were identified, suggesting that the initial conditions at the beginning of the experiment were uniform. The likelihood that the observed differences are attributable to factors other than random chance is low, as the p-value for all four skills exceeds 0.05. The same methodology was applied at the conclusion of the pedagogical experiment, with the results presented in Figure 2.

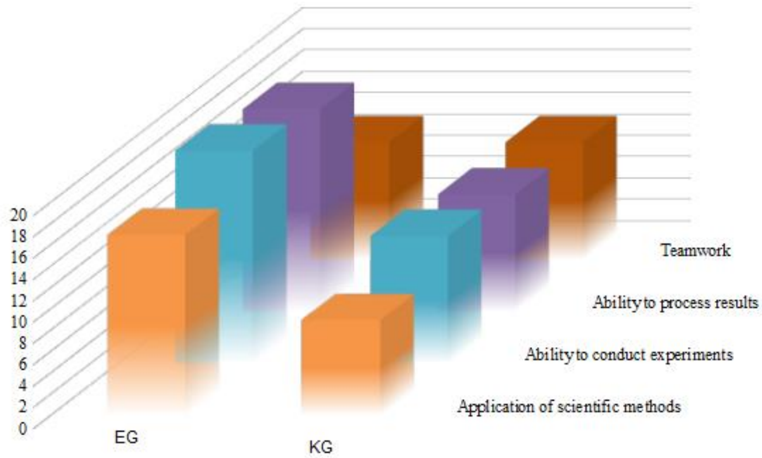

Figure 2. Diagram comparing the levels of research competence of respondents

CG and EG until the end of the experiment.

The diagram in Figure 2 shows significant differences between the results of the CG and the EG. The EG scores significantly increased. Table 3 contains statistical analysis.

Table 3. Statistical analysis of the development of research skills of CG and EG respondents at the beginning of the experiment

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

The data presented in Table 3 indicates that there are statistically significant differences in three of the four skills between the two groups (EG and CG). The obtained results suggest that the use of virtual laboratories is an effective approach for studying biological disciplines. The subsequent phase of the study concentrated on the examination of students' perceptions regarding the learning environment. The EETS methodology was employed to ascertain the level of comfort experienced by the students. Table 4 presents the findings of the study.

Table 4. The results of the analysis of students' attitudes to the learning environment in the EG and CG groups

EETS subscale	Average value CG	Average value EG	p-value (Mann-Whitney coefficient)	p-value (Pearson's chi-square test)
Trust in peers	2.8	3.5	0.03	0.02
Trust in teachers	3.8	4.1	0.01	0.01
Perception of the fairness of the rules	3.1	3.9	0.02	0.01
A sense of belonging	3.3	3.8	0.01	0.01
Perception of support from teachers	3.2	4.2	0.01	0.01

The data presented in the table clearly demonstrates that the mean values of the majority of indicators (trust in peers, trust in teachers, perceived fairness of rules, sense of belonging, and perceived support from teachers) are higher in the experimental group (EG) than in the control group (CG). Moreover, the statistical significance of the difference was corroborated by both evaluation methods (Mann-Whitney coefficient and Pearson chi-square test), thereby underscoring the significance of these differences between the groups. The p-value is greater than 0.05 for all indicators, which demonstrates that the difference between the groups is statistically significant. The results suggest that EG students may exhibit a more favourable attitude towards the learning environment than CG students. In order to assess the relationship between attitudes towards the learning environment and research competencies, Pearson's correlation coefficient will be employed. The results are presented in Table 5 for the reader's convenience.

Table 5. Assessment of the relationship between attitude to the learning environment and research competencies

Mani Whitney's skill	Pearson's correlation coefficient (CG)	Pearson's correlation coefficient (EG)	p-value (Control group)	p-value (Experimental group)
Application of scientific methods	0.41	0.65	0.06	0.001
Ability to conduct experiments	0.38	0.70	0.05	0.001
Ability to process results	0.41	0.66	0.05	0.001
Teamwork	0.01	0.03	0.88	0.83

Table 5 indicates a positive correlation between the application of scientific methods and the ability to conduct experiments, as well as participants' attitudes toward the learning environment in both the control and experimental groups. The Pearson correlation coefficients for the experimental group are higher, indicating a stronger relationship between research competencies and attitudes toward the learning environment in this group. Additionally, the ability to process results shows a moderate positive correlation with attitudes toward the learning environment. However, the correlation coefficients for both groups are less pronounced than those observed for scientific methods and experiments.

5. Discussion

The relationship between teamwork and attitudes toward the learning environment is weak and almost negligible in both groups, with correlation coefficients that are not statistically significant. The p-values for the experimental group are consistently lower than those for the control group, confirming the statistical significance of the correlations observed in the former. This study demonstrates that modern virtual laboratories are complex systems built on the basis of various information technologies, including innovative software, that allow creating an environment for biological research. Virtual laboratories are being developed in accordance with the latest advances in information technology. As observed by J. J. Serrano-Perez, L. González-García, N. Flacco, et al. [28], the expansion of hardware capabilities represents a significant contributing factor in the advancement of virtual laboratories. Such systems permit the utilization of software products with greater compatibility on a reduced number of computers. It has been demonstrated that the utilization of virtual biological laboratories engenders enhanced satisfaction with the educational milieu and the cultivation of research competencies, as corroborated by L. B. Shabat and M. Itzhaki [29] and N. M. Sharipova [30].

Nevertheless, the efficacy of virtual laboratories in the investigation of biological disciplines remains a topic of contention. P. Sharma [31] and C. Song, C. Zhang, Y. Zhao, and A. Li [32] explicitly state that the overarching objective of the laboratory is to equip students with the ability to translate their practical experience in a real-world setting to a professional environment. Those who take a critical view, such as R. Wegerif and L. Major [33], point out that although virtual laboratories are convenient and cost-effective, they do not always contribute to the effective acquisition of practical skills, which is a key goal of laboratory learning.

The theoretical significance of this study is to expand knowledge about the subject of the article and opens up new perspectives on the use of virtual laboratories in biology. In particular, it can identify shortcomings in existing educational theoretical models. In real life, the results of the study can be used to solve problems related to improving the biological training of future specialists.

6. Conclusions

The study's results are noteworthy because virtual laboratories play an increasingly important role in the training of future biology professionals. The study has shown that introducing such innovative tools is invaluable for teaching biology because they can offer students new opportunities for a deeper understanding of complex biological processes. Such laboratories allow students to understand biological processes theoretically and apply their knowledge in realistic conditions without expensive physical equipment or resources.

The findings showed that using virtual laboratories in the context of biology education increased students' interest and preparedness. They are an extremely effective method of learning biological processes because they allow users to visualize complex concepts and experiments in a way that is impossible with traditional methods, without significant material costs.

Virtual laboratories are becoming an increasingly important tool in biology education. They provide a flexible learning environment that can simulate complex processes, which is especially important in resource-limited settings.

In the future, we should expect research related to the study of the impact of virtual laboratories on the development of biological competencies. In addition, it is important to draw researchers' attention to how virtual tools can be integrated into the educational process to improve curriculum development and learning outcomes.

The results can be used to promote the integration of specialized biology education into educational institutions' curricula. In the context of limited funding, the relevance of such innovations is especially growing, as updating the material and technical base is often difficult. Introducing virtual laboratories will compensate for the shortcomings inherent in traditional pedagogical approaches, such as the lack of modern equipment for experimental research.

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