Full research paper

ASSESSMENT OF INFORMATION AND COMMUNICATION COMPETENCE OF FUTURE TEACHERS BASED ON LABORATORY WORK IN NATURAL SCIENCES

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ABSTRACT

In the context of globalization and rapid advancement in information and communication technologies (ICT), ICT competence is crucial in professional training, including education. This study focuses on integrating ICT into the educational processes of future science teachers to enhance their ICT competence. The objective is to evaluate ICT's efficacy in laboratory work within natural sciences for developing ICT competence among prospective teachers.

The research methodology involved an experimental study at Zhetysu University with students in pedagogical physics, biology, and chemistry programs. Participants were divided into two groups: one followed a traditional pedagogical approach, and the other incorporated ICT into their lab work. Initial and final surveys measured the students' ICT competence levels.

The study's findings showed a significant improvement in ICT competence among students who used ICT in their studies, demonstrating the effectiveness of integrating modern technologies into education. The paper recommends that educational institutions incorporate ICT into their curricula and suggests directions for further research in this field.

KEYWORDS

Educational process, future teachers, information and communication competence, information and communication technologies, laboratory work, natural sciences

HOW TO CITE

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Highlights

- *Students of pedagogy in natural sciences who used ICT in laboratory work reported significantly higher improvement in ICT competence.*
- *The improvement was indicated in operational, information and communication competencies, critical thinking and problem-solving, project management, ICT security and ethics.*
- *Using ICT tools in the educational process positively affects the formation of students' ICT competence.*

INTRODUCTION

Modern technology has become integral to learning and teaching in the rapidly evolving educational landscape. Modern technology has heralded a revolution in learning and teaching, fundamentally altering the education landscape. This work sets the stage for exploring modern technology's profound impact and versatile utility in reshaping education and embarks on a journey to explore modern technology's profound use and utility in shaping contemporary educational paradigms (Kumar et al., 2024). The use of ICT in the study of natural sciences will allow to show the fundamental unity of the laws of nature, to greatly increase students' interest in studying these natural disciplines, will intensify the learning process, ensuring a high level of results in the form of key competencies (Hladun, 2020). This becomes important in the context of natural sciences, where the complexity of the material and the need for its visualization and practical application require teachers not only to have in-depth knowledge of the subject, but also the ability to effectively use information and communication technologies to achieve educational goals.

This paper seeks to enhance the existing body of research by evaluating the effectiveness of integrating ICT in laboratory work within the context of natural sciences education. By investigating the influence of this integration on the information and communication competencies of future teachers, this study aims to address a gap in the current scholarly discourse regarding the practical application of ICT in educational environments. We begin by detailing the methodology underpinning our research, including the experimental design, participant selection, and data analysis techniques. Following this, we present the study's results, offering a comprehensive look at the observed enhancements in ICT competencies among the participants. The discussion then situates these findings within the broader scholarly discourse, underscoring their significance for the future of teacher education and the integration of ICT in educational curricula. The article concludes by summarising the key contributions of this research, acknowledging its limitations, and proposing directions for future investigations in the field of ICT in education.

ICT Competencies in the Education of Future Teachers

In 2018, the OECD had already advised that education has a vital role to play in developing the knowledge, skills, attitudes and values that enable people to contribute to and benefit from an inclusive and sustainable future. Learning to form clear and purposeful goals, work with others with different perspectives, find untapped opportunities and identify multiple solutions to big problems will be essential in the coming years. Education needs to aim to do more than prepare young people for the world of work; it needs to equip students with the skills they need to become active, responsible and engaged citizens (OECD, 2018).
For academic institutions to be successful, their model of educational and organizational democratic accountability must be restructured to act rapidly and precisely, create fresh concepts effectively, and enable adaptable and respectful facilities. This attitude transformation toward an 'entrepreneurial mindset' must begin (Stolze, A., Sailer, K., & Gillig, H., 2018). In these conditions, a Higher Education is faced with the task of preparing specialists for professional activity, considering the active use of digital technology.
It should be noted that economically developed and competitive countries invest the most—both materially and financially—in the development of education. Today, universities are experiencing the profound effects of digital transformation, which has not only introduced new challenges but also intensified existing ones. They are increasingly forced to compete for students with emerging players in the digital education market. As noted by the Minister of Science and Higher Education of the Republic of Kazakhstan, Sayasat Nurbek, in an interview with the Astana Times (Ualikhanova, 2023), 'Digital technologies have become an integral part of the modern world and have great potential for the successful implementation of higher education,' which requires 'a transition from traditional educational models to active teaching methods' for the successful digital transformation of higher education. According to the Resolution of the Government of the Republic of Kazakhstan (2018), the improvement of digital competencies of citizens will be continued through the system of training, retraining and obtaining micro qualifications in the field of ICT. Digital competencies will become a mandatory element of all professional standards. Developing the ICT competence of future teachers is therefore essential—not only for effective teaching but also for preparing students to thrive in a knowledge-based, technology-driven society. According to Ghavifekr and Rosdy (2015), ICT competence today goes far beyond the basic use of computer programs. It refers to a teacher's ability to integrate technological tools into the educational process in ways that foster students' critical thinking, creativity, and problem-solving skills.
According by the Sayasat Nurbek, in an interview with the Astana Times (Ualikhanova, 2023), in Kazakhstan, where the educational system is transitioning toward digitalisation, teachers are increasingly required to adopt new pedagogical approaches rooted in ICT. Consequently, more attention is now being paid to developing ICT competence in future educators. This competence is understood as a set of knowledge, skills, and personal qualities that enable the effective use of information and communication technologies to perform diverse tasks, pursue training and self-education, and interact successfully in both social and professional contexts. This competence is particularly vital in teacher preparation, as future educators must not only consume digital content but also become active participants in the information society—capable of creating, processing, and sharing knowledge using modern ICT. Sergeeva et al. (2024) reported that pre-service teachers' ICT competency beliefs can help identify factors influencing their attitudes and intentions to use technology in their future classrooms. By understanding these factors, teacher education programs can provide appropriate support and training to increase prospective teachers' confidence and motivation to use ICT in their teaching practice. In addition, measuring pre-service teachers' ICT competency beliefs can provide insight into the effectiveness of current ICT courses and training programs in preparing them for their future roles as educators.
A study was previously conducted at Zhetysu University, with the participation of 20 teachers and 100 students at the Higher School of Natural Sciences, it was revealed that teachers master basic computer skills and can effectively use ICT in the educational process, including working with multimedia equipment and using ICT to teach specialised disciplines and communicate with students. These findings highlight the need for further development of ICT competence among the teaching staff to improve the quality of the educational process. The students, in turn, positively assessed the use of ICT by teachers, stressing that it contributes to improving the effectiveness of learning. However, they also pointed out the importance of finding the optimal balance between virtual and personal communication. The results of this prior research were presented at an international conference and published in a scientific article (Kabdualiyev et al., 2023).
In the ever-evolving digital era, the role of information and communication technology in interactive learning has ushered in a new chapter in education. This transformation has not only impacted how we learn and teach but has also changed our perspective on education itself. From digital learning platforms that provide unlimited access to knowledge, to the use of multimedia that enhances student understanding, ICT has brought about a revolution in education that is more inclusive and dynamic (Anastasopoulou et al., 2024). This shift enables

teachers to create more engaging lessons that can cater to diverse learning styles, making complex concepts easier to understand. Moreover, ICT has introduced a wide array of educational software and applications designed to reinforce learning through interactive exercises and immediate feedback (Anastasopoulou et al., 2024).

Alférez-Pastor et al. (2023) claim that future teachers must be trained as digitally competent individuals to eliminate the barrier to digital tools in education. Teachers are a key element in technological transformation since their attitude towards educational technologies is a determining factor in responding to educational innovation and technological advances in today's society. Tomczyk et al. (2023) stated that measuring digital competence among future teachers is being carried out worldwide in various ways. Despite the different typologies, there is currently no standardised way of measuring ICT skills in the teaching and learning dimensions. Silva-Quiroz and Morales-Morgado (2022) confirmed that digital competence should be integrated into the curriculum of university programs, especially pedagogy so that students use technology for their academic and personal development. Huamán-Romaní et al. (2022) stated that universities at the national level are training professionals with professional training competence where basic knowledge of the subject predominates, both in the theoretical and practical part, as well as training in ICT.

In a similar study, Bogachkov, Ukhan and Yutsevych (2019) explain the concept of competency level as an index characterizing the probability of successfully performing a task (at a given level) from a defined set of tasks in a specific context by a particular performer. They define information and communication competencies as a set of knowledge, skills, and abilities developed through learning and self-learning in computer science and information technology. These competencies include the ability to perform professional activities using information technology. Specifically, they describe this as the ability to work with information (collection, search, transfer, and analysis); to model and design one's own professional activities; to model and design the work of a team; to navigate the organizational environment using modern ICT; and to use modern ICT tools in professional activities to enhance labour productivity.

These definitions emphasise, in our opinion, a crucial aspect of updating the ICT competence of students for their future professional activities. In the context of the Kazakh educational system, information and communication technologies have become essential tools for improving the quality of education and developing competence among students and teachers. Kopeyev et al. (2020) raised questions about students who lack motivation since they already know the subject being studied. These are students with a good level of knowledge. In contrast, others have less motivation due to a lack of understanding of the material being studied, a lack of basic knowledge, and an insufficient level of learning outcomes in the field of computer science.

Many teachers and methodologists are engaged in methodological issues of integrating ICT tools into educational practice (Alemu, 2015; Lawrence & Tar, 2018; Sutherland et al., 2004). These authors emphasise the importance of using interactive teaching methods in a virtual environment, pay attention to the didactic value of working with computer models, and emphasise the need to increase their functionality, activating the activities of students.

Effective use of computers and technology in teaching is possible with teachers who are knowledgeable and well-trained in using technology. In today's world, where education affects technology and technology affects education, a teaching approach that is not reflected in the educational environment and lacks technology negatively affects success. For this reason, using computers and technology has become compulsory in today's education. In the light of the findings, various suggestions need to be made. In this direction, first of all, teacher trainers should educate, inform and raise awareness of pre-service teachers about digital literacy and technology usage skills, which are considered to be among the requirements of the 21st century and whose importance is expressed in many national and international studies in terms of the educational process (Nurzhanova et al., 2023).

Preparation of students as subjects of professional and pedagogical activity remains one of the current problems, as modern Kazakhstan educational system is in a stage of dynamic renewal caused by, on the one hand, the process of reforming society as a whole, and on the other hand, the logic of the educational system development. Thus, it is important to develop new approaches, new forms of learning (Zhaukumova et al., 2021). The practice-oriented content of the educational material allows bringing teaching closer to specific situations of professional activity, the chosen specialty, to form the life experience of students, thus increasing the level of knowledge and skills, cognitive interest, and, as a result, to form the level of professional competence of students (Manashova et al., 2021). Such training enables students to master modern educational technologies and to apply them in professional activities. In addition, it fosters adaptability to the rapidly changing demands of the information society.

Matviyevskaya et al. (2019) observe that dynamic changes in the modern world dictate the need to find new approaches to the theory and practice of forming ICT competence in all areas of human activity, especially in forming ICT competence of future teachers. Informatization of education is declared as one of the priority directions of the state policy in the field of education. ICT plays a unique role in improving the quality of education. It simplifies the integration of the national education system into the world and facilitates access to international sources of information in education, science and culture. The need to form ICT for future teachers relates to the changing structure of educational information interaction between teachers and pupils.

Klara and Alamash (2023) suggest that digital technologies make it possible to develop existing methods for monitoring and assessing the level of knowledge of future teachers and create new, more advanced, modern methods. At the same time, by analysing a lot of information about students and their activity in the digital environment, the university teacher can provide him with sufficient assistance, opening opportunities for independent work for future teachers in the digital environment.

Based on the research of Kormakova et al. (2021) and Wong and Daud (2018), we propose the following key ICT competencies depicted in Figure 1. These skills include operational, information, communication, critical thinking, problem-solving, project management, and ICT security and ethics.

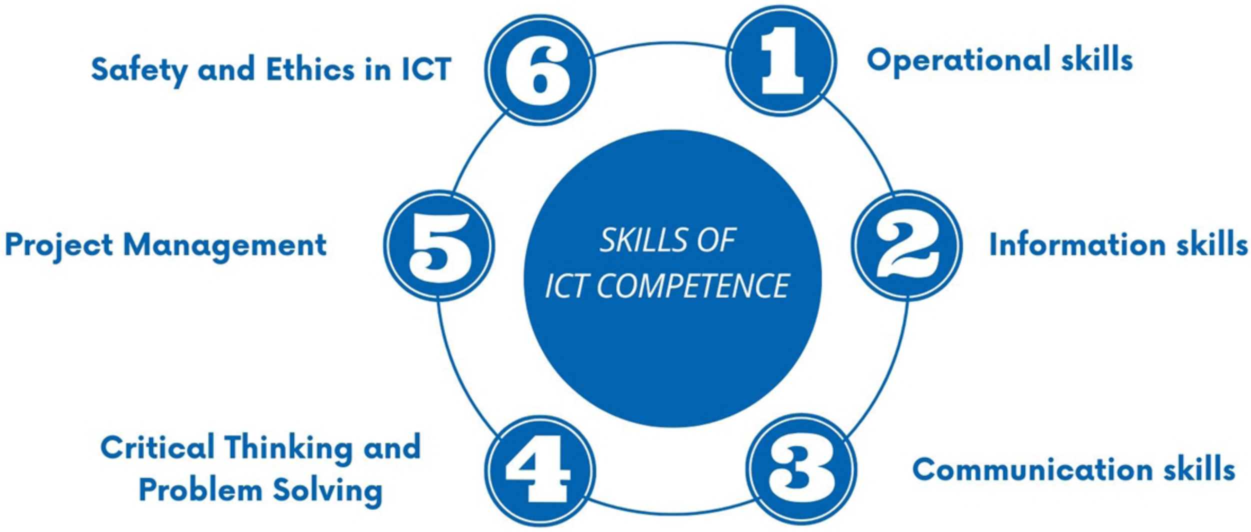


Figure 1: Development of ICT competence through laboratory work (Source: Accepted from Kormakova et al.,2021; Wong & Daud, 2018)

It is of extremely high priority for prospective teachers to establish a rich set of information and communication technologies to advance their professional competence. Every single one of these skills is a part of establishing extensive ICT competence, which is the core part of the professional development of a modern teacher. Teachers who possess these skills become more effective and are allowed to implement technology to transform the educational process and the growth of student motivation to study. Table 1 offers a detailed illustration of every single one of these skills, showing their significance for the competent application of ICT in modern lessons and the efficient implementation of technology into the professional life of teachers.

ICT Competence	Use in laboratory work	Description
Operational skills	Basics of working with a text editor	Learning the functions of a text editor, such as formatting text, inserting images, and creating tables
	Mastering the simulation program	Introduction to software for creating and analysing models
Information skills	Search and evaluation of scientific sources	Development of search strategies in scientific databases and assessment of the reliability of the information found
	Data Analysis using Excel	Using Excel to collect, process, and visualise data
Communication skills	Maintaining a scientific blog	Creating and maintaining a blog to discuss the results of laboratory work.
	Online conference on the results of projects	Organisation and holding of online presentations of projects.
Critical thinking and problem-solving	Laboratory for virtual experiments	Application of theoretical knowledge to solve practical problems.
	Case study on problem-solving	Analysis of real cases and development of solutions
Project management	Planning and management of an ICT project	Development of a project plan, including the allocation of tasks
Security and ethics in ICT	Digital Security Course	Studying the principles of data protection and safe use of the Internet
	Ethical dilemmas in ICT	Discussion and analysis of ethical dilemmas

Table 1: Development of ICT competence in laboratory work (Source: Accepted from Kormakova et al.,2021; Wong & Daud, 2018)

Asare et al. (2023) argues that choosing between traditional and virtual laboratories in science education should be based on carefully considering the educational goals and available resources. Traditional laboratories offer a rich and immersive hands-on experience, fostering a deeper connection to science, but can be resource intensive. Virtual laboratories, while providing accessibility and cost-efficiency, may lack sensory engagement and present technological challenges. A balanced approach, combining both traditional and virtual laboratories, can provide a comprehensive science education that leverages the strengths of each approach, catering to a broader range of student's needs and circumstances.

According to Potkonjak et al. (2016), concepts such as distance learning and open universities are now becoming more widely used for teaching and learning within education. However, due to the nature of the subject domain, the teaching of Science, Technology, and Engineering are still relatively behind when using new technological approaches (particularly for online distance learning). The reason for this discrepancy lies in the fact that these fields often require laboratory exercises to provide effective skill acquisition and hands-on experience. Often it is difficult to make these laboratories accessible for online access. Either the real lab needs to be enabled for remote access or it needs to be replicated as a fully software-based virtual lab.

Type of virtual laboratory	Description	Application
Interactive simulations	Virtual laboratories that allow students to interact with experimental parameters and observe changes in real-time.	The study of complex scientific concepts such as quantum mechanics, genetic mutations, and chemical reactions.
Virtual laboratory stands	Platforms offering virtual versions of real laboratory stands for conducting experiments using standard equipment and reagents.	The study of methods of working with equipment, the safety of laboratory research and techniques for performing experiments.
Process modelling	Tools for creating and testing models of biological, chemical, or physical processes through computer modelling.	Modelling of ecological systems, chemical reactions, and physical phenomena (fluid flow, particle dynamics).
3D labs and VR	The use of virtual reality technologies to create immersive laboratory environments that allow to interact with equipment and conduct experiments in 3D space.	Conducting complex or dangerous experiments that are difficult to implement in a real laboratory.
Online courses with laboratory work	Courses in natural sciences, including virtual laboratory work, providing both theoretical and practical skills.	Providing comprehensive training through videos, interactive tasks and simulations.

Table 2: Types of virtual laboratory work (Source: Accepted from Potkonjak et al., 2016).

These examples show how utilizing traditional laboratory and virtual laboratory work, students can acquire ICT competence while mastering contemporary ICT and acquiring priceless skills for their future professional activities.

Based on the study by Byukusenge, Nsanganwimana and Tarmo (2022), conceptual understanding is the learning outcome that is enhanced most when using virtual labs. Virtual labs improve students' motivation, self-efficacy, and attitudes toward learning biology topics. Virtual laboratories deserve the attention of researchers, teachers, and instructional designers due to their appealing nature as a means of actively involving students in safer and more cost-effective scientific inquiry. The effectiveness of virtual labs, like any other instructional tool, may be significantly influenced by how they are used in the classroom. Moreover, according to a study by Benda, Pavlik and Masner (2019), the virtual laboratory or learning environment applied to a web interface is convenient even for students with mental disabilities. The acquisition of information and communication competence using ICT in laboratory work contributes not only to the increase in the level of education but also to the ability of students to successfully use new technologies in the future, in which the possession of ICT skills is one of the crucial factors.

Hypotheses

Based on the objectives of the study and the findings of the literature review, a series of hypotheses were formulated to assess the influence of ICT integration in laboratory work on the development of students' digital competencies. Each hypothesis addresses a specific area of competence, including operational skills, information skills, communication skills, critical thinking and problem-solving abilities, project management skills, digital security awareness, and overall ICT competence.

Hypothesis 1: the inclusion of tasks in laboratory work on the **use of basic ICT tools**, such as word processors (Microsoft Word, Google Docs), spreadsheets (Excel, Google Sheets), and presentation software (PowerPoint, Google Slides), **does not lead** to a significant **improvement in students' operational skills**.

Hypothesis 2: Encouraging students to **use search engines** (Google, Yandex) and educational resources on the Internet (Coursera) to collect and analyse information within the framework of laboratory work does not contribute to the development of their **information skills**.

Hypothesis 3: Regular completion of tasks requiring **information exchange and collaboration in groups** (Google Drive) and messengers (WhatsApp, Telegram) **does not improve** students' **communication skills** in a digital environment.

Hypothesis 4: Involving students in solving practical problems and projects **using online calculators and simple data visualisation programs** (Google Sheets with a chart function, Canva for creating infographics) does not contribute to the development of their **critical thinking and problem-solving skills**.

Hypothesis 5: the use of simple **project and task management tools** (Google Calendar) in laboratory work does not help students develop **skills in planning and organising** work on projects.

Hypothesis 6: the inclusion in the educational process of elements aimed at teaching the **basics of digital security** (Norton Security) **and ethics** (etiquette of communication on the Internet, conscious use of content) does not help to **raise students' awareness** of the importance of these aspects in the digital environment.

Hypothesis 7: the **use of ICT tools** does not have a significant impact on the ICT competence of students.

MATERIALS AND METHODS

To analyse the materials and results of the study, several methods were employed. General scientific methods included a comparative analysis of pedagogical and scientific-methodical literature related to the research topic. Sociological research methods involved conducting surveys among prospective physics, chemistry, and biology teachers, followed by comparison, classification, and analysis of the collected data. Additionally, empirical research methods were applied, such as implementing a pedagogical experiment, using statistical techniques, and processing and analysing the obtained results. The study examined the impact of ICT integration in laboratory work on the formation of ICT competence among students enrolled in three educational programs: biology, chemistry, and physics. Participants included third- and fourth-year students at Zhetysu University.

Participants

A survey was conducted among students to assess their information and communication competence. The distribution of participants was out through random assignment to ensure comparability and minimize bias.

Biology (N = 48): The cohort was divided into control and experimental groups, each with 24 students.

Chemistry (N = 36): Participants were equally split, with 18 students in each group.

Physics (N = 31): The experimental group had 16 students, while the control group consisted of 15 students.

Data Collection

A structured data collection process was developed to ensure the through and systematic gathering of information necessary for the study. Data collection includes eight consecutive stages, each involving specific methods and tools tailored to the particular tasks at hand. The steps of data collection and analysis methods are shown in Figure 2.

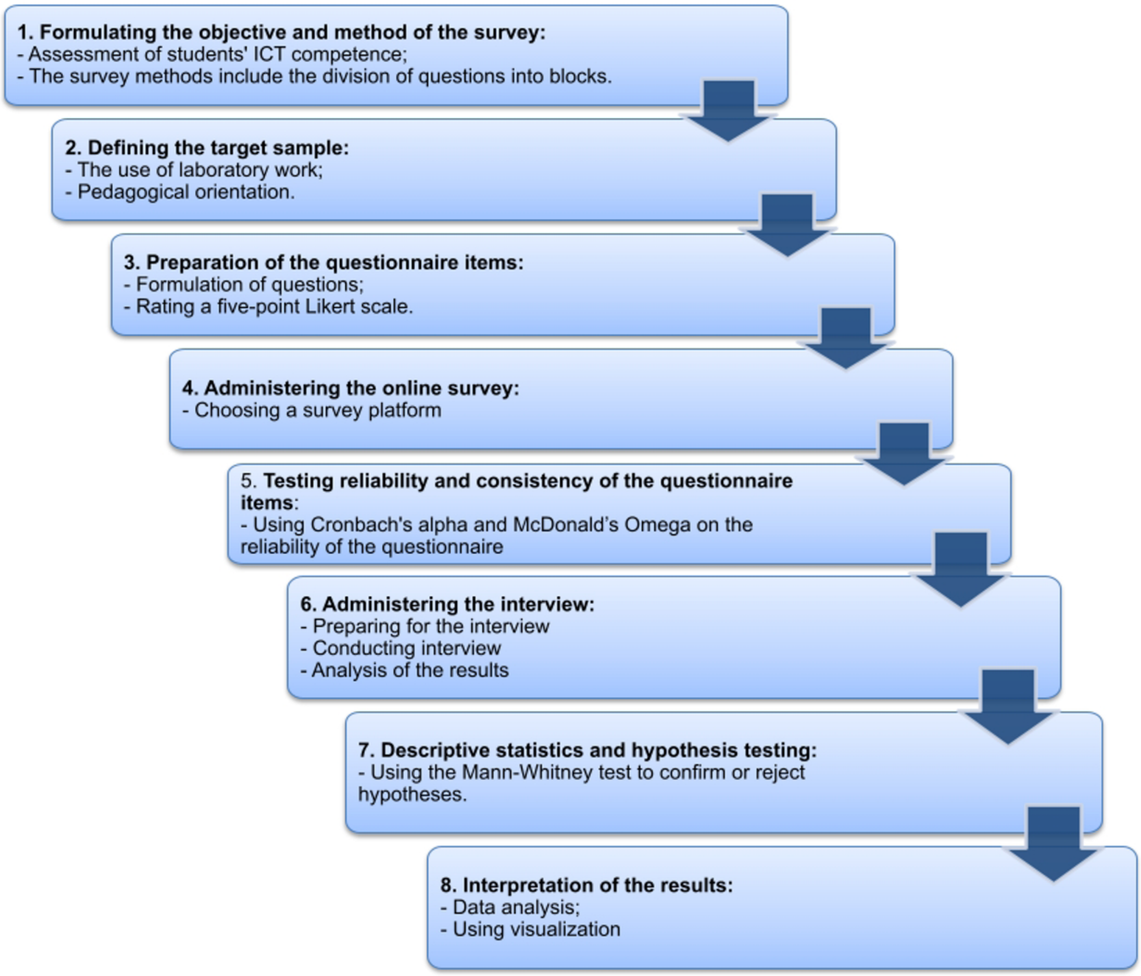


Figure 2: Stages of data collection and analysis methods (Source: own)

As part of research conducted at the Higher School of Natural Sciences of Zhetysu University, students of the educational program for pedagogical physics, biology, and chemistry were involved in the experiment. The purpose of the experiment was to assess the effect of the use of information and communication technologies (ICT) on the development of their information and communication competence, emphasizing the use of ICT during laboratory work rather than in the general learning process.

The participants were divided into two groups: the control group was trained according to the traditional methodology, while the experimental group actively used ICT during laboratory work. All participants' initial level of ICT competence was assessed as below average through a survey conducted before the experiment. This survey revealed limited knowledge of ICT and insufficient use of technology in the educational process.

During the experiment, the experimental group students used various ICTs, including specialised data analysis software, online collaboration platforms, digital tools for visualising scientific concepts and interactive applications for conducting virtual laboratory experiments. This approach allowed students not only to gain a deeper understanding of natural sciences, but also to significantly improve their information and communication skills. At the end of the experimental period, a repeated survey was conducted to test the changes in ICT competence.

Questionnaire Design

The study design provided for conducting a survey among all participants, as well as subsequent interviews with half of them, which allowed us to obtain both quantitative and qualitative data on their ICT competencies.

Based on the work of Caluza et al. (2017), we compiled 36 close-ended questions divided into six blocks representing the following information and communication competencies: operating skills, information skills, communication skills, critical thinking and problem-solving skills, project management, and security and ethics in ICT skills described in Table 1.

The survey questions are presented in Appendix. We employed 5-point Likert scale measuring respondents' skills ranging from '1 - very bad' to '5 – very good'. The questionnaire was designed in Kazakh and distributed online as a Google form between January 15 and February 3, 2024.

Interviews

In addition to the questionnaire, interviews were conducted with 57 students, which made it possible to explore their views and experiences of using ICT in more depth. The interview consisted of a series of open-ended questions aimed at clarifying the practical application of ICT in the educational and daily activities of students. The blocks of questions concerned all six skills. The interview questions are presented in Appendix. This approach allowed not only to confirm the data obtained during the survey but also to expand the understanding of how students perceive their competence and what factors, in their opinion, contribute to or hinder its development.

RESULTS

We analysed the results in two levels. First, we present results of testing the influence of using various laboratory work elements on improving particular ICT competencies. Second, we analysed the results by student specialties and groups.

Survey Tool Reliability and Variance Analysis

To assess the internal consistency of the questionnaire, two reliability coefficients were used: the Cronbach's Alpha coefficient and the McDonald's Omega coefficient. The choice of a dual approach is due to the fact that Cronbach's Alpha is traditionally the most common reliability indicator, which is based on the assumption of equal loads of all scale elements on the measured factor. Additionally, the McDonald's Omega was calculated, which is a more modern and accurate reliability indicator that takes into account possible differences in the contribution of individual issues to the overall result. The calculation of McDonald's Omega allows us to obtain a more accurate assessment of the internal consistency of the scales, especially in the presence of varying degrees of factor load between individual elements of the questionnaire. Thus, the use of both coefficients provides a comprehensive and reasonable assessment of the reliability of the instrument.

The resulting Cronbach's alpha value was 0.89, which indicates a high internal consistency of the scale and reliability of the instrument used. According to generally accepted criteria, Cronbach's alpha values above 0.7 are considered acceptable, and values above 0.8 indicate high reliability, α is found to be an appropriate index of equivalence and, except for very short tests, of the first-factor concentration in the test. (Cronbach, 1951). This suggests that the questionnaire has a sufficient degree of consistency for subsequent data analysis.

To identify statistically significant differences between the factors, a single-factor analysis of variance (ANOVA) was performed (Table 3).

The source of the variation	*SS*	*df*	*MS*	*F*	*P*-Value	*F* critical
Lines	421.38	114.00	3.70	9.67	5.21E-139	1.23
Columns	53.33	35.00	1.52	3.99	4.00E-14	1.43
Error rate	1524.82	3990.00	0.38			
Total	1999.53					
Cronbach's Alpha	**0.89**					

Table 3: the ANOVA results (Source: own calculation)

The analysis of the variance showed that the differences between the groups (lines) are statistically significant: $F(114, 3990) = 9.67$, $p < 0.001$. This indicates that there are significant differences in the responses of respondents between different groups of participants or variables, which indicates the influence of experimental factors on the results of the study. Similarly, the differences between the columns (within the groups) also turned out to be significant: $F(35, 3990) = 3.99$, $p < 0.001$, which emphasizes the importance of individual factors in the overall model. The residual variance (error) was 1524.82 with $MS = 0.38$, which reflects the level of random variability of the data. The total sum of squares (SS) for all factors was 1999.53, which confirms a fairly wide range of variability of the studied data. Thus, the high level of significance of the factors and the high reliability of the tool confirm that the questionnaire has a sufficient degree of consistency.

The internal consistency of each block of the questionnaire was evaluated using McDonald's Omega coefficient. The results are presented in Table 4. Based on commonly accepted standards, a McDonald's Omega value greater than 0.7 indicates acceptable reliability, while values exceeding 0.8 reflect very good internal consistency (McDonald, 1999). Most blocks demonstrated very good or good reliability, with Omega values ranging from 0.77 to 0.83, confirming the high internal consistency of the scales. Only the Communication block showed an acceptable reliability level (Omega = 0.67), which still meets the minimum threshold for social science research instruments. The lower Omega value observed for the Communication block may be due to the broader and more heterogeneous nature of the skills assessed within this dimension.

Block	Name of Block	Number of question	McDonald's Omega	Result
1	Operating	6	0.83	Very good reliability
2	Information	6	0.81	Very good reliability
3	Communication	6	0.67	Acceptable reliability
4	Critical thinking and problem-solving	6	0.79	Good reliability
5	Project management	6	0.79	Good reliability
6	Security and ethics in ICT	6	0.77	Good reliability

Table 4: Results of McDonald's Omega (Source: own calculation)

The analysis of internal consistency, conducted using both Cronbach's alpha and McDonald's Omega, confirmed the reliability of the developed questionnaire. The obtained results indicate that the instrument consistently measures the intended constructs and can be regarded as a reliable tool for subsequent research and educational applications.

Hypotheses Testing

The Mann-Whitney criterion was used for independent samples to test the hypotheses since the sample did not correspond to the assumption of a normal distribution and was not a random sample from the entire population. The Mann-Whitney test (or U-test) is a nonparametric method used to test the differences between two independent samples. It evaluates whether there are statistically significant differences between the medians of the two groups, and is useful when the data does not correspond to a normal distribution (Iuliano and Franzese, 2019).

Interpretation of Results of the Mann-Whitney Test

The *U-statistic* is a numeric value that reflects the difference in the rank sums of the two samples. It serves as the basis for calculating other statistical indicators. In studies comparing two groups before and after an experiment, *U-statistic* is an essential tool for assessing the differences between the distributions of responses in these groups.

The *p-value* reflects the probability of obtaining an observed or more extreme *U-statistic* if there are no real differences between the groups (the null hypothesis is correct). In scientific research, it is considered that the difference is statistically significant if the p-value does not exceed 0.05.

The *Z-value* is a standardized value that shows how far the *U-statistic* deviates from the average for a particular sample. The *Z-value* converts the *U-statistic* to a standard scale, which makes it possible to compare the results of various studies.

The *R-value* is an indicator that characterizes the strength of the effect, reflecting the degree of differences between the groups. It is calculated as the ratio of the *Z-value* to the root of the total number of observations. The *R-value* can take values from -1 to 1. The closer it is to -1 or 1, the stronger the effect. Values close to 0 indicate slight differences between the groups (Sheskin, 2000).

Results of the Mann-Whitney U-Test of ICT Competence Skills

Table 4 presents the Mann-Whitney U-Test results for data before and after the surveys. The study showed statistically significant differences between the control and experimental groups before and after the experiment for each value of ICT competence skills. These results indicate the positive impact of the use of ICT tools in the laboratory works on improving the ICT competence of students, which showed a significant improvement in ICT competence among the students of the experimental group. It was noted that students not only improved their technical skills in dealing with ICT, but also developed the ability to think critically, analyse and interpret data, as well as improved their communication skills in a digital environment. The diagram shows the assessment results of information and communication competencies before and after the experiment, including the control and experimental groups.

ICT Competence skills	Group	*U*-statistic	*P*-value	*Z*-value	*R*-value	Result
Operating	Control Group	1400.5	0.19	-1.27	-0.12	Accepted
	Experimental Group	0.0	8.40e-21	-9.29	-0.86	Rejected
Information	Control Group	1323.0	0.108	-1.57	-0.15	Accepted
	Experimental Group	0.0	1.09e-20	-9.25	-0.86	Rejected
Communication	Control Group	1487.0	0.433	-0.78	-0.073	Accepted
	Experimental Group	58.0	2.38e-19	-8.97	-0.83	Rejected
Critical thinking and problem-solving	Control Group	1473.0	0.387	-0.86	-0.08	Accepted
	Experimental Group	0.0	2.67e-20	-9.21	-0.86	Rejected
Project management	Control Group	1395.0	0.057	-1.85	-0.17	Accepted
	Experimental Group	0.0	4.74e-20	-9.12	-0.86	Rejected
Security and ethics in ICT	Control Group	1354.5	0.033	-2.07	-0.19	Rejected
	Experimental Group	0.0	4.85e-20	-9.12	-0.86	Rejected

Table 5: The results of the Mann-Whitney U-Test, alpha 0.05 (Source: own calculation)

Table 5 shows significant differences between the control and experimental groups in various ICT competencies. P-value values of less than 0.05 indicate a rejection of the null hypothesis, which indicates the presence of significant differences. The results on the competence ‘Security and ethics in the field of ICT’ in the control group are particularly interesting, where the p-value was 0.033, which is close to the threshold value. This may indicate that students from the control group, in particular, students of the educational program in pedagogical physics, showed better results in issues related to the safety and ethics of using ICT. This conclusion is supported by a diagram showing that students from this program improved their results in this competence after the experiment (Figure 5).

For all ICT competence skills (operational skills, information skills, communication skills, critical thinking and problem solving, project management, safety and ethics in ICT), extremely low p-values were observed in the experimental groups (from 8.40E−21 to 4.85E−20), indicating statistically significant differences between the control group and experimental groups. The values of the *Z-statistic* for the experimental groups range from -8.97 to -9.29, which indicates significant deviations. The *R-values* for the experimental groups are -0.86 and close to this, which indicates a strong negative correlation. The study results demonstrate a statistically significant improvement in the ICT competence of students in the experimental groups compared with the control groups in almost all the crucial skills considered. Thus, the conducted research confirms the importance and necessity of integrating ICT into the educational process to improve the skills of future specialists in the field of pedagogical sciences. A more detailed view of the results by student specialties is presented in the following text.

Experimental Results: Biology Program

Within the framework of the biology educational program, emphasis was placed on the use of ICT to study biological data and conduct virtual experiments in the field of molecular biology, genetics and ecology. Students had the opportunity to work with genome databases, conduct virtual laboratory studies and use specialised software to analyse environmental data. This allowed them not only to improve their information skills but also to develop an understanding of modern research methods in biology.

Figure 3 shows the results of evaluating the educational program’s information and communication competence for pedagogical biology students before and after participating in an experiment to integrate information and communication technologies into the laboratory works. ICT competence was assessed in six essential skills: operational skills, information skills, communication skills, critical thinking and problem-solving, project management and ICT security, and ethics.

Operational skills: the experimental group showed an increase from 2.3 to 4.2, which indicates a significant improvement in the ability to use ICT tools and resources.

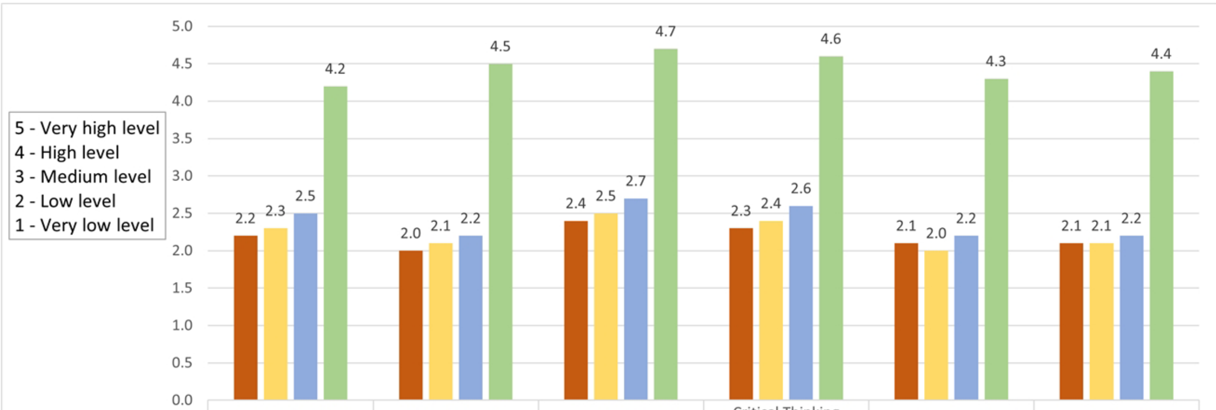
Information skills: the increase from 2.1 to 4.5 indicates that students have become much better at searching and processing information using ICT.

Communication skills: Grades increased from 2.5 to 4.7, reflecting an improvement in students’ ability to share information and interact in the digital space.

Critical Thinking and Problem-solving: the results show an improvement from 2.4 to 4.6, which is one of the most significant gains and highlights the strengthening of analytical abilities and problem-solving skills.

Project management: Here, the experimental group’s performance improved from 2.0 to 4.3, noting progress in project planning, organisation and control.

ICT security and ethics: an improvement from 2.1 to 4.4 indicates a higher level of understanding and application of the principles of security and ethics in the field of ICT.



	Operational	Information	Communication	Critical Thinking and Problem Solving	Project Management	ICT Security and Ethics
Before the Experiment (Control Group)	2.2	2.0	2.4	2.3	2.1	2.1
Before the Experiment (Experimental Group)	2.3	2.1	2.5	2.4	2.0	2.1
After the Experiment (Control Group)	2.5	2.2	2.7	2.6	2.2	2.2
After the Experiment (Experimental Group)	4.2	4.5	4.7	4.6	4.3	4.4

Figure 3: Diagram of the Assessment Results of ICT Competence of Students in the Educational Program for Pedagogical Biology (Source: own)

Experimental Results: Chemistry Program

Students of the educational program for pedagogical chemistry used ICT to simulate chemical reactions, study the structure of molecules and conduct virtual chemical experiments. Using digital tools and software to visualise chemical processes has facilitated the understanding of complex concepts and contributed to developing critical thinking. Virtual laboratories allowed students to experiment with various chemicals safely and study their properties and reactions, which contributed to the deepening of knowledge in the field of chemistry.

Figure 4 shows the results of assessing the information and communication competence of students of the educational program for pedagogical chemistry before and after the experiment. The experiment aimed to assess the impact of information and communication technologies in laboratory work. The data is grouped by the six essential skills.

Operational skills: the student's performance in the experimental group improved from 2.2 to 4.4, indicating a significant development of skills directly using ICT.

Information skills: the improvement from 2.1 to 4.6 reflects the growth of students' skills in finding, analysing and critically evaluating information.

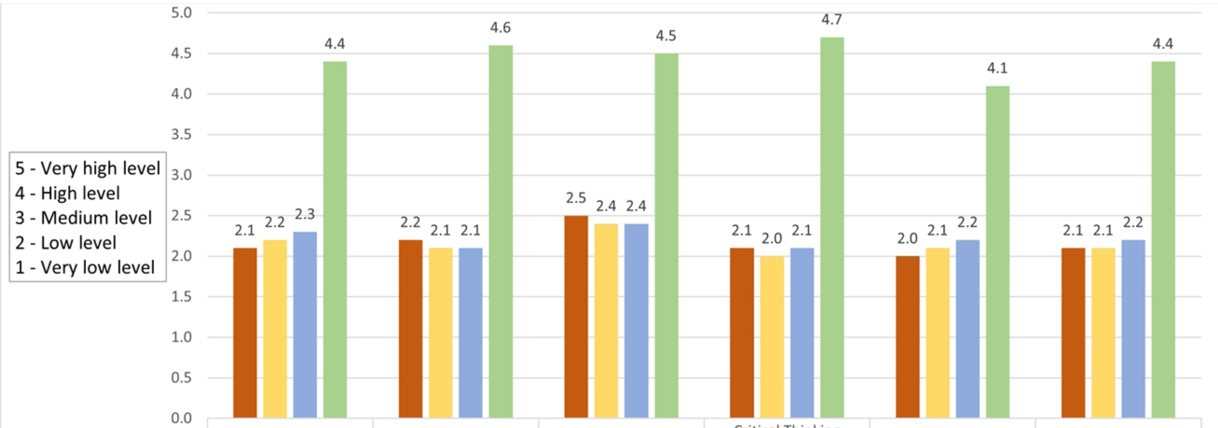
Communication skills: an increase from 2.4 to 4.5 indicates an improvement in students' ability to communicate and interact effectively.

Critical Thinking and Problem-solving: the score increased from 2.0 to 4.7, which is a significant improvement in students' ability to analyse situations and make informed decisions.

Project management: the increase from 2.1 to 4.1 indicates an improvement in skills in planning, organising and managing projects.

Project management: the increase from 2.1 to 4.1 indicates that students have significantly improved their ability to organize their work and manage time and resources effectively.

ICT Security and Ethics: the improvement from 2.1 to 4.4 demonstrates students' increased understanding of security and ethical aspects in the field of ICT.



	Operational	Information	Communication	Critical Thinking and Problem Solving	Project Management	ICT Security and Ethics
Before the Experiment (Control Group)	2.1	2.2	2.5	2.1	2.0	2.1
Before the Experiment (Experimental Group)	2.2	2.1	2.4	2.0	2.1	2.1
After the Experiment (Control Group)	2.3	2.1	2.4	2.1	2.2	2.2
After the Experiment (Experimental Group)	4.4	4.6	4.5	4.7	4.1	4.4

Figure 4: Diagram of the Assessment Results of ICT Competence of Students in the Educational Program for Pedagogical Chemistry (Source: own)

Experimental Results: Physics Program

Students of the educational program for pedagogical physics used ICT to model physical experiments and visualise complex physical processes. This allowed them not only to better understand the fundamental physical laws and principles but also to learn how to explain these phenomena in an accessible language, which is extremely important for future teachers. The use of interactive simulations and virtual laboratories helped to increase students' interest in the subject and develop their analytical skills.

Figure 5 presents the results of assessing various aspects of information and communication competence among students for pedagogical physics before and after the experiment conducted as part of the study. The assessment of ICT competence was also divided into six skills. It shows that in each skill, students in the experimental group significantly increased grades after the experiment compared with their baseline level and with the results of the control group, which adhered to traditional teaching methods.

Operational skills: In the experimental group, the skill level increased from 2.3 to 4.4, indicating a significant improvement in the ability to work with ICT.

Information skills: Here the improvement was from 2.1 to 4.5, demonstrating an increase in skills in finding, evaluating and using information.

Communication skills: the score increased from 2.5 to 4.7, which is one of the most considerable improvements and reflects the development of effective communication skills.

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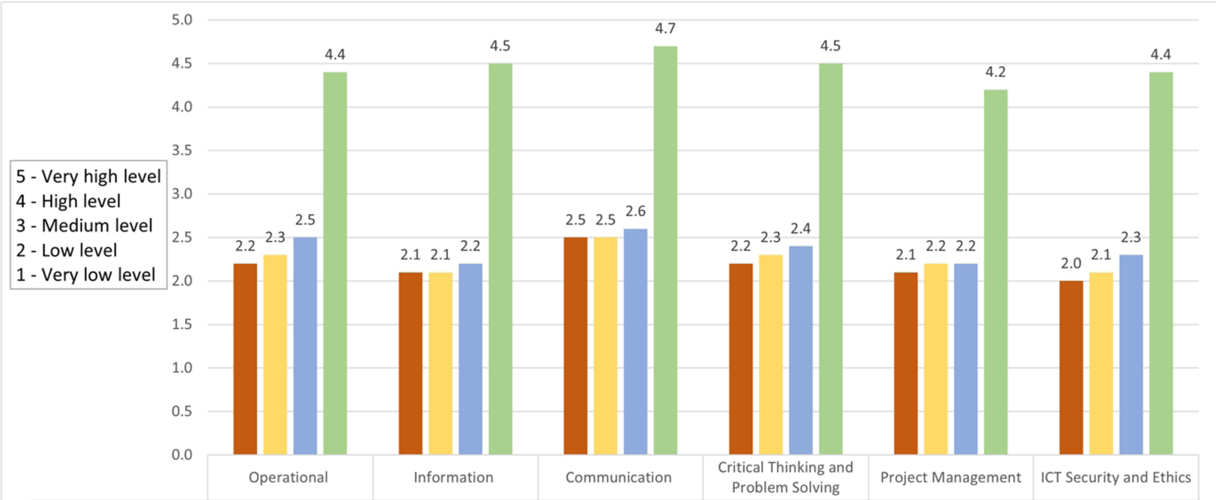
Critical thinking and problem-solving: In this category, the results increased from 2.3 to 4.5, emphasising the development of analytical abilities and the ability to solve complex problems.
Project management: the increase from 2.2 to 4.2 shows that students have improved at organising their work and managing time and resources.
ICT security and ethics: Here, the improvement from 2.1 to 4.4 indicates increased awareness of the importance of security and ethical standards in the field of ICT.



	Operational	Information	Communication	Critical Thinking and Problem Solving	Project Management	ICT Security and Ethics
Before the Experiment (Control Group)	2.2	2.1	2.5	2.2	2.1	2.0
Before the Experiment (Experimental Group)	2.3	2.1	2.5	2.3	2.2	2.1
After the Experiment (Control Group)	2.5	2.2	2.6	2.4	2.2	2.3
After the Experiment (Experimental Group)	4.4	4.5	4.7	4.5	4.2	4.4

Figure 5: Diagram of the Assessment Results of ICT Competence of Students in the Educational Program for Pedagogical Physics (Source: own)

Results of the Mann-Whitney U-Test of Educational Programs

Our results indicate that the integration of ICT into the laboratory work had a significant positive impact on the development of information and communication competence of students of educational programs of biology, chemistry, and physics. Improvements were seen in all ICT skills: operational skills, information skills, communication skills, critical thinking and problem solving, project management, ICT security and ethics (Table 6).

Educational program	Group	*U*-statistic	*P*-value	*Z*-value	*R*-value	Result
Pedagogical Biology	Control Group	259.5	0.55	-0.59	-0.08	Accepted
	Experimental Group	0.0	2.09e-09	-5.94	-0.86	Rejected
Pedagogical Chemistry	Control Group	256.5	0.51	-0.65	-0.09	Accepted
	Experimental Group	0.0	2.0e-09	-5.94	-0.86	Rejected
Pedagogical Physics	Control Group	234.5	0.254	-1.10	-0.16	Accepted
	Experimental Group	0.0	2.0e-09	-5.94	-0.86	Rejected

Table 6: Results of Mann Whitney U-Test (Source: own)

In all educational programs (pedagogical biology, pedagogical chemistry and pedagogical physics), extremely low p-values are observed for experimental groups (on the order of 2.09E−09 and 2.00E−09), which confirms statistically significant differences between the control and experimental groups. High negative values of *Z-statistic* (-5.94 for all programs) indicate significant deviations, and *R-values* (-0.86 for experimental groups) indicate a strong negative correlation. These data indicate a significant impact of the intervention, which indirectly confirms the presence of a large effect of magnitude. The study results demonstrate statistically significant improvements in the ICT competence of future teachers in the experimental groups compared with the control groups in all educational programs and essential skills considered. This allows us to confidently reject the null hypothesis 7 and confirm the alternative hypothesis 7, according to which the introduction of ICT tools into the educational process positively affects the ***formation of students' ICT competence***. Thus, the study confirms the importance and necessity of integrating ICT into laboratory works to improve the ICT skills of future specialists in the field of pedagogy of natural sciences.

Results of the Interviews

The interview was conducted with the aim of a deeper analysis of the level of students' ICT competencies and verification of the questionnaire data obtained. Through an open discussion with the respondents, the practical aspects of their use of ICT in educational activities were clarified. The questions covered the same key aspects as in the questionnaire, such as operational, information, communication skills, critical thinking and problem solving, project management and digital security and ethics.

The results of the responses showed that the data obtained largely coincided with the results of the questionnaire survey, confirming the average and below average level of ICT competencies among most students. Students demonstrated confidence in using basic ICT tools, but often faced difficulties in solving more complex tasks such as data processing and Internet security.

DISCUSSION

Kormakova et al. (2021) and Wong and Daud (2018) explore the essential skills required by teachers, highlighting the impact of these competencies on teaching efficacy and student engagement. Conversely, for example, the study by Maende and Opiyo (2014) examines the broader structural and systemic elements involved in deploying ICT in education nationally. This analysis details the critical roles of various stakeholders, including government entities and policy frameworks, emphasising a comprehensive and cooperative approach crucial for effectively integrating ICT in educational infrastructures.

The Teachers' Digital Competence Frameworks by Kiryakova and Kozhuharova (2024) and the ICT Competence Framework for Higher Education (UNESCO, 2018), both emphasise the development of essential digital skills for effective technology integration in teaching. Frameworks like DigCompEdu (Redecker, 2017) focus on areas such as digital literacy, pedagogical application, and digital citizenship, while the Kazakhstani framework additionally stresses self-efficacy, attitudes towards ICT, and institutional infrastructure. These frameworks informed the structure of the present study, particularly in selecting key competence areas for evaluation. The study's findings confirm that targeted ICT integration supports the development of operational, informational, and communication skills, aligning with the priorities outlined in the frameworks. Furthermore, the role of institutional support identified in the Kazakhstani context was reflected in the results, reinforcing the need for comprehensive training programs and supportive policies.

The decision not to use other standardised surveys was based on the fact that they did not consider the requirements for measuring the specific six ICT skills we sought to evaluate. In the study by Caluza et al. (2017), the survey on the assessment of ICT competencies of public-school teachers was divided into two domains: Technology Operations and Concepts and Pedagogical Indicators. The division of questions into blocks for all ICT skills ensured focus and accuracy in the assessment, allowing for a thorough examination of every aspect of ICT competence. This facilitated the analysis, making it possible to study in-depth the strengths and weaknesses of learning in each specific area of ICT.

The survey elements used in this study were tested for compliance and reliability using Cronbach's alpha coefficient of 0.89. Furthermore, McDonald's Omega coefficient was computed, yielding similarly high results and further supporting the internal consistency of the questionnaire. The high reliability indices indicate that the questionnaire items are well interconnected. Thus, it allows us to confidently use this questionnaire to research further and assess students' ICT competence.

Only physics pedagogical students (N = 126) participated in the study by Firmansyah et al. (2020). We tested three different pedagogical specialties (N = 115). In both studies, there were samples from only one institution. In a follow-up study, we would like to conduct research at other universities, possibly from different countries, to compare the results.

The study's findings highlighted the importance of integrating various ICT tools into laboratory work to enhance future teachers' digital competencies. Students also recognised the potential benefits of incorporating virtual laboratories into the learning process, highlighting a promising direction for the future development of ICT integration in education. The advantages of a virtual laboratory over a physical one, regardless of whether the latter is used for on-site or remote work. Advantages include savings benefits, flexibility, multiple access points, manageable changes to system configuration, damage resistance, and the ability to make the unseen visible. Expected advances and emerging trends lie in the area of alternative input and output devices for virtual worlds (e.g., haptic/force feedback, motion sensing, stereoscopic displays). The advent of consumer-level immersive VR headsets (e.g., Oculus Rift) may also have implications for the field. Implementing immersive education, distance learning, and virtual worlds open up significant questions in pedagogy and the design of effective learning experiences (Brabec et al., 2024; Potkonjak et al., 2016). As a further study, we can take a course not only on the use of ICT tools during laboratory work but also on the introduction and use of virtual laboratories in the educational process, which can also positively affect the formation of ICT competence of future teachers.

Limitations

Several limitations need to be considered. First, we selected respondents from only one university, so the sample was not representative enough to generalise the conclusions. On the other hand, our research describes the path we want to take in the future and can become an inspiration for other researchers. Follow-up studies should create a sample from multiple institutions in one or more countries with similar educational systems (e.g., CIS or CEE countries) while aiding the data from interviews and test results. This should help to reduce the bias resulting from self-reported data and common-method variance (CMV) that might artificially inflate relationships among study variables (Sharma, Yetton, and Crawford, 2009).

Virtual labs in science education have emerged as a viable and potentially transformative alternative to traditional hands-on laboratory experiences. Even though every strategy has advantages and disadvantages of its own, the best option should be determined by the limits, resources, and particular learning objectives. Virtual labs are instrumental in scenarios where traditional labs are not feasible since they can improve accessibility, scalability, and cost-efficiency (Asare et al., 2023). This confirms the relevance of research and can also contribute to the formation of ICT competence among students of pedagogical specialties.

CONCLUSION

The findings confirm the pivotal role of ICT in enhancing students' communication skills, improving laboratory interactions, and boosting motivation. However, challenges such as unequal access to technology and the need for extensive teacher training persist. Integrating ICT into the education system has emerged as a crucial element in improving the pedagogical landscape, particularly in training future teachers in the field of natural sciences. This research highlights the transformative potential of ICT in the development of information and communication competencies among aspiring teachers, demonstrating a marked improvement in these competencies through the innovative use of ICT in the laboratory.

Empirical data collected during the research demonstrate a positive correlation between the integration of ICT and the improvement of information and communication competencies. Students who have used ICT tools in laboratory work demonstrated excellent operational, information, communication skills, and critical thinking. These findings not only advocate for the inclusion of ICT in the curriculum but also highlight the need for educational institutions to re-evaluate and adapt their teaching strategies to train teachers who can navigate the digital landscape.

In conclusion, the advent of ICT represents a pivotal shift in educational methodologies, particularly within the natural sciences. Our research confirms the positive impact of integrating ICT on the development of future teachers' competencies and serves as a catalyst for further investigation into innovative pedagogical approaches.

Future research should be directed toward several key areas that build upon the findings of this study. First, it is important to assess the long-term impact of ICT integration on the professional training and career development of graduates, examining how the skills acquired during their studies influence their future success. In addition, further research should analyse the ways in which ICT transforms traditional teaching methods, identifying which innovations are most effective across different educational settings. Another important direction involves determining the most suitable ICT tools and pedagogical strategies for various learning environments, including online, blended, and traditional classroom formats. Finally, there is a need to develop, implement, and test new pedagogical approaches and ICT solutions aimed at enhancing the quality of education and improving educational interactions. Addressing these areas will contribute to a deeper understanding of the role of ICT in modern education and support the creation of more effective, adaptive learning environments.

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APPENDIX

SURVEY QUESTIONS

The assessment in the submitted questionnaire is based on a 5-point Likert scale, where: *1 – 'very bad', 2 – 'unsatisfactory', 3 – 'satisfactory'/'neutral', 4 – 'good', 5 – 'very good'.*

Block 1. Operational skills

1. How do you rate your text formatting skills in a text editor?
2. How confident can you insert images and create tables in text documents?
3. Evaluate your level of familiarity with the functions of a text editor for creating professionally designed documents.
4. How often do you use modelling software in educational or research projects?
5. How well do you understand the principles of the modelling program?
6. How do you assess your ability to quickly master new functions in specialised software?

Block 2. Information skills

1. How do you rate your skills in searching scientific sources in databases?
2. How effectively can you assess the reliability of scientific information?
3. How often do you use Excel to analyse data?
4. Evaluate your ability to visualise data using Excel.
5. How well can you organise and analyse large amounts of data?
6. What is your confidence level in using advanced Excel functions for data processing?

Block 3. Communication skills

1. How do you rate your science blogging skills?
2. How well do you know how to discuss and present the results of laboratory work in a blog?
3. How often do you organise online conferences to present projects?
4. Evaluate your ability to effectively interact with the audience during online presentations.
5. How well do you know how to use digital collaboration tools?
6. How do you assess your ability to adapt communication styles for different platforms?

Block 4. Critical thinking and problem-solving

1. How often do you apply theoretical knowledge in virtual laboratories?
2. How successfully do you solve practical problems using virtual experiments?
3. How do you rate your skills in analysing real cases?
4. How effectively do you develop solutions to complex problems?
5. How often do you use analytical thinking to solve problems?
6. Evaluate your ability to think innovatively in difficult situations.

Block 5. Project management

1. How do you rate your ICT project planning skills?
2. How successfully do you allocate tasks and resources in projects?
3. How often do you participate in project management?
4. Evaluate your ability to coordinate the activities of the team within the framework of projects.
5. How well do you handle time management in projects?
6. How do you assess your ability to adapt to changes and surprises during the course of the project?

Block 6. Security and ethics in the field of ICT

1. How do you assess your knowledge of the principles of digital security?
2. How well do you understand the laws and regulations governing data protection?
3. How often do you update your data security software?
4. How well are you aware of the methods of preventing cyber-attacks?
5. How do you assess your ability to conduct security training for other users?
6. How often do you face ethical dilemmas in ICT and how do you solve them?

INTERVIEW QUESTIONS

1. Operational skills:

- Can you tell us how you usually work with text editors (for example, Microsoft Word or Google Docs)? What functions do you use most often?
- Describe how you create tables and work with data in spreadsheets (for example, Excel, Google Sheets). What types of data are you processing?
- What types of presentation software have you worked with? How do you structure information in your presentations?

2. Information skills:

- How do you search and evaluate the reliability of information on the Internet or in scientific databases?
- Can you tell us about your experience in data processing (for example, in laboratory work)? What tools have you used for data analysis?

3. Communication skills:

- How do you use digital platforms for communication and collaboration (for example, social networks, messengers, online conference tools)?
- Can you describe how you presented your work or projects on digital platforms? What problems have you encountered while doing this?

4. Critical thinking and problem-solving skills:

- Describe a case where you needed to solve a practical problem using ICT. What tools did you use and how did you come to a decision?
- How do you approach information analysis and decision-making based on data obtained from digital sources?

5. Project management skills:

- How do you organize your work in the framework of projects using ICT? What tools do you use to plan and distribute tasks?
- How do you coordinate the work of the team or your tasks within the framework of training projects?

6. Security and ethics in ICT:

- How do you protect your personal data and project data on the Internet? What security measures do you take?
- What ethical aspects of using ICT are important to you, and have you faced ethical dilemmas when working with information technology?