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Formation of students' research skills in digital transformation of physics teaching

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ABSTRACT

Rapid changes in the learning system, renovative student audience needs and the requirement to intensify practical classes led to the need to reconsider the usual approaches to teaching physics. This study examines the use of digital technologies, including the creation of a virtual laboratory, in order to enhance students' research skills without sacrificing face-to-face learning. The focus is on the potential of digital tools to replicate hands-on learning and facilitate a more engaging and effective learning process. A mixed-method study was conducted at the Kazakh National Women's Pedagogical University and Kazan Federal University. It included experimental research and a cross-sectional survey to assess students' academic achievement using pre- and post-testing. The data collected were analyzed using ANOVA and other statistical methods. The introduction of virtual laboratories significantly improved student motivation and engagement in the learning process. This platform promoted the development of research skills. They as well allow students actively study the material and perform simulation experiments. In this process teachers use accessible learning paths and tools to create individualized educational programs. At the same time, certain difficulties were identified related to technical aspects and ensuring proper user support. The use of digital technologies, in particular virtual laboratories, contributes to the growth of students' interest in physical culture and the improvement of their research skills. To achieve the best results, it is important to overcome technical difficulties and ensure proper training for both students and teachers. Important conditions for the successful implementation of digital tools in the educational process are the provision of comprehensive support and the organization of high-quality training.

Keywords: Virtual laboratory, Teaching strategy, Motivation, Natural Sciences, Learning trajectories

1. Introduction

Teaching natural sciences, especially physics, is gaining strategic importance due to the growing role of science in modern society. Education, which is constantly digitalizing, creates new prospects for forming research competencies in students, a key element of scientific thinking. This is especially important for physics, where students are required to master theoretical knowledge as well as to be able to apply it in solving practice applied problems. The formation of scientific thinking should begin from the early stages of education and gradually improve through the introduction of research approaches into the educational process [1]. In the context of the modern digital era, when information is available in large volumes, skills such as critical thinking, data analysis, information synthesis and the use of modern technologies. They are focused on solving scientific problems, thus becoming important. A striking example is the experience of Kazakhstan, where large-scale projects are being implemented to modernize education and introduce digital technologies into physics teaching [2]. Initiatives such as the Concept of Education Development of the Republic of Kazakhstan for 2023–2029 and international programs, particularly the UNICEF Global Transfer Skills System, emphasize the importance of training teachers working in a digital environment [3]. The achievement of positive results in this area is possible in case of laboratory equipment modernization, as well as when practical classes are included in the curricula, and teachers are continuously trained to work with digital tools. Research in the field of physical education reveals a number of obstacles that affect the quality of teaching in

the digital era. These include insufficient attention to experimental methods, which limit the development of practical skills; a shortage of material and technical resources, which complicates laboratory work; low level of use of information and communication technologies (ICT) in education; and insufficient support for the professional development of teachers regarding the integration of digital tools into the educational process. The effective resolution of these issues requires both high-quality infrastructure and modern pedagogical approaches to develop research skills in students [4]. In this context, the use of virtual laboratories and simulations allows students to gain experience with experimental data even in the absence of physical equipment. Moreover, interactive platforms can increase student engagement in research activities by developing their critical thinking, analytical skills and decision-making independence.

Thus, the purpose of this study is to assess the possibilities of introducing experimental methods in a digital format in the study of physics with an analysis of teachers' practices in the formation of students' research skills and to determine the prospects for using modern technologies to improve the efficiency of the educational process in physics.

Particular attention is paid to the analysis by means of a questionnaire of the virtual laboratory workshop implemented in the teaching process with the prospect of simulating physical experiments, engaging students in active learning even in a distance format, ensuring equal access to practical training regardless of the material and technical conditions of the institution, and creating conditions for the improvement of teachers' digital competences, particularly through professional development programs (Annex A).

1.1. Research questions

1. How does the digital transformation of physics education affect students' academic performance?
2. Is there a significant difference in the results of research assignments between students who are engaged in the use of digital technologies and students who use traditional teaching methods?
3. How does the use of digital tools affect the level of students' research skills in physics education?
4. What aspects of digital technologies do students consider most useful for developing research skills?
5. What difficulties do students face when using digital tools for research tasks?

Thus, the results of the study could contribute to the development of innovative approaches to teaching physics that meet the requirements of digital transformation. They will allow the formation of competitive specialists in the modern scientific and technological environment.

2. Literature review

Amid the digital transformation of education, the teaching of physics in Kazakhstan's higher education institutions is gaining increasing relevance. According to the pedagogical guidelines of the Ministry of National Education of Kazakhstan, the main goal is to form a scientific and technological culture among students [5]. This includes the development of critical thinking, the ability to analyze and synthesize information, as well as to apply the knowledge in practical situations. In today's world, where information technology is central, it is important to adapt physics teaching methods so that students can actively research, experiment and acquire knowledge individually [6].

The physics curriculum in Kazakhstan's higher education institutions provides an even distribution of study time between lectures and practical classes [7]. This enables students to gain theoretical knowledge and develop practical skills through experimental research. In this context, [8] adds that it is important that teachers use modern information and communication technologies. It gives the possibility to create an interactive environment that encourages students to research, solve problem-solving and teamwork. In a similar paper [9], the author proposes a methodology based on the gradual complication of concepts. This plays a key role in the formation of research skills. The authors emphasize that the use of such forms of learning as projects, problem-based tasks, and research approaches contributes to a deeper assimilation of the material and the development of critical thinking. An important element is the ability of students to independently formulate hypotheses, perform experiments, and analyze the obtained data, which is the basis of research activities.

Reference [10] believe that experimental work is a necessary component of physical education. It not only contributes to the assimilation of scientific knowledge but also develops practical skills that help to better understand complex scientific concepts. Reference [11] adds that to achieve high learning outcomes, it is necessary to ensure the integration of experimental activities with theoretical classes, as this allows students to more clearly understand the connection between theory and practice.

In the same vein [12] notes that traditional forms of experimental activities, such as laboratory work, demonstration experiments, and practical classes, need to be adapted to modern conditions. The involvement of digital tools, in particular modeling and virtual laboratories, can significantly increase the effectiveness of the educational process. This creates opportunities for conducting experiments in an environment that is as close as possible to scientific research.

Other papers [13] also draw attention to the problems that arise during the implementation of experimental practice. In the same context, in the paper [14] is argued that students often face difficulties in linking theory to practice, which can lead to misconceptions. Therefore, teachers should actively work to develop students' critical thinking and reflection by encouraging them to analyze experimental results in more depth.

Accordingly, the development of students' research skills during the digital transformation of physics education is an important aspect that requires the integration of modern technologies, active learning methods and experimental practice [15]. This will improve the quality of education and prepare students for the challenges of the modern world.

However, the current stage of development of educational systems requires adaptation to rapid changes, particularly due to digitalization. This process opens up wide opportunities for the improvement of students' research skills, especially in the field of physics [16]. Information and communication technologies (ICT) are gradually becoming an integral part of the educational process, contributing to both improving its quality and developing the competencies necessary for the modern world. Thanks to the ICT, interactive educational environments are created. They provide a deeper understanding of physical concepts. Namely, modeling and virtual laboratories make it possible to conduct experiments that may be inaccessible or dangerous in real conditions.

According to other similar research [17], the use of such technologies not only arouses interest in learning but also develops critical thinking and problem-solving skills. It can be said that they are the basis for success in scientific activities [18].

It is worth noting that the introduction of information and communication technologies is not aimed at replacing traditional approaches in learning, but at improving and adapting them to modern realities. Within the framework of this study, the attention was focused on the use of experimental methods in teaching physics, as well as on the significant role of ICT in this process. To obtain data, a survey was conducted among students studying physics. The results of the survey became a valuable basis for further analysis.

The results obtained can be used to improve curricula, introduce modern technologies into the educational process, and develop students' research skills in the field of physics, which fully meets current educational requirements.

3. Methods

The aim of this study was to determine the impact of digital technologies on the development of students' research skills in terms of study physics. A mixed methodology that combined an experimental approach as well as a questionnaire was used in the work.

For the analysis two student groups were formed. The experimental group studied with the involvement of digital technologies with a particular focus on a virtual laboratory. The control group adhered to traditional teaching methods. To evaluate the results, a comparative analysis was carried out in order to establish statistically significant differences.

3.1. Experimental study

The experimental part of the study was aimed at assessing the academic performance of students in both groups. The study was conducted at the Kazakh National Women's Pedagogical University and had two stages. The first stage consisted of a pre-test to assess students' academic knowledge before the course to confirm the homogeneity of the sample. The second stage included a post-test to assess students' academic performance after the course. An appropriate statistical method (ANOVA) was used to analyze the data. The theoretical part of the study was conducted at Kazan Federal University.

3.2. Cross-sectional survey

A cross-sectional survey was conducted among the students of the experimental group after completion of the course. Qualitative data was collected using a semi-structured interview. After explaining the survey process and obtaining consent, students were asked to rate the use of digital technologies in learning on a Likert scale (1 – "completely disagree", 5 – "completely agree"). This allowed quantifying the qualitative responses (Table 1):

Table 1. The semi-structured interview for the assessment of digital technologies impact on physics learning

Question	Clarifying question	Answer options
1. How does the digital transformation of physics education affect students' academic performance?	Have you noticed any changes in your academic performance when using digital technologies?	Yes, the results are positive. No, no changes were detected. Yes, the results are negative.
	Please rate the following statements on a Likert scale:	Digital technologies contribute to a deeper understanding of theoretical aspects. The use of modern tools stimulates your interest in the learning process. Digital tools make learning physics more accessible and understandable
	What digital technologies do you find most useful for improving academic performance?	Your answer.
2. Is there a significant difference in the results of research tasks between students who study using digital technologies and students who use traditional teaching methods?	How would you rate your results in research tasks compared to students who study using the traditional method?	Your answer.
	Please rate the following statements on a Likert scale:	The use of digital technologies contributes to increasing the efficiency of research tasks. However, tasks involving the use of digital tools require more time compared to traditional approaches. The use of digital technologies improves the accuracy and quality of tasks performed.
	Are there any examples where digital technologies have significantly helped or, on the contrary, complicated research tasks?	Your answer.
3. How does the use of digital tools affect the level of students' research skills in physics education?	How does the use of digital tools affect the level of students' research skills in physics education?	Your answer.
	Which of your research skills have improved thanks to digital technologies?	
	Please rate the following statements on a Likert scale:	

Question	Clarifying question	Answer options
4. What aspects of digital technologies do students consider most useful for developing research skills?	Have you used digital tools outside the classroom to complete research assignments? Choose the aspects that you consider most useful for developing research skills: Please rate the following statements on a Likert scale: What problems have you encountered most often? Please rate the following statements on a Likert scale:	Digital tools contribute to better mastery of experimental methods. The use of digital technologies allows you to prepare more effectively for research tasks. Thanks to the use of digital tools, I feel more confident in conducting research tasks. Your answer. Interactive reproduction of physical processes Using virtual laboratories Access to open learning resources Automating calculations Interactive reproduction contributes to a deeper understanding of complex concepts. Virtual laboratories provide the opportunity to conduct experiments without any risks. Automated calculations save time and minimize the likelihood of errors.
5. What difficulties do students face when using digital tools for research tasks?	What do you think could be improved in the use of digital technologies in physics education?	Technical problems (software crashes, low internet speed, etc.). Lack of clear instructions on the use of digital tools. Difficulties in integrating new technologies into the educational process. Lack of time or additional resources. Technical issues reduce my desire to use digital tools. I feel confident working with digital technologies. I need additional support from a teacher or mentor. Your answer.

Source: Authors' own research.

3.3. Data collection methods

Quantitative data included pre- and post-course academic performance assessments. Additionally, an analysis of variance was used to identify significant differences between groups.

Qualitative data were obtained through semi-structured interviews, which allowed for a detailed examination of the impact of digital technologies on the development of research skills in students (Annex B).

3.4. Data Analysis

Student learning outcomes were quantitatively assessed by using statistical methods to identify differences between the experimental and control groups. A qualitative analysis was conducted using student responses from the interviews. The collected data was coded and analyzed to identify key themes, including the impact of digital technologies on motivation, engagement, and research skills.

4. Results

The study examined the results of a focus group consisting of 40 students. The data collected were divided into quantitative and qualitative for further processing. The quantitative analysis included a comparison of students' performance before and after completing the course. In the experimental group, where digital technologies were used, the average score increased from 68 ± 8.5 to 81 ± 7.2. In the control group, which studied using traditional methods, the average score before the start of the course was 69 ± 7.8, and after its completion - 74 ± 8.1. Statistical analysis using ANOVA showed a significant difference between the experimental and control groups (main effect: $p < 0.001$), as well as significant changes in performance in the experimental group before and after the course (interaction: $p = 0.002$). This confirms that digital technologies significantly improve academic performance compared to traditional teaching methods (Figure 1):

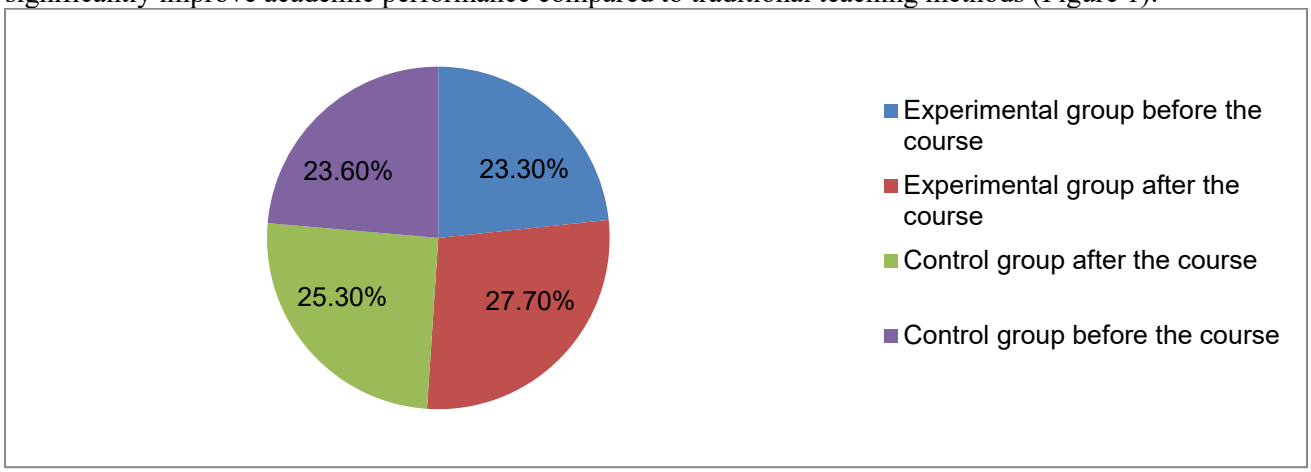

Figure 1. Quantitative indicators of student performance.
Source: Authors' own research.

Qualitative data from the semi-structured interviews highlighted several key themes. Firstly, 70% of students said that digital technologies made the learning material easier to understand and more accessible. Second, 65% of students acknowledged that interactive resources increased their motivation to learn. At the same time, 50% of respondents reported difficulties with learning new technologies or technical problems. In addition, 75% of students emphasized that digital tools helped to improve their research skills, such as data analysis, experiment design and interpretation of results (Figure 2):

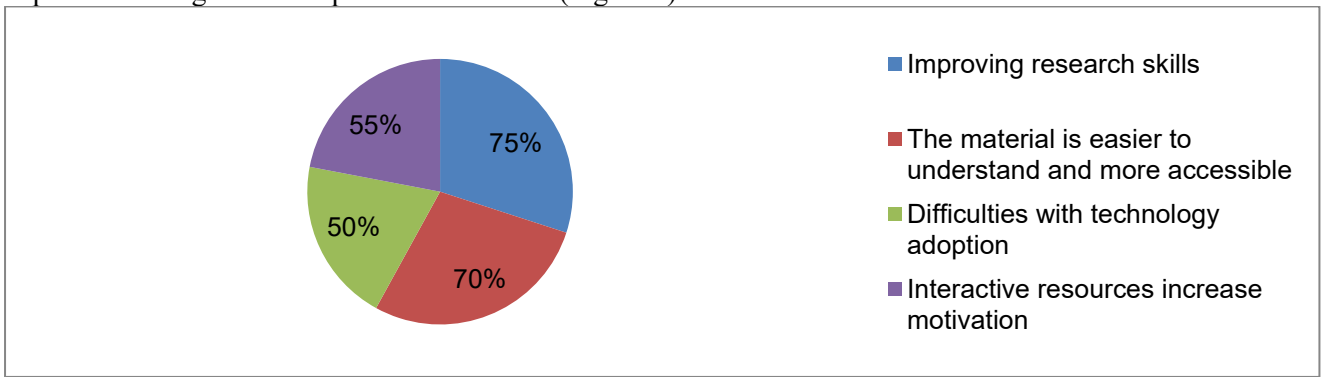

Figure 2. Key themes highlighted in the qualitative data
Source: Authors' own research.

The overall analysis showed that digital technologies facilitate individualized learning, allowing students to work at their own pace. As for interactive simulations and virtual laboratories, they were found to be the most

useful for practical learning. However, students expressed the need for additional support from teachers to overcome technical difficulties.

The results of the quantitative analysis confirmed the significant impact of digital technologies on academic performance, especially in the experimental group, which showed a greater increase than the control group. The qualitative analysis highlighted the importance of digital tools in the improvement of motivation, accessibility of materials, and the development of research skills.

The results of the semi-structured interview based on 40 students' responses yielded interesting results.

According to students, the digital transformation of physics education has a significant impact on academic performance. 65% of respondents noted positive changes, 25% did not notice any changes, and 10% indicated a negative impact. The majority of students (80%) believe that digital tools help them to better understand theoretical material, 70% indicated an increase in motivation to study, and 75% confirmed that these tools make learning more accessible. Interactive simulations (40%), virtual laboratories (35%) and educational platforms (25%) were recognized as the most useful technologies.

Regarding the results of research assignments, 60% of students reported improvements, 30% did not notice any changes, and 10% reported deterioration. Digital technologies were found to be effective in completing research tasks (75%) and improving accuracy (70%), although 45% said they were more time-consuming. The help from digital technologies was confirmed by 65% of students, while 20% said that these tools made tasks more difficult.

The use of digital tools has had a positive impact on the development of research skills. The skills that increased the most were data analysis (50%), conducting experiments (45%), interpreting results (40%), and formulating hypotheses (30%). Digital tools improved the understanding of experimental work (70%), preparation for assignments (65%), and confidence in performing assignments (60%). 75% of students used these tools outside the classroom.

Among the useful aspects of digital technologies, interactive simulations (45%), virtual laboratories (40%), open educational resources (35%) and computing automation (25%) are highlighted. Interactive simulations contribute to a better understanding of complex topics (80%), virtual laboratories provide a safe experimental experience (70%), and computing automation saves time (65%).

Difficulties faced by students include technical problems (50%), lack of instruction (40%), difficulty learning new technologies (35%), and lack of time or resources (30%). Technical difficulties reduce motivation (55%), 60% feel confident with technology, but 70% need additional support from the teacher.

These results demonstrated their importance and became the basis for analyzing the impact of digital technologies and developing recommendations for their effective implementation in the physics education process.

Accordingly, recommendations may include integrating digital technologies in order to support academic performance and skills development, providing additional training for teachers and students on the use of digital tools, and ensuring access to stable technical resources.

A qualitative analysis of students' responses to interviews about the impact of digital technologies on physics learning according to the main questions showed a positive impact among 65% of respondents who noted that digital technologies contributed to the improvement of academic results. This may be due to increased opportunities for self-study and ease of access to materials. 25% did not notice any changes, and 10% indicated a negative impact, which may indicate insufficient preparation or inadequate use of technology. 70% of students reported increased motivation to study. Digital tools have made learning more interactive, which may explain this effect. 75% of students believe that digital technologies make learning more accessible, which contributes to engagement in the process. 60% of students noted an improvement in the results of research tasks. 75% consider digital technologies to be effective for research. Data analysis (50%) and experimentation (45%) skills have increased the most. This demonstrates the real impact of digital tools on the development of critical thinking and practical skills. The most useful were interactive simulations (40%) and virtual laboratories (35%), indicating their important role in the learning process. The majority (70%) believed that digital tools contribute to a better understanding of experimental work. At the same time, 50% of students encountered technical problems that reduced their motivation to learn, highlighting the need for technical support and appropriate training. Over 70% of participants noted the need for additional assistance from teachers, indicating the importance of careful planning for the integration of digital technologies into teaching.

Digital technologies have a positive impact on the study of physics, increasing motivation, engagement and the development of research skills of students. However, to achieve the best results, it is necessary to consider technical challenges and provide additional support for both students and teachers [19]. The integration of digital tools should be accompanied by training and accessible technical assistance.

The study has several limitations that could have affected its results and interpretation. The small sample size limits generalizability in terms of a small number of participants can reduce the statistical significance. The duration of the experiment was only one academic year. It could be insufficient for assessing the long-term impact of digital technologies on the development of research skills. It also did not consider all external factors, including the initial level of knowledge, motivation of students, or their individual characteristics in using digital tools.

The use of a mixed approach allowed for a wider range of questions to be covered. However, it may introduce some subjectivity into the qualitative analysis as students' answers during interviews may have been partly due to social expectations or a desire to answer questions in accordance with the researchers' expectations. In this context, future studies could focus on expanding the sample, conducting longer-term observations, and better controlling external factors. This would allow for a more objective picture of the impact of digital technologies on the development of students' research skills.

5. Discussion

The research results showed that many physics teachers did not realize the importance of the pedagogical quality of digital tools that should help organize students' knowledge and skills [20]. Modern technologies play a key role both in the preparation of teaching materials and in supporting students in independent learning and developing research skills [21]. The introduction of artificial intelligence and virtual reality into physics education can significantly transform the way physical phenomena are studied by students.

In addition, research results emphasize the importance of experimental learning for forming the right ideas in students [22]. Although teachers conduct experiments during lectures, most students do not have the opportunity to work directly with laboratory equipment, which indicates that training is often focused on the theoretical part and the practical component is absent, especially in distance learning conditions. In this regard, the management of virtual laboratories and the use of integrated curricula can become the basis for effective delivery of practical classes in physics [23]. This confirms the need for educational reform, particularly by actively implementing virtual experiments in order to develop students' research skills in the era of digital transformation.

Research by [24] also highlights that practical classes in physics are crucial for the development of research skills in science and engineering students. According to the scientists, they provide an opportunity to apply theoretical knowledge in practice, master experimental methods and develop critical thinking. However, modern conditions, according to [25], namely the massive scale of education and the lack of laboratory equipment, create significant obstacles to conducting practical classes in the traditional format. This is especially true for distance learning.

In a similar work [26] is noted that the use of digital technologies in physics teaching is becoming increasingly widespread. In particular, the integration of virtual laboratories (VLs), according to scientists, opens up new opportunities for the development of students' research skills. This idea corelates with the proposed paper as such laboratories allow for simulating practical experiments, providing access to learning activities without space and time constraints. An example of a successful implementation is the EXPERES project described by Reference [27], which developed a virtual laboratory integrated into the Moodle platform. It provides individualized learning paths, monitoring of student progress, and convenient interaction with other learning activities.

Authors [28] note that virtual laboratories help increasing student motivation and engagement in the learning process while allowing teachers to adapt their teaching methods. The digital transformation of education, namely through the use of virtual laboratories, has great potential to improve the quality of learning [29, 30, 31]. At the same time, as ref. [32] pointed out that it is important to consider technical challenges and provide appropriate support for teachers and students, which is crucial for the effective integration of digital tools into the learning process. In this context, scientists [34] discuss the impact of digital technologies, in particular virtual laboratories, on the development of students' research skills. Scientists believe that virtual laboratories can become a powerful tool that can solve problems associated with insufficient laboratory equipment and a large number of students. They allow students to experiment at any time and from any place, which significantly increases the accessibility of the learning process.

In other paper [35] is emphasized that virtual laboratories not only increase accessibility but also provide an opportunity to integrate innovative teaching methods. The article reviews the EXPERES project, which aims to create models for studying physical phenomena such as optics and thermodynamics. The study shows that modeling contributes to a better understanding of complex concepts that are often difficult to learn in

traditional laboratory settings. Reference [36] analyzes the possibility of replacing practical work with real equipment with virtual laboratories. Scientists highlight that physics as an applied science requires interaction with real devices as although simulations provide effective visualization, they cannot fully convey the experience of working with physical equipment. Reference [37] argues that virtual laboratories should complement real laboratories, not replace them. They are useful for preliminary experimentation, giving students the opportunity to prepare for real laboratory work. The use of virtual laboratories contributes to the formation of key research skills in students, such as planning experiments, interpreting results, and solving complex problems. For example, in the EXPERES project, students were given the opportunity to change the parameters of experiments and investigate the consequences of these changes.

The integration of such technologies, according to the scientific thought by [38], reduces the workload on teachers, allowing them to focus on educational goals and freeing them from organizational tasks. Reference [39] studied the Moodle system, which is integrated with virtual laboratories and automatically tracks student progress, allowing the creation of individualized learning plans. However, technical challenges must be considered. It means that teachers must have appropriate training to work with such tools, and students must have access to the necessary equipment, including computers or tablets with Internet access [40]. In the context of the proposed study, we can agree with the authors that virtual laboratories are a powerful tool for the digital transformation of physical education, but their implementation requires a comprehensive approach [41]. As can be said they contribute to the development of research skills, reducing barriers to access practical training. However, it is important to strike a balance between virtual and real-life practical classes, considering technical and pedagogical aspects. In response to the research question of whether new technologies can effectively contribute to the development of students' research skills, especially in physics education, in the paper [42] is noted that much depends on the chosen digital tools, such as remote laboratories and virtual laboratories, each of which has its own advantages and limitations. In this sense, hands-on learning plays a key role in the development of students' research skills in science and engineering disciplines [43]. It allows students to acquire theoretical knowledge and skills in working with equipment, data analysis, and experimentation. In the digital era, the role of practical laboratories is transforming, and computer laboratories are coming to the fore [44].

In a related study [45], it is argued that remote laboratories provide access to real equipment without the need for physical presence. They are particularly useful for experiments that are expensive or dangerous. Such laboratories can be integrated into the education of students from remote regions, reducing inequalities in access to quality education. Authors [46] cite also disadvantages such as high dependence on internet connection and technical support can limit their effectiveness, limitations in interaction with equipment that can reduce hands-on skills, and automation of experiments reduces opportunities for students to be creative in their research. The paper [47] postulates that virtual laboratories are a new learning format. The researchers provide arguments in favor: virtual laboratories are accessible to a wide audience, even if real equipment is not available. A similar study by [48] proved that they allow experiments to be conducted without the risk of equipment damage or danger. Such laboratories contribute to a better understanding of theoretical concepts through interactivity and visualization. In a similar study [49], a counterargument is provided, namely that the lack of physical interaction with real equipment can limit the development of practical skills. Scientists [50: 51] note that simulations without context do not always accurately reflect the conditions of real experiments, and the use of virtual laboratories can create a false sense of competence without proper development of practical skills.

Additionally, the development of remote and virtual laboratories requires close collaboration between specialists in the fields of computer science, pedagogy, and didactics [52]. This approach allows for the creation of modern learning platforms that consider technical and educational aspects that are important for the development of research skills. According to studies by [53], the combination of virtual and traditional laboratories can be an effective option, allowing students to gain both theoretical and practical knowledge. This also contributes to the development of research skills in the context of digital transformation. It is important for the achievement of the optimal balance between the accessibility and effectiveness of remote and virtual laboratories. While digital changes in physics education open new opportunities, they also create new challenges that require careful analysis and discussion.

6. Conclusions

The results of the study confirm the significant positive effect of digital technologies use in teaching physics. They particularly improve student performance. Students who used digital tools during the experiment

demonstrated significantly greater progress compared to those who studied using traditional methods. The statistical analysis (ANOVA, $p < 0.001$) confirmed the effectiveness of introducing digital technologies into the learning process.

Digital tools contribute to the development of important research skills, such as critical thinking, data analysis, experimental design and interpretation of results. For example, 50% of students improved their data analysis skills, and 45% improved their experimental abilities. There was also an increase in motivation and interest among students, most of whom noted that digital technologies make learning more accessible and interesting.

On the other hand, some difficulties were identified. Half of the participants encountered technical problems. Some of them had difficulties in mastering new technologies, and most needed additional support from teachers. This highlights the need for effective technical assistance and adequate training of participants.

The most effective digital tools for students were interactive simulations and virtual laboratories, which significantly facilitate the understanding of both theoretical and practical aspects of physics.

For the successful implementation of digital technologies in physics education, it is necessary to ensure continuous training of teachers and students, as well as organize effective technical support to solve possible problems with the use of such tools. In addition, it is important to create adaptive learning platforms that take into account the individual needs of students, providing a personalized approach to learning. The interactive modeling and virtual laboratories should become the main components of curricula focused on the development of research skills.

Thus, digital transformation in physics education is a promising path to increase the efficiency of the educational process, the development of critical thinking and practical skills of students. Future research may include expanding the sample by involving students from other educational institutions, as well as conducting a longitudinal study to test the long-term retention of knowledge and skills of students from the experimental and control groups. Such a study will provide a comprehensive analysis of the impact of digital technologies on the formation of students' research skills, which will contribute to the further development of innovations in the field of physical education.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

The contribution to the paper is as follows: N. Zh. Akhmetova, N.A. Sandibayeva: study conception and design; G.I. Garnaeva: data collection; N. Zh. Akhmetova, N.A. Sandibayeva, G.I. Garnaeva: analysis and interpretation of results; N. Zh. Akhmetova: draft preparation. All authors approved the final version of the manuscript.

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Annex A

Computer Program No. 2024681269
Virtual Laboratory Practicum in Geometric Optics
Rights Holder: Federal State Autonomous Educational Institution of Higher Education
Kazan (Volga Region) Federal University (RU)
Authors:
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Application No.: 2024696459
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Registered in the computer program registry on: September 6, 2024

РОССИЙСКАЯ ФЕДЕРАЦИЯ

СВИДЕТЕЛЬСТВО

о государственной регистрации программы для ЭВМ

№ 2024681269

Виртуальный лабораторный практикум по геометрической оптике

Правообладатель: *федеральное государственное автономное образовательное учреждение высшего образования «Казанский (Приволжский) федеральный университет» (RU)*

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Заявка № **2024669459**
Дата поступления **20 августа 2024 г.**
Дата государственной регистрации
в Реестре программ для ЭВМ ***06 сентября 2024 г.***

Руководитель Федеральной службы по интеллектуальной собственности

Ю.С. Зубов

Annex B

Survey: The development of students' research skills while studying physics under the influence of digital technologies

Instructions: You are asked to answer the following questions. Your opinion will help analyse the impact of digital technologies on education.

1. How has the digitalization of physics education affected your academic performance?
What changes have you noticed in your academic performance after the integration of digital technologies?
Rate the following statements on a Likert scale (1 – "strongly disagree", 5 – "strongly agree"):
Digitalization of education and technology have a profound impact on the understanding of theoretical aspects.
Modern tools and their use stimulate interest in learning.
Digital technologies contribute to the study of physics in an accessible and understandable format.

2. Have you noticed a difference in the results of research tasks between students who have access to digital technologies and those who study using traditional teaching methods?
Name the most useful digital technologies for improving academic performance?
Evaluate your own results in research tasks in comparison with students who use the traditional method?
Rate the following statements:
The use of digital technologies significantly increases the efficiency of research tasks.
Tasks involving digital tools take more time compared to traditional teaching methods.
Digital technologies make the tasks performed accurate and of high quality.

3. How does the implementation of digital tools affect the level of research skills of students in physical education?
Have you used digital tools outside the classroom to complete research tasks?
What are the most important and useful aspects of digital technologies for the development of research skills?
Rate the following statements:
Interactive reproduction of material allows for a deeper understanding of complex concepts.
Virtual laboratories are a modern know-how for conducting experiments without risks for students.
Automated calculations save time and minimize the likelihood of errors.

4. Describe the obstacles and difficulties that students encounter when using digital tools for research tasks?
Could you give examples of when digital technologies were very relevant or, on the contrary, hindered the completion of research tasks?
Can you describe the most common problems within the framework of the digitalization of education?
Rate the following statements:
Technical problems demotivate the desire to use digital tools.
I feel confident when using digital technologies.
I need additional support from a teacher or mentor.

5. Give your own opinion on improving the use of digital technologies in physics teaching.
(Open answer)