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The influence of virtual laboratories on students' interest in STEM fields: a longitudinal study in secondary education

Batesh Karimova[1], Bibigul Zhumabekova[2], Sholpan Hamzina[1]
[1]High School of Natural Sciences, Alkey Margulan Pavlodar Pedagogical University, Pavlodar, Kazakhstan
[2]High School of Natural Sciences, Department of Biology, Alkey Margulan Pavlodar Pedagogical University, Pavlodar, Kazakhstan

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ABSTRACT

The objective of this article is to investigate the impact of virtual laboratories (biology, chemistry, physics, and mathematics) on students' interest in science, technology, engineering, and mathematics (STEM) fields over six months of study. The study involved 317 participants from Alkey Margulan Pavlodar Pedagogical University (Pavlodar Region, Kazakhstan), who were divided into experimental and control groups. An experimental approach was employed, wherein participants underwent training using virtual laboratories for six months. Statistical methods, specifically t-tests for paired and independent samples, were employed to analyze the results. The experiment revealed a statistically significant positive influence of virtual laboratories on students' interest in STEM fields. Participants in the experimental group exhibited an increased interest in biology, chemistry, physics, and mathematics compared to the control group. The research findings hold important practical implications for enhancing STEM education. The implementation of virtual laboratories may contribute to an increase in students' interest in studying STEM disciplines, which is crucial for shaping the future generation of specialists in these fields. Future considerations should involve exploring various types of virtual laboratories, taking into account sociocultural context, and addressing individual differences among students. Additionally, it is essential to investigate the longer-term effects of using digital technologies in STEM education.

Corresponding Author:

Batesh Karimova
High School of Natural Sciences, Alkey Margulan Pavlodar Pedagogical University
28 Kabanbay Batyr Avenue, Pavlodar, 140000, Kazakhstan
Email: btshkarimova@gmx.com

1. INTRODUCTION

The flourishing of technologies in the contemporary world is transforming the paradigm of education and unlocking new possibilities for in-depth exploration of science, technology, engineering, and mathematics (STEM) in secondary education [1]. One of the most significant aspects of this evolution is the utilization of virtual laboratories as an innovative means to enhance students' interest in STEM disciplines [2]. In this context, a longitudinal study becomes imperative, as it allows for a deeper understanding and identification of the sustained impact of virtual laboratories on student interest and motivation. The issue of waning interest among students in STEM fields is pressing, as these domains shape technological and innovative progress, and students sometimes encounter difficulties in comprehending abstract concepts and insufficiently interacting with real-world examples [3]. It is precisely in this context that virtual laboratories can emerge as a pivotal tool for transforming STEM education.

In the realm of utilizing virtual laboratories to enhance students' interest in STEM disciplines, several key issues and challenges warrant attention and resolution. The use of virtual laboratories is often associated with the requirement for high-speed internet connectivity and powerful computers, posing obstacles for some students and educational institutions due to limited accessibility and high equipment costs [4]. The effective utilization of virtual laboratories demands educators to acquire new skills and knowledge; some teachers may encounter challenges in mastering digital technologies and integrating them into the instructional process [5]. There is a need to develop effective strategies to engage students with virtual laboratories, encompassing the creation of engaging and substantive exercises that stimulate curiosity and foster critical thinking [6].

The development of assessment systems for studies conducted using virtual laboratories and ensuring adequate support for teachers during the teaching process are also pivotal tasks [7]. Financial constraints can impede the implementation of virtual laboratories in educational institutions, particularly in locations with insufficient financial resources [8]. Therefore, it is essential to meticulously examine and ensure the high-quality content of virtual laboratories to align with academic standards and requirements. Addressing these challenges will enable the maximization of the potential of virtual laboratories in stimulating students' interest in STEM disciplines.

The importance of conducting new research in this field is driven by the need to unlock the potential of virtual laboratories in enhancing students' interest in STEM disciplines. The contemporary generation of students is growing up in a digital world, making the use of interactive technologies potentially enriching the educational process. Investigating the impact of virtual laboratories on long-term student interest represents a step forward in strengthening STEM education and identifying optimal methodologies for preparing the next generation of specialists. The relevance of this topic is underscored by the rapid pace of changes in STEM sectors and the demand for highly skilled professionals to address contemporary challenges.

In recent decades, there has been a growing interest in the use of virtual laboratories in education, particularly in STEM fields [9], [10]. Many studies focus on the impact of these innovative tools on students' interest in the study of natural sciences, technology, engineering, and mathematics [11]–[13]. However, while virtual laboratories are recognized as potentially valuable, the literature often highlights several important aspects that require attention and research. One key discrepancy in virtual laboratories is the approach to pedagogical design and utilization. Some studies emphasize the importance of interactivity and the realism of simulations to achieve maximum pedagogical effectiveness [14]. On the other hand, others point to the importance of adhering to standards and the accuracy of virtual laboratories [15].

Another point of contention is the methodology for measuring the effectiveness of virtual laboratories. Some research is based on quantitative indicators, such as students' grade improvement [16], [17]. On the contrary, other researchers have sought to incorporate both quantitative and qualitative aspects, examining teachers' and students' impressions of virtual laboratories [18], [19]. The utilization of virtual laboratories in STEM education presents both advantages and disadvantages that warrant careful examination. Virtual laboratories enable students to access experiments and simulate real scientific phenomena without the constraints of physical equipment, proving particularly beneficial for schools with limited resources or students facing challenges in performing specific experiments [20]. They mitigate the risks associated with handling hazardous substances or complex equipment, especially pertinent to experiments involving dangerous chemical reactions or high temperatures [21]. This allows the modelling of intricate scientific processes that are challenging or impossible to conduct in real conditions, enabling students to observe and analyze phenomena that may be inaccessible in traditional laboratory settings [22].

Virtual laboratories can be engaging and attract students, particularly those inclined towards technology; interactivity and visualization can enhance interest and comprehension of the material [23]. However, certain drawbacks exist. Virtual laboratories cannot entirely substitute the tangible experience of working with real equipment and materials, limiting interaction with physical objects that can be touched [24]. Their use requires appropriate technical equipment and internet access, posing challenges for schools or students with limited technology access [25]. Virtual laboratories may restrict opportunities for collaboration and interaction among students and teachers, whereas real collaborative experiences on projects can be essential elements of STEM education [26]. Some virtual laboratories may be subject-specific, not covering the full spectrum of possible experiments, thereby limiting the diversity of research and investigative opportunities [7]. Considering these advantages and disadvantages, the effective integration of virtual laboratories into STEM education necessitates a balanced approach and careful attention to individual student needs and capabilities.

The inadequacy of existing data and concepts represents a significant gap in the literature. Some studies fail to provide clear definitions of virtual laboratories, universal standards, or success criteria [27], [28]. Another issue pertains to the limited depth of research concerning the psychological and sociocultural aspects of virtual laboratory utilization. Many works restrict themselves to technical aspects, overlooking crucial psychological aspects of student motivation or sociocultural variations in the use of these tools [29], [30]. Considering the conflicts and limitations, it becomes evident that the relevance of this article lies in expanding the understanding of the impact of virtual laboratories on students' interest in STEM disciplines. The novelty of the approach lies in integrating technical and pedagogical aspects, coupled with an examination of psychological factors to gain a comprehensive understanding of the issue. Such analysis aims to assist teachers and school administrations, as virtual laboratories may enhance STEM education in secondary schools.

This article aims to investigate the impact of virtual laboratories (biology, chemistry, physics, and mathematics) on students' interest in STEM disciplines over six months of instruction. The objectives of the study are: i) survey students on questions aimed at identifying their interests and perceptions of STEM; ii) conduct training in the experimental group using virtual laboratories, while the traditional group receives instruction through real laboratories; and iii) administer a follow-up survey at the end of the six months to assess changes in the level of interest and perceptions of STEM disciplines.

It is expected that the use of virtual laboratories in biology, chemistry, physics, and mathematics over six months will positively influence students' interest in STEM disciplines. It is anticipated that the interactivity and engagement in virtual experiments will contribute to deepening knowledge and fostering a positive attitude toward STEM disciplines. The study on the impact of virtual laboratories on students' interest in STEM disciplines holds significant societal and educational implications. Firstly, given the rapid technological progress, it is crucial to determine how modern tools, such as virtual laboratories, can influence the development of interest in science and technology among the younger generation. The use of virtual laboratories can be a key factor in improving students' access to STEM education, especially in cases where physical laboratories are inaccessible. This may open new opportunities for education in fields where there are constraints on real access to laboratory equipment or the associated costs. The research aims to identify the specific impact of virtual laboratories on individual students' interest in various STEM fields, and testing the proposed hypothesis will help determine whether virtual learning can make science and technology more appealing and accessible to students.

Conducting this research has the potential to contribute to the development of STEM education methods, making them more effective and adaptable to students' needs. The obtained results can also serve as a basis for developing strategies to enhance educational programs and tools for attracting and retaining interest in STEM disciplines among the youth. Thus, the study aims to improve the quality of STEM education and influence the demand for scientific and technical specialties in the future.

2. METHOD

2.1. Study design

The research design was based on an experimental approach aimed at a meticulous examination of the impact of virtual laboratories on students' interest in STEM disciplines. The study was meticulously planned to ensure objective and reliable results. Within the experiment, participants were divided into two groups: the experimental group and the control group. The experimental group had access to virtual laboratories in biology, chemistry, physics, and mathematics for six months, while the control group continued to acquire knowledge through traditional methods, utilizing real laboratories and instructional materials. The choice of an experimental approach was made considering its several advantages. Firstly, such a method allows for the effective control of the influence of virtual laboratories, establishing causal relationships between their use and students' interest levels. Secondly, the experiment enables the consideration of potential variables and the elimination of other factors that may impact the results. The selection of the experimental research method is based on the assumption that it best aligns with the research question and will yield credible conclusions regarding the influence of virtual laboratories on students' interest in STEM disciplines.

2.2. Participants

A total of 317 participants from secondary schools in the Pavlodar region in Kazakhstan took part in the research. Inclusion criteria were defined as having an active interest in STEM disciplines and a willingness to participate in the six-month experiment. Participants were required to possess basic skills in using technological devices and have internet access since they utilized virtual laboratories, involving online interaction. The selection of participants was conducted across different classes to ensure the representativeness of the STEM context. The age of participants ranged between 12-13 years, corresponding to the same academic year. Exclusion criteria included a lack of interest in STEM disciplines and the inability to regularly participate in the research. Participants with prior positive or negative experiences with virtual laboratories were also excluded to maintain result integrity and avoid distortion of the experimental impact. Additionally, exclusion criteria involved the absence of medical limitations that could affect participation in the six-month study. Demographic information about the participants is presented in Table 1.

Table 1. Participant demographic data

Group	Number of participants	Average age	Number of males	Number of females
Experimental	158	12.3	92	66
Control	159	13.7	90	69

Students learned about the opportunity to participate in the research through an announcement on the official website of the educational institution. Participants responded to the announcement and expressed their willingness to participate, after which a selection was made according to the inclusion criteria. This group of individuals was chosen for the study because its representatives met the criteria defined to ensure the representativeness and reliability of the results in the context of the impact of virtual laboratories on interest in STEM disciplines. Participants were divided using randomization (random number generator).

During the study, ethical standards were adhered to, ensuring the confidentiality and safety of participants. Consent to participate in the research was obtained from all parents of participants, and they were provided with information about the purpose and procedure of the study. Personal information was processed according to privacy requirements. Participants were allowed to withdraw from participation at any time without negative consequences. Additionally, the research results were used only for scientific purposes and did not disclose participants' data. The entire process adhered to ethical standards in research and the study of human subjects.

2.3. Research instruments

The STEM interest questionnaire was designed to assess the level of interest among students as shown in Table 2. It comprised 20 questions covering various aspects of STEM fields, addressing personal interest, beliefs in the importance of STEM education, and readiness to consider career opportunities in STEM. The questionnaire was structured to encompass different facets of the STEM domain, including natural sciences, mathematics, engineering, technology, and a general perspective on STEM education and professions. Each question employed a five-point response scale, allowing participants to evaluate their level of agreement or interest. This questionnaire was utilized to collect data on the impact of virtual laboratories on students' interest in STEM fields over a specific period. It enabled the gathering of reliable data concerning participants' interest in distinct STEM facets, which is essential for scrutinizing how virtual laboratories affect their beliefs and motivation. The questionnaire underwent validation through Cronbach's alpha coefficient, resulting in a value of 0.86, indicating stability and consistency in measuring students' interests in STEM fields. Additionally, the test underwent expert validation, during which experienced STEM education specialists examined it. The results of the expert validation confirmed that the questionnaire accurately reflected key aspects of interest in STEM. Specialists affirmed the questionnaire's validity, confirming its alignment to measure students' interests in the aforementioned areas.

Table 2. Survey "STEM interest"

No.	Item
1	I am interested in studying natural sciences.
2	Technological inventions and new technologies fascinate me.
3	I find mathematics interesting.
4	Studying the principles of physics helps me better understand the world around me.
5	I prefer engineering tasks over humanitarian ones.
6	I believe that science can change the world for the better.
7	I am interested in career opportunities in STEM.
8	I see the importance of STEM education for modern society.
9	Technological progress is crucial for the future development of the world.
10	Studying chemistry is an interesting activity for me.
11	The idea of robotics and artificial intelligence intrigues me.
12	I believe that learning STEM disciplines develops logical thinking.
13	My future profession is related to the field of science or technology.
14	I believe that mathematical skills are useful in everyday life.
15	Engineering challenges encourage me to solve problems.
16	I am interested in studying the history of scientific discoveries and inventions.
17	I see STEM education as an opportunity for my personal growth.
18	Learning about new technologies is fascinating to me.
19	I believe that STEM education contributes to the development of critical thinking.
20	My interest in STEM fields determines my choice of educational trajectory.

Rating scale: 1=strongly disagree, 2=disagree somewhat, 3=undecided, 4=agree, 5=strongly agree

The STEM diagnostic test is an instrument aimed at measuring students' specific interest in individual STEM disciplines: biology, chemistry, physics, and mathematics as shown in Table 3. The test consisted of four sections, each corresponding to a specific STEM discipline and containing five questions. Participants were required to assess their interest in each discipline on a five-point scale. The Cronbach's alpha value for the test, 0.81, indicated a high degree of internal consistency. This implies that the questions in the test interact and measure the same construct-interest in STEM disciplines. The test underwent expert validation, which involved examination and evaluation by qualified experts. Experts confirmed that the test questions accurately reflect the fundamental aspects of students' interest in specific STEM disciplines. The results of expert validation confirm that the test genuinely measures what it is intended to measure.

Table 3. STEM diagnosis

Subject	Item
Biology	1. My focus is centered on studying new achievements in biological sciences and innovations in this field.
	2. I have an interest in designing and creating various biological systems and devices.
	3. Solving challenges in the field of biotechnology and developing new biological technologies intrigues me.
	4. I would like to create my own biological solutions to address widespread issues.
	5. I am interested in exploring the impact of biotechnological innovations on modern society, especially in the context of biological sciences.
Chemistry	1. I find it interesting to study chemical reactions and their impact on the environment.
	2. I have an interest in exploring the structure of various chemical elements and their properties.
	3. Solving chemical problems and determining the quantities of substances in compounds fascinates me.
	4. I would like to investigate new materials and their properties through chemical experiments.
	5. I am interested in understanding how chemical processes are applied in various industrial sectors.
Physics	1. My interest is focused on studying methods of designing and developing new physical structures and systems.
	2. I am passionate about solving complex physics problems and challenges, as well as developing new methods to address them.
	3. I am engaged in creating and improving technical systems in the field of physical sciences.
	4. I desire to create innovative solutions to enhance physical processes and experiments.
	5. I am interested in researching the interaction of technical systems in a physical context and their application in various areas of physics.
Mathematics	1. I find it interesting to study mathematical models and their application in various fields.
	2. I feel interested in solving complex mathematical problems and puzzles.
	3. Developing new mathematical theories and methods intrigues me.
	4. I would like to apply mathematical approaches to analyze and solve real-world problems.
	5. I am interested in exploring mathematical connections and properties in various scientific areas.

Rating scale: 1=absolutely not interesting, 2=not very interesting, 3=moderate interest, 4=interesting, 5=very interesting

2.4. Procedure

2.4.1. Preliminary assessment

The research procedure commenced with a preliminary assessment, aiming to confirm the equality of groups in terms of their interest levels in STEM disciplines. Participants underwent the “STEM interest” and “STEM diagnostic” surveys. Instructions for completing the tests were provided, ensuring the confidentiality of responses. The survey took place in a physical computer lab. To prevent variation-related changes in results, all participants were allotted the same amount of time to complete the tests (45 minutes). The testing process was monitored to verify participants' adherence to specific procedures and time constraints. Google Forms were employed for conducting online tests. Technical support and a validated methodology ensured the smooth operation of the resources.

2.4.2. Instruction

Following the preliminary assessment, participants were divided into experimental and control groups. The training in the experimental group took place using virtual laboratories in a modular learning format. Each module lasted for 2 to 3 weeks. The curriculum (topics) was the same for both groups and is comprehensively as presented in Table 4. At the beginning, the experimental group had access to virtual laboratories in the fields of biology (virtual biology laboratory, shown in Figure 1), chemistry (chemistry lab, shown in Figure 2), physics (physics studio, shown in Figure 3), and mathematics (math’s lab, shown in Figure 4). These laboratories were distinguished by adequate modelling quality and interactivity.

The educational process was meticulously organized and involved the implementation of virtual laboratories. Each STEM instructional module was accompanied by a corresponding set of exercises, contributing to a deeper understanding of the material and the development of students' key competencies. The assignments outlined in the instructional program facilitated participants' interaction with virtual laboratories, enhancing their engagement and deepening their knowledge. Additional educational resources, including articles, video lectures, and books, were utilized to support the learning process and complement the virtual laboratories. Sessions were conducted twice a week, each lasting 1.5 hours, ensuring the consolidation and systematic organization of acquired knowledge.

Table 4. Training program

Block	Program			
Block 1: Biology	1.	Ecosystems	7.	Discharge
	2.	Classification of living organisms.	8.	Movement
	3.	Cell biology. Water and inorganic substances	9.	Coordination and regulation
	4.	Transport of substances	10.	Heredity and variability
	5.	Nutrition of living organisms	11.	Reproduction. Growth and development
	6.	Breathing	12.	Microbiology and biotechnology
Block 2: Chemistry	1.	Basic concepts of chemistry	7.	Alkalis and their properties
	2.	Atomic structure	8.	Solutions and their properties
	3.	Chemical elements and periodic law	9.	Chemical energy and its types
	4.	Chemical reactions	10.	Classification and properties of gases
	5.	Oxides and their properties	11.	Chemistry in everyday life
	6.	Acids and their properties	12.	Elements of organic chemistry
Block 3: Physics	1.	Mechanics	7.	Sound formation and propagation of sound
	2.	Power and movement	8.	Light and its properties
	3.	Newton's laws	9.	Optical devices
	4.	Work and energy	10.	Electricity
	5.	Pressure and its application	11.	Magnetism
	6.	Thermal phenomena	12.	Electric circuits
Block 4: Mathematics	1.	Arithmetic	7.	Practical geometry
	2.	Geometry	8.	Areas and volumes
	3.	Expressions and equations	9.	Linear equations and inequalities
	4.	Graphic presentation of data	10.	Calculations with quantities
	5.	Actions with decimal and common fractions	11.	Geometric designs
	6.	Percentages and proportions	12.	Interactive math problems

Figure 1. Virtual biology laboratory

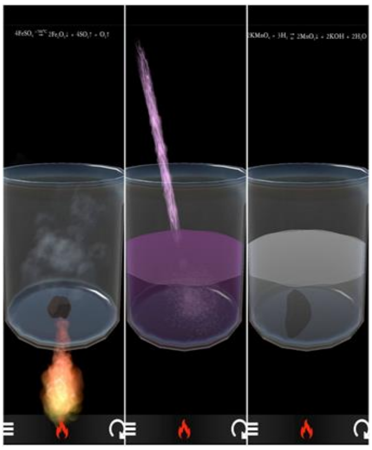

Figure 2. Chemistry lab

Figure 3. Physics studio

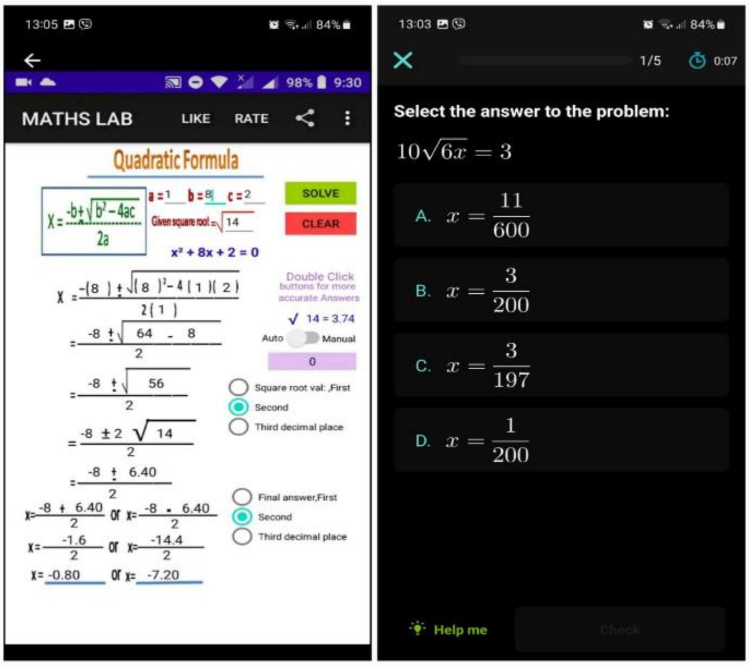

Figure 4. Math's lab

The sessions were conducted by experienced instructors who were familiar with the nuances of using virtual laboratories and capable of effectively teaching STEM subjects. The control group received education through traditional methods without the use of virtual laboratories. The sessions were based on classical textbooks, lectures, and practical assignments. Teaching was structured by thematic blocks for each STEM discipline, focusing on traditional methods of research and material exploration. Participants did not utilize virtual laboratories during their education, as their study was based on traditional physical laboratories. The education in the control group also lasted for six months, with sessions held twice a week for 1.5 hours, ensuring equal conditions in terms of duration and intensity compared to the experimental group. Following the completion of the education, participants underwent a final assessment analogous to the initial evaluation, which included the 'STEM interest' and 'STEM diagnostic' assessments. The results were compared with the previous scores to determine the effectiveness of using virtual laboratories in enhancing interest in STEM disciplines among students.

2.5. Data analysis

For data analysis, the SPSS statistics version 27.0 was employed. This software enabled the efficient processing and analysis of a large volume of numerical data characteristic of our study. The t-test for paired samples was utilized for the statistical processing of preliminary assessments. It was chosen to compare the mean values of the same group before and after the intervention. The final assessment was analyzed using a similar t-test for independent samples to determine whether statistically significant changes in student interest occurred after the conducted education in different groups. The selection of these tests was justified by their ability to detect differences between groups and internal changes within a single group, ensuring a robust statistical analysis of the effectiveness of the introduced modifications.

3. RESULTS AND DISCUSSION

To assess the effectiveness of the education, paired and independent samples t-tests were employed. The results of the analysis of preliminary and final assessments are presented in Tables 5 and 6. It is important to note that before the commencement of the education, the experimental and control groups exhibited homogeneous levels of preliminary interest in STEM disciplines. The paired samples test did not reveal statistically significant differences between the groups in this regard ($p>0.05$). This confidently asserts that any identified changes in students' interest after the education can be attributed to the influence of virtual laboratories rather than initial differences in interest levels between the groups.

An analysis was conducted to assess changes in students' interest levels in STEM disciplines after the implementation of virtual laboratories in the educational process. Initial data indicated that average interest scores in general STEM disciplines biology, chemistry, physics, and mathematics were at levels of 22.5, 15.8, 18.7, 20.2, and 17.6, respectively. Following the educational intervention involving virtual laboratories, a significant increase in students' interest was observed in all measured areas. The average scores after the education period became 28.1, 19.6, 24.3, 26.5, and 21.8, respectively. The t-statistic values and p-values indicate a statistically significant increase in interest ($p<0.05$) across all areas. These results suggest that the use of virtual laboratories positively influences students' interest in STEM disciplines, promoting an active and visualized learning format that can generate greater engagement with the educational material.

Table 5. Results of preliminary and final assessment analysis in the experimental group

	M before	SD before	M after	SD after	t-statistics	p-value
Overall interest	22.5	3.2	28.1	2.8	6.7	0.001
Interest in biology	15.8	2.5	19.6	1.9	5.4	0.003
Interest in chemistry	18.7	2.9	24.3	2.2	4.8	0.007
Interest in physics	20.2	3.1	26.5	2.5	5.1	0.005
Interest in mathematics	17.6	2.7	21.8	2.1	4.6	0.009

Table 6. Results of the analysis of pre-assessment and post-assessment in the control group

	M before	SD before	M after	SD after	t-statistics	p-value
Overall interest	23.0	3.1	23.8	2.5	1.2	0.245
Interest in biology	16.2	2.3	16.8	2.0	1.6	0.173
Interest in chemistry	19.0	2.7	19.5	2.3	1.0	0.315
Interest in physics	21.5	3.0	22.2	2.6	1.4	0.201
Interest in mathematics	18.1	2.5	18.7	2.2	1.8	0.143

In the control group, an analysis of the intervention's effectiveness was conducted through pre-assessment and post-assessment, considering overall interest and interest in specific STEM disciplines. The pre-assessment average score for overall interest before the start of the training was 23.0 with a standard deviation of 3.1. After the training, the average score increased to 23.8. However, the difference is not statistically significant ($t=1.2$, $p=0.245$), indicating the absence of significant changes in overall interest. The analysis showed that interest in specific areas such as biology, chemistry, physics, and mathematics also did not undergo statistically significant changes. For instance, interest in chemistry increased from 16.2 to 16.8, but this change is not statistically significant ($t=1.6$, $p=0.173$). Similar conclusions can be drawn for other disciplines. In summary, pre-assessment and post-assessment in the control group did not confirm statistically significant changes in the level of interest in STEM disciplines. Therefore, the results of the analysis indicated that the experimental group, which underwent training using virtual laboratories, significantly improved their overall interest in STEM disciplines, as well as specific interests in biology, chemistry, physics, and mathematics. In the control group, which did not receive such training, no statistically significant changes were observed.

The obtained results of the study indicate a significant positive influence of virtual laboratories, particularly in the fields of biology, chemistry, physics, and mathematics, on the level of students' interest in STEM disciplines over six months. Discussing the research findings in the context of similar studies from other sources reflects a broad scope of knowledge and understanding regarding the impact of virtual laboratories on students' interest in STEM fields. Verifying the results and comparing them with similar studies allows for a deeper comprehension of the circumstances and concepts underlying the obtained outcomes. Differences and similarities with other research contribute to a comprehensive understanding of the broader context of the impact of virtual laboratories on students' interest in STEM disciplines.

One of the key distinctions lies in the selection of virtual laboratories in specific fields (biology, chemistry, physics, and mathematics) for investigation, enabling a deeper examination of the impact in each particular area. Additionally, this research approach takes into account aspects of interest, differing from other studies that predominantly focus on students' academic achievements [31], [32]. On the other hand, similarity with other studies lies in confirming the positive influence of virtual laboratories on students' interest in STEM disciplines [29], [33], [34]. Thus, similar results have been found in previous research, indicating consistency in the impact of these tools on student interest. However, it is important to note that this study enhances the understanding of the issue of interest in STEM disciplines in secondary education, providing an additional foundation for further research in this area.

The obtained results can be explained from the perspective of several scientific theories and concepts that consider psychological and educational aspects. The study results can be elucidated through the lens of motivation theory, which posits that stimulation and interest in a subject can positively impact learning [35], [36]. Students who had the opportunity to use virtual laboratories may exhibit greater interest in STEM disciplines, influencing their engagement and performance. From a constructivist standpoint, virtual laboratories provide students with the opportunity to construct their knowledge independently, experimenting and interacting with virtual objects, potentially leading to a deeper understanding of the material and increasing student interest [37].

Focusing on virtual learning, the results can be analyzed in terms of which virtual environments more effectively contribute to the pedagogical process and engage students in studying STEM disciplines [38], [39]. The analysis of results can also be grounded in psychological theories of personality development, which examine the influence of education on shaping individual interests and preferences, particularly during the learning period [40], [41]. The described theories and concepts help us understand why the use of virtual laboratories can impact students' interest in STEM disciplines and their academic motivation.

It is essential to acknowledge that this study has its limitations that should be considered when interpreting its results and drawing conclusions. The student sample was limited geographically and ethnically, which may affect the external validity of the findings. The study results may not reflect the diversity of the impact of virtual laboratories on students' interest in STEM disciplines in other cultural contexts. The six-month study period might be insufficient to identify the long-term effects of the influence of virtual laboratories on students' interests. Additional research with more extended observation periods could provide a more comprehensive picture of the dynamics of this impact. The results could be influenced by the Hawthorne effect, a phenomenon where study participants alter their behavioral or productive style merely because they are aware that their actions are being observed [42]. This can lead to biases in reporting results and diminish the internal validity of the study. Consideration of psychological and sociocultural factors was limited in this research. While interest was addressed, a more detailed analysis of mental aspects and interactions with sociocultural influences may require separate investigations.

The sample was also restricted to secondary education students, and the results may not be generalizable to students at other levels. Expanding the study to different educational levels could provide a deeper understanding of the impact of virtual laboratories. Taking these limitations into account will allow for proper contextualization and generalization of the obtained results, as well as identifying directions for further research in this field. The obtained research results may have significant implications for education, educational policies, and other fields. The identification of the positive impact of virtual laboratories on students' interest in STEM disciplines suggests the potential enrichment of the learning process through digital technologies. The use of virtual tools can make education more engaging and comprehensible for students. The study results can serve as an argument for the integration of technology in STEM education. Incorporating virtual laboratories into educational programs may contribute to the development of scientific thinking and the preparation of a new generation of professionals in STEM.

As the use of virtual laboratories may require new teaching approaches, it is crucial to provide pedagogical support to teachers. Educational programs and teacher training can facilitate the successful integration of digital tools into the learning process. The consequences of the study can stimulate the development of new pedagogical strategies that emphasize the use of interactive technologies. Innovative teaching methods can enhance student engagement and increase their interest in STEM disciplines. In conclusion, the use of virtual laboratories can be a promising tool for advancing STEM education, ensuring high motivation, and fostering active participation among students. During the discussion, limitations of the study were also acknowledged, such as the uncertainty regarding certain psychological aspects. Considering these factors, it is important to continue the development and refinement of virtual laboratories to ensure their effectiveness in increasing students' interest in STEM disciplines.

4. CONCLUSION

The main conclusion of the study is that the use of digital technologies in education enhances students' interest in biology, chemistry, physics, and mathematics. The observed positive long-term effect indicates the potential of virtual laboratories as a tool to stimulate students' interest in STEM disciplines. The practical value of the research lies in its indication of opportunities for optimizing learning through digital means. The implementation of virtual laboratories could be a promising step toward improving the quality of STEM education and preparing future professionals. The practical application of the results is possible in the fields of education, and curriculum development, as well as in the planning and implementation of STEM initiatives in educational institutions. Understanding how virtual laboratories influence students' interests can be beneficial for teachers, curriculum developers, and educational technology designers. From the perspective of future research, it is important to explore the interaction of other factors, such as sociocultural context and individual differences among students. Different types of virtual laboratories and their impact on various age groups should also be considered. This would contribute to a broader understanding of the processes occurring when digital tools are used in STEM education.

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BIOGRAPHIES OF AUTHORS

Batesh Karimova is Master of Natural Sciences, currently works at High School of Natural Sciences, Alkey Margulan Pavlodar Pedagogical University, Pavlodar, Kazakhstan. She can be contacted at email: btshkarimova@gmx.com.

Bibigul Zhumabekova is Doctor of Biological Sciences, currently works as a Professor at High School of Natural Sciences, Department of Biology, Alkey Margulan Pavlodar Pedagogical University, Pavlodar, Kazakhstan. She can be contacted at email: bibi_gul.zhumabekova@gmx.com.

Sholpan Hamzina is Candidate of Pedagogical Sciences, currently works as a Professor at High School of Natural Sciences, Alkey Margulan Pavlodar Pedagogical University, Pavlodar, Kazakhstan. She can be contacted at email: hamzina88sh@gmx.com.