Using digital tools in STEM education and the impact on student creativity in the field of tribology

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ABSTRACT

From a preliminary analysis of the scientific literature, it can be seen that knowledge of science, technology, engineering and mathematics (STEM) has a positive impact on the development of necessary skills in students' professional activities. However, there are very few studies on the effectiveness of using STEM elements in developing the creativity of future physics teachers in specialized fields. The aim of this study was to develop digital resources as a basis for STEM knowledge and to assess their impact on the development of students' creativity. Based on special principles of education, constructive method in teaching, modeling methods, digital educational resources were developed and an evaluation experiment was conducted. The experiment involved 86 students (40 in the control group and 46 in the experimental group), and compared the results of traditional learning and STEM learning by using digital resources. The results of the questionnaire assessment showed that STEM education can be very effective in developing students' creativity. The pedagogical experiment was implemented during the teaching of the author's course entitled "The physical foundations of tribology." The results of the study contribute to finding solutions to scientific problems in the field of teaching tribology.

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1. INTRODUCTION

Among the Central Asian States, the Republic of Kazakhstan was among the first to become a member of the Bologna Process and a full participant in the European higher education area and began conducting research in the field of education in accordance with the requirements of employers. This made it possible to ensure the recognition of educational programs, science, technology, engineering and mathematics (STEM) curricula, academic mobility of students, and the right of graduates to find employment in any country [1]. Also, Kazakhstani researchers and students, using the latest achievements of digital technologies, were able to determine the technical and scientific progress of any sphere of human activity, to form new types of activities [2], [3].

It is necessary to take into account the fundamental changes in the modern education system in accordance with the goals of sustainable development, the conditions for the transition to distance education, the importance of the transition to a digital society. We understand that the use of STEM technologies and digital education is relevant. STEM resources occupy an important place in the development of professional training of future teachers. Therefore, it is important to use them [4].

Creativity in education is a set of indicators of the ability of future physics teachers to apply their knowledge in the fields of natural STEM to achieve innovative results. Nevertheless, from previous studies, one can notice the lack of work on the creative training of future physics teachers in STEM education, according to individual profile content [5]–[7]. It is also known that for future physicists, understanding the complex phenomena occurring in research centers and installations, innovative technologies used in production, and mastering the principles of their functioning create a lot of difficulties.

One of the important and difficult areas for future physics teachers is the field of tribology. Tribology is a specific branch of the science of physics that studies related interactions in the relative motion of highly deformable bodies [8]. Given the wide application of knowledge in the field of tribology-in such important areas of human activity as electronics, digital technologies, mechanical engineering, energy, transport, biotechnology, medicine and the defense industry, we understand the need to develop the creativity of future physics teachers in this field [9].

Tribology is an international scientific field of interest to researchers from different countries [10]. From recent studies [11]–[13], it is possible to trace the achievements in various fields of tribology over the past 2-3 years. Interestingly, studies in the field of surface properties of solids show an increase [14]–[16]. Along with developed countries, technical universities of the Republic of Kazakhstan study specific issues of tribology [17]. However, an analysis of the literature devoted to this problem indicates the insufficiency of appropriate educational resources for educational institutions entrusted with the task of training future physics teachers. Nevertheless, the inclusion of the study of the physical foundations of tribology in the university curricula corresponds to the principles of professional development. This can significantly expand students' understanding of the methodological foundations underlying modern scientific research.

As a result of a meta-analysis of articles published in recent years, it can be seen that digital tools are used based on STEM knowledge as an advanced experience in shaping the creativity of future physics teachers [18]–[20]. Digital tools in STEM knowledge allow you to visualize complex phenomena and patterns in the field of physics. It is widely recognized that digital educational materials encompass a variety of resources, such as simulations and interactive multimedia components [21]. These resources play a crucial role in enhancing skills within the realm of tribology [22], fostering self-directed learning, generating greater interest in the learning process and serving as valuable tools in STEM education [23].

At present, digital resources are extensively utilized in education across nearly all technical universities. For instance, reference [24] serves as a contemporary, conceptual, and visually engaging primer on physical chemistry. The authors underscore the contemporary relevance of physical chemistry and demonstrate its significance to our surroundings by incorporating modern applications from biology, environmental science, and materials science. Additionally, the digital textbook [25] merits attention for its comprehensive coverage of circuit analysis and circuit theory. Within its pages, fundamental concepts are presented in a coherent sequence, facilitating the continual expansion of students' knowledge. Step-by-step analytical methods furnish a robust framework for housing problem-solving abilities and equipping future specialists with the skills to advance the concepts of practicing engineers.

However, the analysis of literary sources shows that there are no digital resources on the physical foundations of tribology, which are necessary in the process of training future physics teachers. In addition, the educational programs for the training of future physics teachers show a shortage of subjects related to the production sector and problems in its effective implementation. The methodology of teaching individual subjects using new STEM technologies in the process of training, in particular, future physics teachers, does not form a single system, but remains at the level of individual proposals. This work allows us to find a solution to the problems of this study.

In connection with the explanation, the purpose of this work is to develop digital educational materials for the course of the physical foundations of tribology and their use on the basis of STEM at the university in the process of developing the creativity of future physics teachers. Thus, the hypothesis of the study is formulated as:

H_1: There is no significant difference between the results of the survey before and after the experiment on self-assessment of students' creativity.

H_2: According to the results of the post-experimental survey of 3rd year students, there is no significant difference in the indicators of creativity between the experimental group and the control group.

2. METHOD

In accordance with the objectives of the study and the scientific hypothesis, the following methods were used, differing in the degree of novelty:

- Methods of systematic analysis and selection of articles in high-ranking journals of the educational direction STEM and tribology in sources WOS and Elsevier’s Scopus [26].

– Empirical methods such as questionnaires and pedagogical experiment, constructive method in teaching, modeling methods are used to study and confirm the effectiveness of a digital textbook on the physical foundations of tribology for the development of creative abilities of future physics teachers [27].
– The statistical method is used to collect and analyze experimental data, which makes it possible to determine the statistical significance of the results obtained in the experimental part of the study.

To achieve this goal, the available educational programs of universities (S. Amanzholov East Kazakhstan University, Khoja Akhmet Yassawi International Kazakh-Turkish University) served as material. A total of 86 students from the above-mentioned universities took part in pedagogical experiments. The participants were selected according to the interview method. Also, when selecting participants, it was taken into account that they had completed the study of special physics disciplines. Detailed information about the student participating in the experiment is shown in Table 1.

Table 1. Participants of the pedagogical experiment

University name	Educational program	Number of students	Gender
S. Amanzholov East Kazakhstan University	Physics, 6B01502	46	Female (26) Male (20)
Khoja Akhmet Yassawi International Kazakh-Turkish University	Physics, 6B01503	40	Female (25) Male (15)
Total		86	Female (51) Male (35)

We used the Google Forms service to conduct a survey and evaluate the results. The survey was conducted on the psychometric Likert scale, in accordance with previous study [28]. The points of the survey were simple statements where respondents were asked to rate their creativity on a five-point Likert scale: 1=strongly disagree; 2=disagree; 3=neutral; 4=agree; 5=completely agree. For clarity on the gradation of consent and the criterion of readiness, Figure 1 shows a schematic diagram.

The content of the questionnaire consisted of 8 main questions. The content of the questions can be found in Table 2. This survey was aimed at determining the indicators of creativity of students, and the data obtained from the survey were analyzed on the basis of the SPSS evaluation program. Based on the t-test, the effectiveness of the dependent variable between the control and experimental groups was evaluated using data from the survey results.

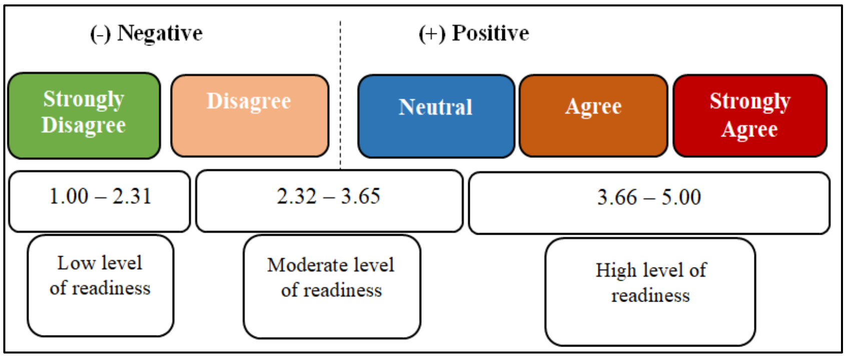


Figure 1. Gradation of consent and criterion of creativity of participants

Table 2. A self-assessment questionnaire for creativity

No.	Questions
1	In physics, I can implement my own and other ideas and make suggestions in the implementation of STEM projects.
2	I like to think differently in the STEM field.
3	I am ready for any changes in the implementation of STEM projects.
4	I can work independently on interesting STEM tasks.
5	I like research, invention, and production in STEM projects.
6	My ideas in the field of STEM are basic, new ideas arise quickly.
7	When I am asked a problematic question, I often offer several options for the answer.
8	When a problem situation arises in the implementation of STEM projects in physics, I think of several ways to find a solution to it

3. RESULTS AND DISCUSSION

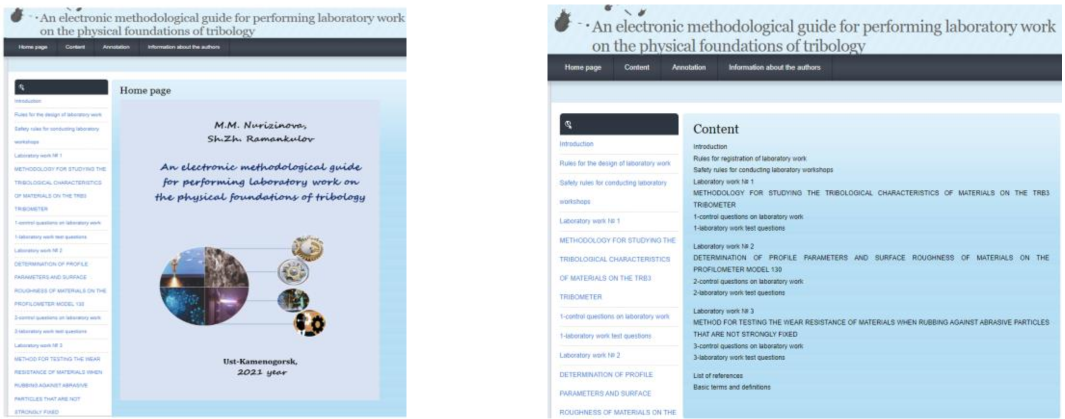
3.1. Author's STEM developments in the field of tribology

More than 30 scientific articles on key words were systematically analyzed. The result made it possible to conclude that STEM has a positive impact on the creative aspects of education, the formation of physical knowledge. Also, the analysis of educational programs and scientific and methodological literature in physics made it possible to introduce the discipline "Physical foundations of tribology" into the educational process.

As a realization of the goals and objectives of the research, we have developed a set of STEM knowledge, which includes a digital textbook and a set of laboratory work on the physical foundations of tribology. In the development of the digital learning tool, we considered both the content and the organization of educational information, along with the theoretical principles governing the visual perception of knowledge in the field of tribology, as well as the requirements inherent in acquiring new knowledge within the STEM framework. As a result, the digital textbook on the physical foundations of tribology employs content and structure that have been meticulously crafted to align with the logic of the educational process.

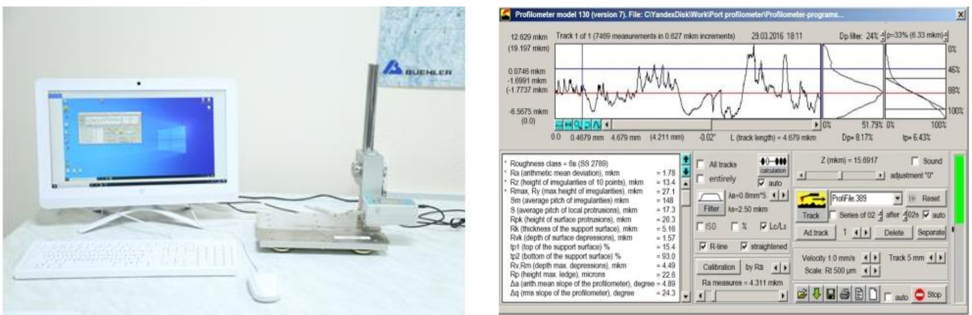
Currently, there is a wide range of software in which you can create electronic textbooks: iSpring Suite, CourseLab, TurboSite, 3D modeling software "Blender" and a number of others. With this approach, a digital tool "physical foundations of tribology", "electronic methodological manuals for practical training on the physical foundations of Tribology" have been developed. In creating the content of the digital textbook, we focused on developing students' creativity through STEM elements. The interface of a digital instrument is shown in Figure 2. Figure 2(a) represented how the digital instrument's first page looks, and Figure 2(b) presented the instrument's contents.

It can be seen that this digital manual has a navigation panel on which all sections of the training course are displayed. For example, by clicking on "No. 2 Laboratory work", we open the content and procedure of laboratory work. Theoretical information on the surface roughness of a machine part and its characteristics are given. Information about roughness measuring devices is also provided. A profilometer is shown in Figure 3. Figures 3(a) and (b) represent the model 130 and the control window, respectively.



(a) (b)

Figure 2. The interface of the digital tool of (a) the appearance of the first page of the digital tool and (b) the content of the tool



(a) (b)

Figure 3. Profilometer (a) model 130 and (b) the control window

Future physics teachers, using a digital tool based on STEM knowledge, make sure that the roughness of the surface on which the operation of the profometer is measured is determined by touching the probe of an inductive sensor – a needle in the process of moving along its surface. It is then understood that this movement is converted into an analog digital signal and that it undergoes digital processing. The block diagram of the procedure for performing work on the profilometer model 130 on a digital instrument focused on the development of creativity of future physics teachers is shown in Figure 4.

Along with this, the navigation bar contains a block of videos by topic: “Tribometer. Introduction to the device”, “Introduction to device ‘Tribometer TRB3’ for tribological research”, “Introduction to the device ‘Profilometer 130’ for determining the roughness of the surface of the material”, and introduction to the device for measuring microhardness “Metolab 5021”. These videos can be accessed at YouTube. Figure 5 shows one example from the YouTube page.

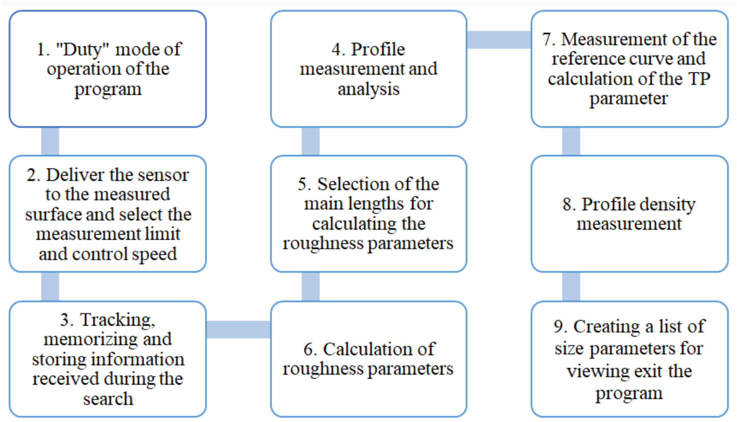


Figure 4. Procedure for working on the Profilometer model 130 focused on the development of creativity of students

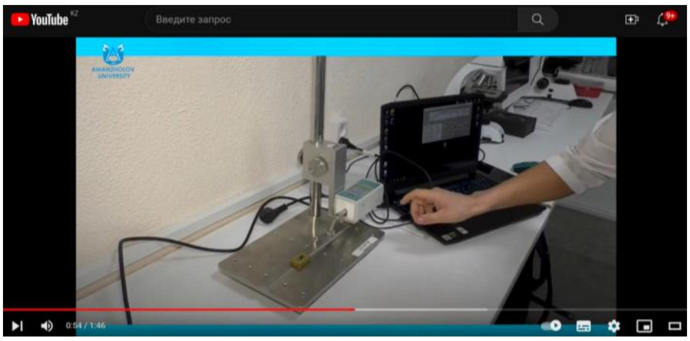


Figure 5. Video view on the topic “Introduction to device ‘Tribometer TRB3’ for tribological research”

To begin creative laboratory work on a digital instrument, each student must master the theoretical material. Then he performs practical STEM-based work on the topic. We believe that a lecture in a higher educational institution is an important form of the educational process and that the future physics teacher should receive information from the lecture not in a ready-made form, but in the process of searching and creative thinking. The search for forms aimed at solving this problem has led to an expansion of understanding of the possibilities of STEM cases in higher education [29]. An example of a STEM case on the topic “materials of the tribology system” on a digital instrument is shown in Table 3.

The effectiveness of mastering theoretical material was evaluated by us according to the developed criteria, after which students begin to perform STEM cases, according to the digital tool. STEM cases are performed as a research project. The digital material and technical base created for students in the effective implementation of the STEM case task is shown in Figure 6. Students who have developed a 3D model of a necessary product in the field of tribology will print it on a 3D printer in accordance with the expected result of the STEM case.

Table 3. Example of a STEM case in a digital tool

STEM-case theme	Determination of surface roughness of materials
Task	Development of a model for explaining surface friction in Blender
Description	Introduction of the possibility of determining the friction force with the introduction of the coefficient of surface friction
Position and role	You are a future physics teacher in tribology and a creative engineering specialist
Lecture hall	Stem and creativity training laboratory
Problem	Printing the models developed in Blender on a 3D printer and creating a realistic experience
Creative product	3D model and printed creative product
Evaluation criteria	Demand of the created STEM product by the user

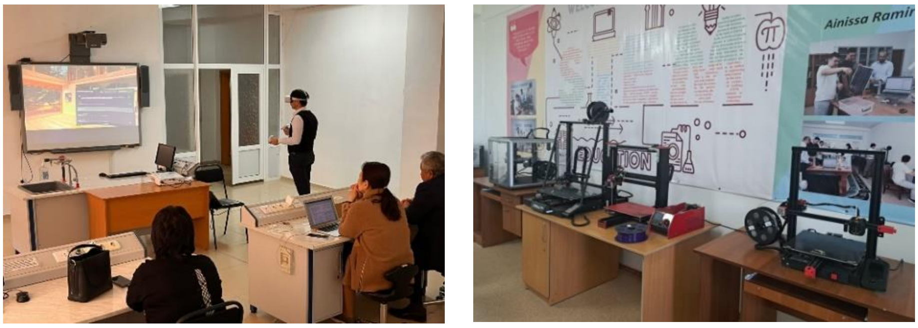


Figure 6. Equipped digital material and technical base for students

3.2. Pedagogical experiment and student survey results

In order to determine the effectiveness of digital tools based on STEM knowledge, focused on the development of creativity of future physics teachers, a pedagogical experiment was conducted on the course physical foundations of tribology. In the control groups, this course was taught using traditional methods, and in the experimental groups, the basics of STEM education were taught using digital tools created by the researchers. To determine the effectiveness of the STEM knowledge-based learning process in the field of tribology using a questionnaire for self-assessment of students' creativity, the results of a paired selective t-test are presented in Table 4.

Table 4. The results of a paired selective t-test based on the creativity of future physics teachers

Category	Group	Survey	M	SD	t	df	p (2-tailed)	MD
Creativity	EG	Pre-survey	2.57	0.78	-9.90	45	<0.001*	-0.86
		Post-survey	4.27	0.22				
	CG	Pre-survey	3.33	0.58	-1.63	39	0.10	-0.18
		Post-survey	3.48	0.60				

We conducted a descriptive analysis based on the results of a survey of students of the 3rd year of the educational program pedagogical physics before and after studying the course physical foundations of tribology. After studying the course, the students showed a statistically significant increase in creativity indicators from the questionnaire. If before the experiment (M=2.57, SD=0.78), after the experiment, these indicators were (M=4.27, SD=0.22). The average increase was 0.86 at a confidence interval of 95%. In the control group, however, there was no statistically significant increase in creativity. The average increase was 0.18 at a confidence interval of 95%.

This result refuted the H_1 hypothesis and showed that there is a difference between the results of a survey before and after the experiment to determine the creativity of future physics teachers. That is, the use of STEM-based digital tools in the educational process had a positive impact on the development of creativity of future physics teachers. Table 5 presents the outcomes of an independent selective t-test conducted to evaluate the efficacy of the STEM knowledge-based learning process in the realm of tribology. This evaluation was performed utilizing a questionnaire designed to measure the creativity indicators of future physics teachers across both experimental and control groups.

From the point of view of students, there was a significant statistical difference between the pedagogical experiment, that is, the experimental one after completing the course (M=4.5, SD=0.35) and the control groups (M=3.5, SD=0.40): t (84)=9.10, p<.001. The value of the difference in average values is 0.85.

Based on the results obtained, the H_2 hypothesis was refuted. That is, according to the results of a post-experimental survey of 3rd year students, there was a significant development in the indicators of creativity between the experimental group and the control group. As part of the project, the results of a study based on STEM knowledge in physics showed the dynamics of growth in students' readiness to study in a new innovative format, unlike other studies.

Table 5. The results of a paired selective t-test based on the creativity of students

Category	Group	M	SD	Levene's test		t-test			
				F	*p*	t	df	p (2-tailed)	MD
Creativity	EG	4.5	0.35	0.40	0.50	9.10	84	<.001*	0.85
	CG	3.5	0.40						

Assessing students' innovative readiness for physics education is important in the digital environment [30]–[32]. Numerous researchers [33]–[36] who have delved into the study of creativity among future physics specialists assert that creativity is distinguished by a constellation of personality traits evident in their professional endeavors and in the pursuit of novel outcomes within the domain of physics knowledge. It is also possible to cite the works of scientists studying approaches to teaching, including conclusions from the line "industry 4.0" and thereby contributing to the formation of future physics teachers as creative personalities in industrial activities [37], [38]. The results of this research also show the degree of readiness of future physics teachers for digital literacy in tribology. It can be seen that their level of creativity and positive attitude to innovative educational activities turned out to be high and they are sufficiently prepared to use digital educational materials for the course "Physical Fundamentals of Tribology".

4. CONCLUSION

On the basis of quantitative and qualitative research methods used in the course of the study, the possibilities of teaching the field of tribology in the educational program of pedagogical physics were identified. Considering that the development of creativity of future physics teachers in the field of tribology has a positive impact on the development of world science and technology, a course on the physical foundations of tribology was introduced into the educational process. During the course, STEM-based digital tools have been developed, focused on the effective implementation of the course teaching and the development of creativity of future physics teachers.

To develop the creativity of future physics teachers, a pedagogical experiment was conducted to determine the effectiveness of a digital tool developed on the physical foundations of tribology. The results showed a certain advantage in the levels of professional activity of students in experimental groups compared to control groups. The practical significance of the study is characterized by the creation of conditions for future physics teachers to strive for promising knowledge, the development of a didactic model for the introduction of STEM disciplines into educational programs of physics. Also, the mechanism for implementing the development of creativity, thereby increasing the possibilities of improving the quality of human capital.

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