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Research and development of a teaching model for the physical foundations of tribology

Makpal. M. Nurizinova*, Sarsen Amanzholov East Kazakhstan University, Higher School of IT and Natural Science, Adress: 148 Shakarim Str., Ust-Kamenogorsk, Kazakhstan https://orcid.org/0000-0001-8319-4928

M. K. Skakov, Sarsen Amanzholov East Kazakhstan University, Higher School of IT and Natural Science, Adress: 148 Shakarim Str., Ust-Kamenogorsk, Kazakhstan https://orcid.org/0000-0003-3716-8846

Sh. Zh. Ramankulov, Khoja Ahmet Yassawi International Kazakh-Turkish University, Department of Natural Science, Adress: 29 Sattarhanov Str., Turkestan, Kazakhstan, https://orcid.org/0000-0002-4786-942X

Ali Çoruh, Sakarya University, Department of Arts and Sciences, Adress: Esentepe Campus 54050 Serdivan/Sakarya, Turkey https://orcid.org/0000-0002-7362-6173

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Abstract

This article proposes to develop a method for the preparation of future physics teachers and for students to master tribology. In addition, the necessity of the above-mentioned proposal and the technological importance of tribology in the industry are emphasised and proven. To ensure the development of students' perspective on tribology, various scientific search methods were used, including the analysis, synthesis and comparison of visual research results with known achievements. The initial and final knowledge levels of students in the field of tribology were determined by the first tests and final tests published before and after the implementation process of the proposed programme. A book has been developed that contains educational and methodological complexes, such as laboratory studies, methodological guides, general and experimental physics course sections and test studies. An elective course about tribology was taken into the programme for physics students. Experiments were conducted related to elective course.

Keywords: Tribology; experimental foundations; professional training, scientific centre, future physics, innovative education.

* ADDRESS OF CORRESPONDENCE: Makpal. M. Nurizinova, Sarsen Amanzholov East Kazakhstan University, Higher School of IT and Natural Science, Adress: 148 Shakarim Str., Ust-Kamenogorsk, Kazakhstan
Email address: makpal.nurizinova@gmail.com

1. Introduction

1.1. Related research

It is known (Bhushan, 2013) that the role and importance of tribology in various fields of science and technology has significantly increased over the past decade. Accordingly, the research activity of practically important aspects of tribology has also intensified. In particular, intensive work is underway in the field of surface engineering (Buitkenov et al., 2020; Martini et al., 2021; Meng et al., 2020; Zhilkashinova et al., 2021). However, when looking for the curriculum and course concepts of the physics and pedagogical physics programmes of the relevant departments, there are not enough studies in the current literature dedicated to the formation of ideas of future specialists, especially teachers, in the field of modern tribology. At the same time, the inclusion of concepts of technological importance in the curriculum for the training of future physics teachers, in our opinion, is a mandatory step, and this can be carried out at any necessary stage of the teaching of a physics course. To accomplish this, selected tribology topics can be directly involved in the study of molecular physics, mechanics, thermodynamics, electricity and magnetism (Gulnara et al., 2021). However, technology-oriented topics at times contain some concepts that are very complex and not so easy to perceive. The rapid pace of the development of science leads to an increase in such concepts, evidence, ideas and patterns. For both schoolchildren and students of higher education institutions, the complex idea of research encountered in research centres used in production and in education, the explanation of the principles of operation causes various difficulties. One of these fields is tribology. The concept and laws of tribology, as a science, are found in all spheres of our life. Tribology is a science that studies and describes contact interaction in the relative motion of highly deformable bodies, one of the specific areas of condensed matter physics (Gudehus, 2000; Persson, 2000).

1.2. Conceptual or theoretical framework

Tribology solves such urgent national problems as energy savings, reduction of the use of structural materials, reliability and safety of mechanical systems, as well as environmental problems. In our opinion, the ‘physical foundations of tribology’ integrates modern scientific ideas of the interaction of bodies of molecular physics, mechanics, thermodynamics, electrodynamics, materials science and metallophysics. The current stage of tribophysics development is characterised by a comprehensive approach to the study and cognition of the phenomena of processes occurring on surfaces and in the surface layers of interacting bodies, using highly effective physical, chemical and mathematical research methods and computer technology.

The main stages in the development of tribology, like the development of other sciences, are responsible for discoveries and opportunities for implementation. As it is very well known, tribology, as a subject, is a real international science based on the works of scientists from different countries. Bushan’s (2013) updated second edition gives the reader a solid understanding of tribology, which is necessary for engineers involved in the design and reliability of machine parts and systems. He takes as the basis of the theory of practice, deriving tribology from an integrated point of view of mechanical engineering, mechanics and materials science. Khopin and Shishkin (2021), in their courses, analysed the current state of the science of friction and its practical application in various branches of mechanical engineering. The fundamentals of tribology are considered. The types and modes of friction, the main characteristics of antifriction properties and wear are given. Much attention is paid to the structure of solids, surface effects during friction.

It is necessary, then, to train future physics teachers and in this way to improve the knowledge of the physics student about the mechanical nature of tribology. Since tribology is one of the most important scientific branches of materials research, students of related scientific branches such as physics students, materials engineering students and mechanical engineering students should be informed about this in the first days of their education. Students should be guided to think about it.

The result of this approach will increase students' interest in the subject of tribology and support research in the field of tribology.

1.3. Purpose of the study

Our proposal is aimed at training future physics teachers and in this way improving the knowledge of the physics student about the mechanical nature of tribology. Since tribology is one of the most important scientific branches of materials research, students of related scientific branches such as physics students, materials engineering students and mechanical engineering students should be informed about this in the first days of their education. Students should be guided to reflect on this issue. As a result, this approach will increase students' interest in the subject of tribology and support research in the field of tribology. To the best of our knowledge, there is not enough module in the educational programmes of universities dedicated to the study of the achievements of tribology and its teaching methods, and however, in modern educational practices and pedagogical systems of developed and developing countries, several methods have been developed for teaching students of pedagogical specialties of new electrical and electronic technologies (George, 2020, Gulnara, 2022; Love and Hughes, 2022). In connection with the above, the aim of this study is to explain the importance of tribology in the process of training future university physics teachers, to reveal its place in technology and to develop an experimental and theoretical tribology teaching model.

1.4. Literature survey

Popov (2018) stated that tribology has a great aspect in technology but poor publicity in the engineering publications. He warns that it is time to integrate the necessary fundamentals in the weekly course programme of universities (Popov, 2018). As a result of thermal annealing, the preservation of surface wear resistance and microhardness in U9/Y9 steels by composite coating from Ti-Si-C or TiC has been investigated by Buitkenov et al (2020). Nanotechnology teaching for future physics teachers is analysed by Gulnara et al. (2022) developed a methodology for nanotechnology course to be given together with the general physics course and stated that this course contributed to the development of nanotechnology knowledge of physics teachers. Love and Hughes (2022) randomly used the TEES-PCK est for teaching engineering content on 55 educators. Meng et al. (2020) prepared a nice paper on different many aspects of tribology and they stated that there are many more aspects of tribology also.

2. Method and materials

2.1. Research model

The experimental work consists of three stages: statement, research and training. Inquisitive experiments contributed to the examination of the basic hypothesis of our study, the state of formation of ideas related to tribology among students who are candidates for physics or materials engineering in the research phase of the decisive experiment, we explored how we could incorporate tribology concepts into the curriculum of teaching physics teachers. As a result of the research, it has emerged that the concepts and terms of tribology should be included in education in two ways: compulsory and elective subjects. In line with the opinions of the experts involved in the project, a list of the basic concepts of tribology has been arranged. This list is presented to teachers to be explained to students within the framework of the lessons taught. Experiments are designed to be performed in accordance with the tasks and tests in control groups. East Kazakhstan Sarsen Amanzholov University, Khoja Ahmed Yassawi International Kazakh-Turkish University, South Kazakhstan Pedagogical University, which were selected as the application site of this study, have developed a course on the physical foundations of tribology to be applied in the educational process of these universities for the students of the specialty '6B01502 – Physics (education)' who participated in the experiment and were included in the teaching process. Through this course, the application of the entire methodological system in the aforementioned universities was measured by exclusive tests. The main purpose of these experiments was to test our proposal, which we present in this article.

To determine the beginning level and prior knowledge of tribology, the students are subjected a questionnaire. The questionnaire consisted of 32 questions with different levels of complexity, recommending a basic level of knowledge in the field of tribology (Sharoschenko, 2019, p. 135). This level of knowledge can be obtained from school, media, popular science magazines and films, for example, based on life experience and knowledge in related sciences (Saputro et al. 2022).

The questions were arranged to determine the level of interest in different areas of tribology and were conditionally divided into four groups:

1. Basic level questions that require knowledge about the level of tribology and related concepts.

2. Questions that require logical thinking, the answers to which can be obtained by eliminating incorrect options.

3. Questions that require knowledge from the field of tribology obtained at previous stages of training.

4. Issues that are closely related to other related disciplines.

The result of the first survey we conducted to confirm the first part of the hypothesis, the research of the student's information method, shows that the preliminary knowledge of the students about tribology is selective knowledge, not systematic knowledge, which is formed due to curiosity. Looking at the results of the last survey of the first part, it can be concluded that the interest of students in tribology has increased significantly after the methodology we have applied, and that the increasing interest of students in the subject of tribology confirms the first part of our hypothesis. We used the intermediate and final tests we conducted on the students to confirm the second part of our hypothesis, the acquisition of knowledge in the field of tribology. The mid-term tests applied to the students were applied within the elective course ‘physical foundations of tribology’ that we included in the curriculum (Skakov et al., 2021). After taking the elective ‘physical foundations of tribology’ course with department courses such as general physics, molecular physics, mechanics and thermodynamics to measure the amount of conclusive knowledge about the subject of tribology, the final test was applied in the fourth year. In order to prove the correctness of the hypothesis and to measure the accumulation of knowledge in the student about the science of tribology, students were presented with a questionnaire consisting of the purpose of valuing their observations and studies (Bruna, 2022). In addition, in order to objectively demonstrate the effectiveness of the methodology we propose in experimental understanding, students conducted laboratory studies before and after the training, which required the use of content, tribological knowledge and concepts. This study was also intended to evaluate a part of the posttest application.

In the statistical evaluation of the answers obtained from the tests, numerical results of the test data such as the general sampling average and the changes in the sampling average (the scoring figures obtained as a result of the students in each of the tests) were used. These statistics were evaluated to determine the degree of increase in knowledge of tribology in each group of subjects. Then the sampling results were compared to the mean values; the relative formation of the relevant information was determined by comparing each evaluation group. As is known, sample variance as a statistical data shows how much the selected value deviates from the mean value in a given sample (Bohm & Zech, 2010).

3. Results

In the teaching of the physics course, the course material is taken into account in terms of two components: basic and professional orientation. The basic physical component allows the student to understand the subjects of tribology at a basic level and determines the laws and concepts of physics. The professional component allows us to study deeply and set the boundaries of the study and is designed to support the professional training of the teacher of the future. After the planned educational criteria for any course have been determined and its structural elements have been classified as requirements, important and educational for the course subject, the subject can be divided into areas of study – optional subjects and elective subjects. In doing so, the parts that must be given compulsorily are first added to the compulsory curriculum and then the higher-level subjects are addressed in elective courses. In the compulsory curriculum of general physics courses, there are topics in molecular physics, electricity and magnetism, fundamentals of thermodynamics and statistical physics, mechanics. As mentioned above, detailed information about tribology cannot be given in compulsory courses, but rather defines a list of the basic subjects and processes of physics and extensive explanations about the purposeful teaching of tribology cannot be allowed. However, molecular technologies, nanotechnology, materials science and metal physics are needed to explain the tribological concepts.

As we mentioned at the beginning, we recommend including the elective course ‘physical foundations of tribology’ in the student profile development module and to have final proficiency studies and, if possible, scientific projects to be organised by students within the scope of this course. This module will provide us with the opportunity for the student to deepen tribology. This part of the training programme should be organised by considering the existing technological opportunities and the technical infrastructure that exists in the region and at the university. As can be seen, another purpose of teaching the course ‘physical foundations of tribology’ is to relate the knowledge traditionally taught in the universities of the Republic of Kazakhstan with the disciplines of an applied nature that will be given in the future. In this way, it is possible to create courses that allow the training of lecturers who teach in the undergraduate programme (physics-computer science, physics, materials science etc.) to study new course areas and therefore tribology. Students are expected to: know and understand the basics of adaptation of knowledge and research methods in tribology; the objectives of the course, taking into account the special circumstances: the student can make the correct interpretation of the information provided in order to make the most appropriate decisions under the current conditions, relates the problems that may arise during the application with the physical structure of the subject and finds the right physical solution, designing and creating new objects related to the subject and, for example, new device, and uses the acquired knowledge to solve new problems.

Our training model, which takes into account the physical foundations of tribology, is presented in the following sections, and Figure 1 shows a diagram of this methodological model that must be acquired by a future physics educator in the field of tribology.

Evaluator and descriptive unit. The descriptive and effective unit of the methodological system allows us to assess the quality of the learning method of students in the field of tribology.

The model we present here does not claim that an educator will always be in full alignment with the methodological system he or she uses or prefers.

Steps of education. The educational steps of the tribology subject are as follows: for the beginning, the form of study and the topics are determined. The main part is the mandatory part; it contains detailed questions, concepts and principles in the field of tribology. As a final part, with the help of special research work and workshop or laboratory work, the knowledge and skills gained in the field of tribology are reinforced. In addition, students are tested and their knowledge and skills are evaluated.

Content and transaction blocks. Block refers to the educational work of compulsory and elective courses. The compulsory section includes the areas of foundations of tribology (general and experimental physics course). The optional section includes the course ‘physical foundations of tribology’, assignments, qualification studies, developments in the field of tribology.

Target block. The goal of the proposed training method is to increase students' interest in the field of tribology, to increase the amount of information about tribology, to ensure its completeness and to increase its impact, as well as to support and encourage students' project activities in the field of tribology. The aim of the proposed training method incorporates increasing students' interest in the field of tribology, increasing the volume, completeness and depth of information about tribology, as well as supporting and encouraging students' project activities in the field of tribology.

Theoretical basis. The process of preparing the future physics teacher in the field of tribology is executed considering the factors in which the probability and necessity of studying certain subjects are determined. Therefore, competencies, personal, effectiveness-like approaches, basic and professional orientation, principles such as scientific consistency, the availability of laboratory equipment, the effectiveness and the interest of the students are important.

The models mentioned above express the framework and general characteristics of the scientific method by which future teachers are trained in the field of tribology. In this study, while working on the theoretical part, different options for arranging classes are also presented:

1. The part that is determined as compulsory in the model consists of the courses that the students will take compulsorily and is applied by adding certain parts of the content on the basics of tribology to the curriculum. In this study, together with experts from the universities where the mentioned study was conducted, the analysis of the level of the course was discussed and methodological suggestions were made about the use of the parts whose content was prepared within the scope of accepted basic and specialised training programmes. Table 1 demonstrates the approach of presenting the concepts of tribology in the compulsory part of the curriculum, the analysis of the physics course and the topics of tribology.

2. Choosing an educational route and conducting and planning optional school knowledge training, conducting and developing research and development related to tribology, and teaching more comprehensive educational programmes can be included in the scope of the proposed model.

In the elective curriculum we propose, there is a definition of the subject, understanding of the problem, the final goal, possible solutions to problems, additions, corrections and evaluation standards. The elective course ‘physical foundations of tribology’ includes theoretical courses, laboratory courses in the form of physical workshops, totalling five credits and forming a comprehensive idea of the technologies of study and their meaning and place in technology.

Another part addressed in the study was that, in addition to the training of teachers, more experimental work was included in the education of students. 6B01502 – for physics students, theoretical lecture and laboratory course hours on ‘physical foundations of tribology’ are not enough. In our regulation, it aims to address the subject of tribology more specifically and sensitively in the courses and to create a scientific basis and method for students to work more effectively. Table 1 shows the necessary sections and uses of tribology subjects in the elective ‘physical foundations of tribology’ course at universities.

Figure 1

Model Scope Template for the Training of Future Physics Teachers in the Field of Tribology.

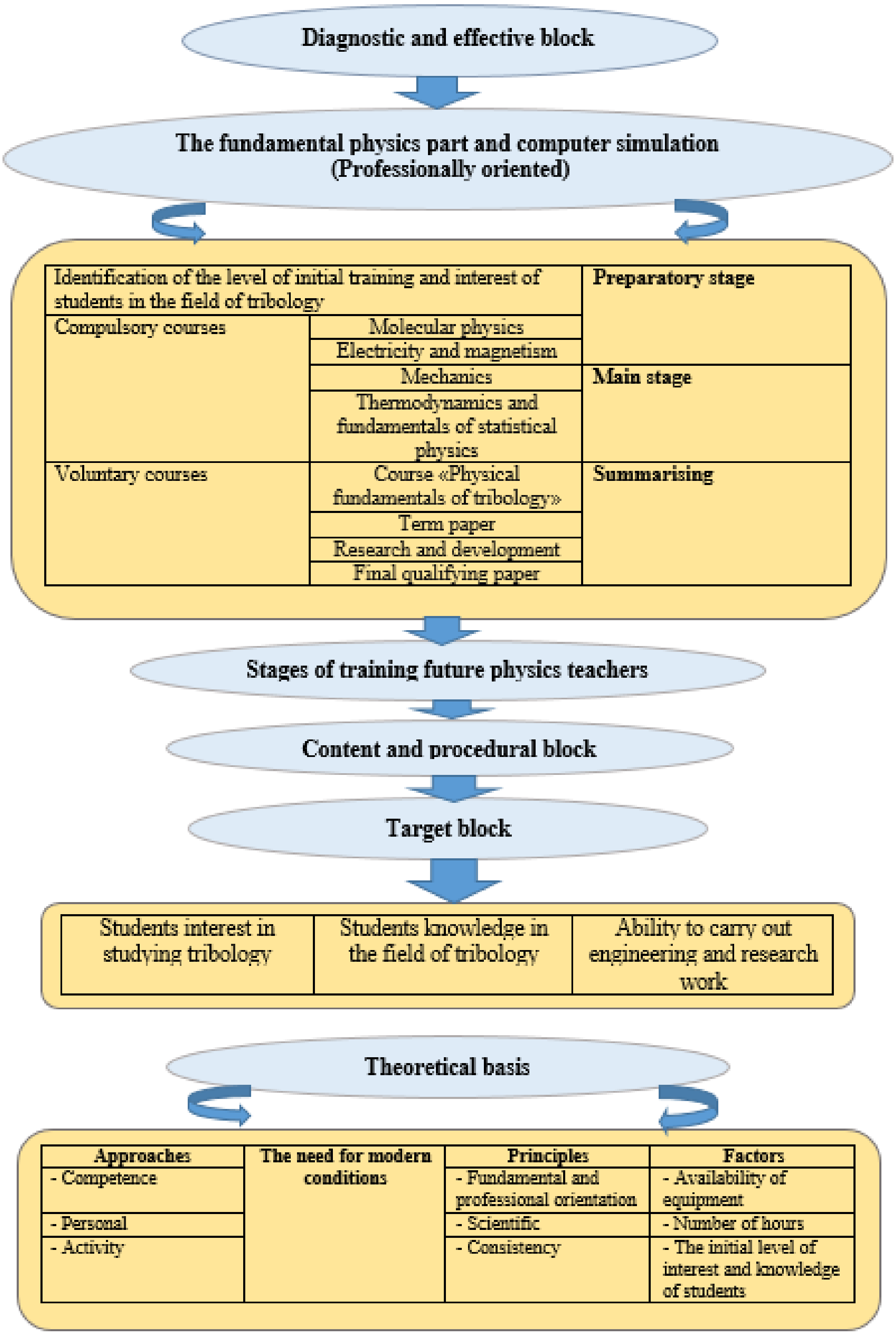


Table 1

Tribology is Offered as Required Additional Departments Within Physics Courses.

Name of course	Mean concepts	Related tribology concepts
Mechanics	Forces in nature. Friction forces. The strength of elasticity.	Physical model of the friction and wear process
	The law of conservation of momentum centre of mass.	Relaxation processes during friction.
	Energy, work, power. The law of conservation of energy.	Influence of contact pressure on phase transformations
	Absolutely elastic and inelastic impacts.	Contact interaction of solids.
Molecular physics	Entropy	Thermodynamic eigenstructures of metal tribosystems. Thermodynamic modelling of wear or friction of a metal or polymer.
	Self-diffusion, viscosity, thermal conductivity	Kinetics of structural processes under friction conditions
	Mutual diffusion	Diffusion processes under friction
	Surface tension	The influence of external influences on the phase-structural state of the surface layer.
	Crystalline and amorphous structure of substances. Crystal symmetry	Polymers and polymer composite materials Structure and structural defects of metallic materials. Structure and structure of polymer materials. Physical and mechanical properties of metal and polymer materials. Influence of the type of crystal lattice on the processes of friction and wear
	Phase transformations	General patterns of changes in the structure, phase composition and properties of steel during friction Kinetics of structural processes under friction conditions. Physical methods for studying the structural-phase state of materials. Structural-phase transformations of PCM with fibrous dispersed filler Influence of temperature on phase transformations
	Thermodynamic functions	Thermodynamic approach to the description of friction and wear processes. Mechanisms of formation of a polymer film of frictional transfer and dissipative tribostructures. Thermodynamic model of friction and wear processes of a metal polymer tribosystem

Thermodynamics and statistical physics	Basic concepts of thermodynamics	Structure and structure of polymer materials. Thermodynamic approach to the description of friction and wear processes.
	Entropy and its properties	Thermodynamic model of friction and wear processes of a metal polymer tribosystem
	Application of the second principle of thermodynamics	Kinetics of structural processes under friction conditions
	Thermodynamic functions and their properties	Mechanisms of formation of a polymer film of frictional transfer and dissipative tribostructures
	Equilibrium conditions of thermodynamic systems	Thermal and electrical processes
	Phase transitions of the I and II kind	Structural self-organisation of metal polymer tribosystems
	The third principle of thermodynamics	Tribosystem as an open thermodynamic system
	Statistical ensemble in phase space	Thermodynamics of biochemical processes. Metals and alloys
	Canonical and microcanonical Gibbs distribution	Structural self-organisation of metal tribosystems
	Derivation of the basic equation of thermodynamics from the Gibbs distribution	Influence of temperature on phase transformations. Structure and structural defects of metallic materials
	Quantum statistics	Structural Phase transformations of PCM with fibrous dispersed filler.
Electricity and magnetism	Conductors in an electrostatic field. Boundary conditions. The method of images. Electrical capacity. Capacitors. The energy of the interaction of charges. The energy density of the electrostatic field.	Electrical processes during friction

Since the methodology to be provided to the physics teacher in the field of tribology includes theoretical, practical and laboratory studies, the most important place for students to practically reinforce the theoretical knowledge they have acquired is the physics laboratory (Isupova et al., 2021). It consists of three laboratory works, i.e., investigation of the tribological characteristics of materials on the tribometer TRB3, determination of the roughness and surface parameters of materials on the model of the profilometer 130 and testing of materials for wear resistance under friction on strongly loose abrasive particles (Valdes et al., 2020). The physics workshop, which is included in the elective course 'physical foundations of tribology', includes the analysis of the results in addition to research work. One of the laboratory studies is given as an example.

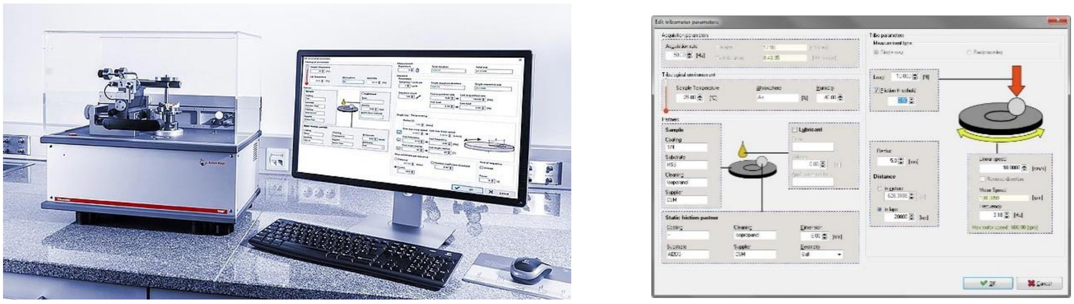
Topic 1: 'Study of tribological characteristics of materials on the TRB3 tribometer'. The purpose of the work is to study the design of the TRB3 tribometer and the model tribosystems implemented on it and to get acquainted with the work of the measuring and recording equipment of the tribometer. The necessary equipment and materials are Tribometer TRB3 and samples for measuring the coefficient of friction of solid materials.

Tribometry is a branch of tribology that studies methods for determining tribological (friction) parameters of materials. Tribometers or friction machines are used to determine the tribological properties of materials in laboratory conditions. Testing on a tribometer allows us to determine the operational characteristics of a friction pair in a short time, in particular the coefficient of friction and wear resistance. This allows us to choose the optimal materials for the manufacture of components and lubricants for their maintenance.

During the tests, the moment of friction, the clamping force, the speed of rotation, the temperature in the contact zone and other characteristics are measured. The universal friction machine TRB3 meets such requirements (Figure 2).

Figure 2

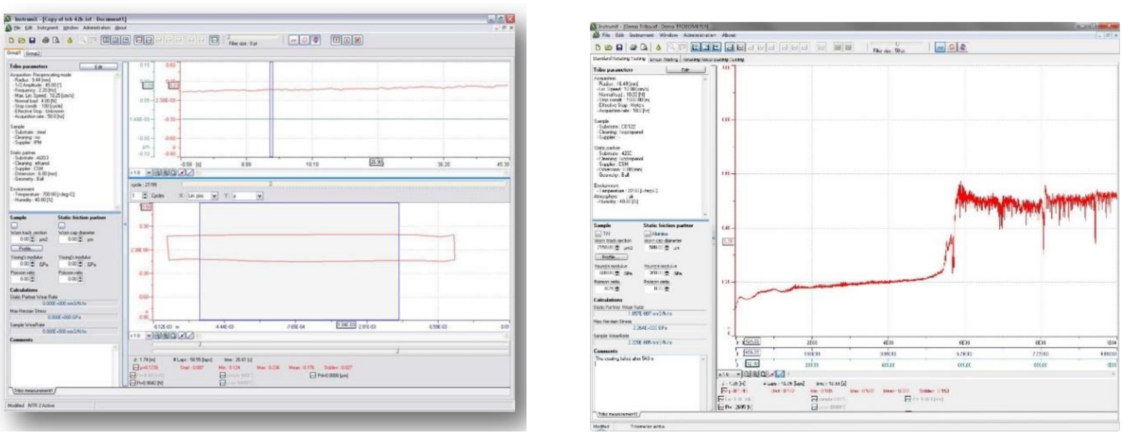
TRB3 Tribometer



The TRB3 tribometer is used to measure the service life of coatings, study the effects of friction and study the wear of solid materials depending on time, contact pressure, speed, temperature, humidity and oil availability (Stachowiak et al., 2004). Figure 3 shows the analysis of the results of the experiment and the calculations of wear resistance.

Figure 3

The Window for Analysing the Results of the Experiment and Carrying Out Wear Resistance Calculations



Topic 2: 'Determination of profile parameters and surface roughness of materials on the profilometer model 130'. The purpose of the work is familiarisation with the parameters of surface roughness and obtaining skills for determining the roughness parameter Ra using the profilometer model 130. Necessary equipment, materials are profilometer model 130, samples of material for measuring surface roughness. Roughness is a set of micro-irregularities on the surface of the part under study with relatively small steps forming a surface relief within the base length l. Devices for measuring the surface roughness of the SRM (hereinafter referred to as devices, profilometers) are

designed to measure the roughness parameters of the surfaces of products whose cross-section in the measurement plane is a straight line (forming cylindrical surfaces, holes, flat surfaces, curved surfaces within the stroke of the probe), as well as grooves and recesses of mechanisms. The necessary equipment and installations are available at the research centre 'Surface engineering and tribology' of the university (http://tribology.vkgu.kz/index.php/scientific/pages). Figure 4 shows the design of the model 130 profiler.

Figure 4

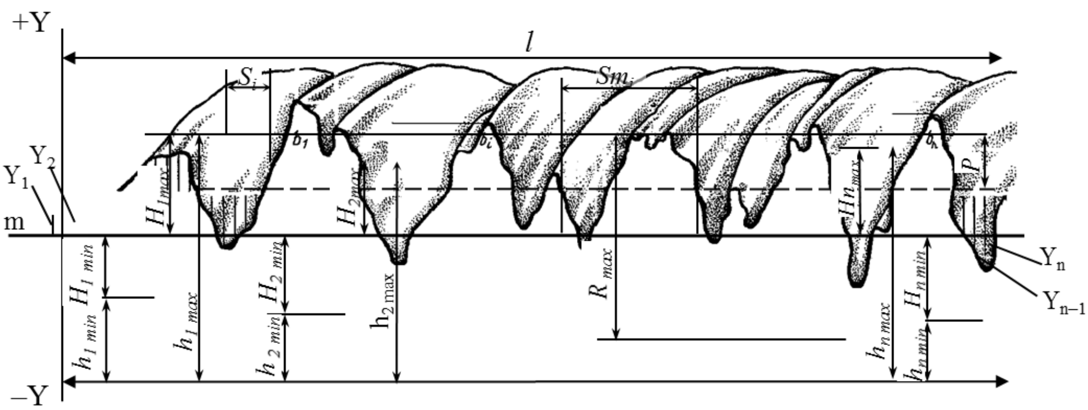
Designs Profilometer Model 130

The surfaces of the parts after processing are not perfectly smooth, since the cutting edges of the tools and the grains of the grinding wheels leave traces on the surface in the form of irregularities, small protrusions, depressions and scallops (Figure 5a and b) or as they are otherwise called, micro-irregularities.

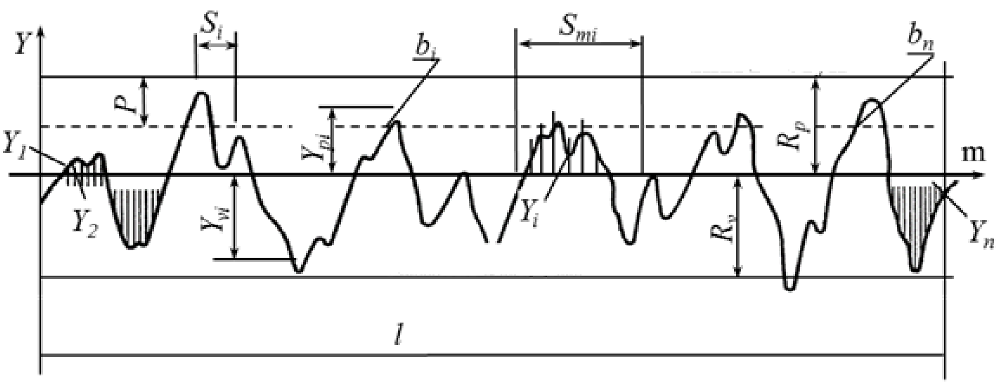
Figure 5

The Main Roughness Parameters, Where Y is the Distance Between Any Point of the Profile and the Centre line and S is the Average Pitch of the Local Protrusions of the Profile. (a) A Longitudinal Section of Micro-Dimensions on the Surface Under Study. (b) A Profilogram of the Longitudinal Section of the Part Under Study and the Main Parameters of Surface Roughness

a)



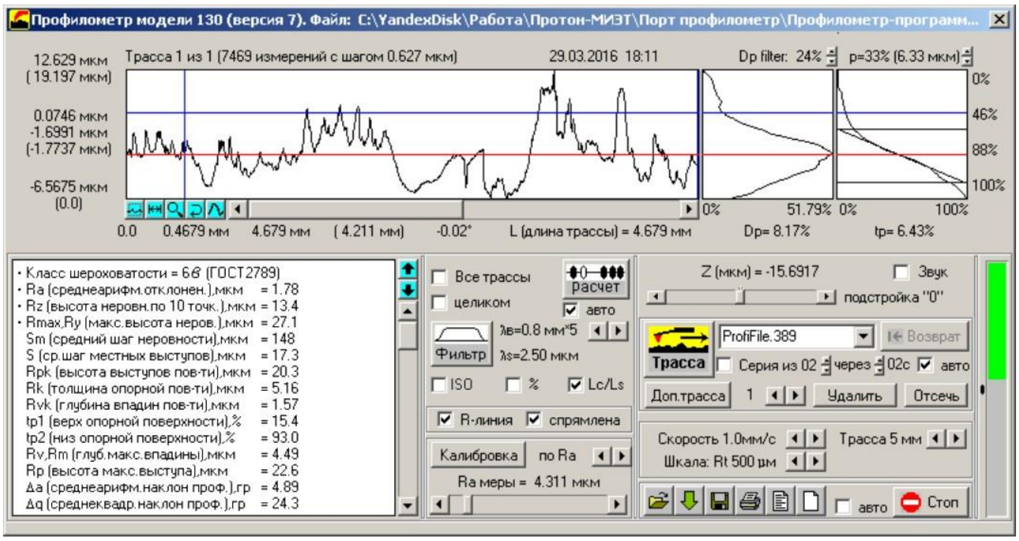
b)



In mobile landings, when the rubbing surfaces of the parts are separated by a layer of lubricant and do not directly contact, roughness errors lead to uneven clearance in the longitudinal and cross sections, which disrupts the laminar flow of the lubricant, increases the temperature and reduces the bearing capacity of the lubricant layer (see Figure 6).

Figure 6

Model 130 Profilometer Control Window



Updating and improving the knowledge of the staff of the research centre 'Surface engineering and tribology' of the university (Kozhakhmetov, et al., 2020; Sagdoldina et al., 2019; Skakov et al., 2012, 2020) is involved in the academic process, allowing the development of students' knowledge and skills. Having prior knowledge about the proposed study topic, choosing the research topic, literature research, writing reports and preparing presentations are the results expected from the student.

The qualities expected to be possessed by the student who is successful in the course are to be able to use the knowledge gained in the course by combining it with his own skills, and to use it together with the information he / she has taken in other similar and appropriate courses. Therefore, attention should be paid to whether the student understands the modern definition of tribology.

3.1. Analysis of experimental work

Table 3 shows the selected different experimental groups, the results of the methodological system we developed or the tests we carried out before and after implementation. The latest test results obtained show a significant increase in the number of correct results after applying the proposed theory. While the correct answer rate was between 50% and 75% in the first test, the correct answer rate was 85%–95% in the last test

A series of pedagogical experiments have been carried out to test the research dimension of our hypothesis, to test students' experience in conducting academic and research work. The main criteria that show the formation of academic research ability in students are listed as follows: to write and complete qualified work on 'Tribology'; and to be able to document that they have applied their research and development work (to participate in regional or international conferences and symposiums). Data from the proposed experimental study results showed that after the application of the methodological system proposed by us, the students' ability to conduct research on surface engineering increased significantly. The gradual increase in the number of articles directly related to 'tribology' suggests that the students' interest in the subject has increased significantly and their level of knowledge has improved. It is noteworthy to see that the selection of students has been affected by the increase in the number of courses related to tribology in the curriculum and the interest of teachers in the subject.

Table 2

Comparison of the Increase in Surface Engineering Knowledge in the Student Before and After the Methodological System We have Applied

Name of University	Correct answer rate before the implementation of the methodological system				Rate after the implementation of the methodological system		
	2019–2020	2020–2021	2021–2022	Average value	2020–2021	2021–2022	Average value
S. Amanzholov East Kazakhstan University	78	88	83	83	78	84	81
International Kazakh-Turkish university named after Khoja Ahmed Yasawi	66	71	85	74	83	87	85
South Kazakhstan Pedagogical University	69	76	77	74	89	91	90

To objectively verify the efficiency of our proposed system, laboratory studies are proposed before experiments. In this first laboratory study, three tasks were proposed to determine the previous level of knowledge. After the experiment, a second laboratory study was conducted. This second work also covered the main part of 'tribology' and included three tasks. The fulfilment of the task in each case before and after the experiment was examined separately. Thus, the level of knowledge acquired by future physics teachers in the field of tribology was determined. The topic of laboratory work No. 1 is given as follows: 'Study of the tribological properties of materials in the tribometer TRB3' and its tasks:

1. Learning the physical use of the tribometer.
2. Examining the physical foundations of tribology.
3. Determining the coefficient of friction on the tribometer for the specified materials

The topic of laboratory work No. 2: 'Determination of profile parameters and surface roughness of materials on the profilometer model 130' and tasks are as follows:

1. Determination of surface roughness.

2. Study of the parameter of the surface roughness characteristic.

3. Investigation of methods for quantifying roughness.

The answer to each question was scored on a scale of 0–2. The students' level of knowledge in tribology was determined as the sum of the scores obtained (0 is the lowest value and 4 is the highest). The average and variance assessments obtained from the test results for the study groups of the students are presented in Table 3.

The initial values obtained from the sampling averages and variances show that the students of each group (control group, CG, and experimental group, EG) have almost the same level of tribology knowledge. However, when similar evaluation results are repeated after the completion of experimental training, it is seen that there is a significant difference in the results. In fact, this result tells us that the proposed methodology has a positive effect on EG students' tribological knowledge formation. In CG and EG, the difference between the levels of tribological knowledge formation at the beginning and end of the experiment is clearly seen in the graphs (Figures 7 and 8).

When the experimental data are processed statistically using secondary methods (especially the comparison of the average samples), it will be determined that there are significant statistical differences between the means. That is, the study itself can check the effectiveness of the proposed method of creating tribological information. In such statistical evaluations, *t*-test practice can be used for statistical comparison of mean values. The *t*-test formula is as follows (2):

$$t = \frac{|\overline{x_1} - \overline{x_2}|}{\sqrt{|m_1^2 + m_2^2|}}$$

where $\overline{x_1}$ and $\overline{x_2}$ are the average value of the variable for the first data (at the beginning of the experiment) and the second data (at the end of the experiment), respectively. m_1^2 and m_2^2 are the values that represent the average deviation from the corresponding mean values (3; 4):

$$m_1^2 = \frac{S_1^2}{n_1}$$

$$m_2^2 = \frac{S_2^2}{n_2}$$

where S_1^2 and S_2^2, respectively, are the sample variances of the first and second variables of the first and second samples, and $n_1$and n_2, respectively, are the numbers of students in the first and second samples.

Table 3

Tests Results on CG and EG

		Test group No. 1		Test group No. 2		Test group No. 3	
		$\overline{X}$	$\overline{s^2}$	$\overline{X}$	$\overline{s^2}$	$\overline{X}$	$\overline{s^2}$
CG	Before the experiment	0.92	0.74	1.68	0.65	0.92	0.90
	After the experiment	1.15	1.32	2.02	1.93	1.66	3.00
EG	Before the experiment	1.05	0.74	1.6	0.3	0.94	0.71
	After the experiment	1.89	1.14	2.50	0.95	2.17	1.13

Figure 7

The Formedness of Tribological Knowledge in the Control Group of the Formative Stage the Experiment

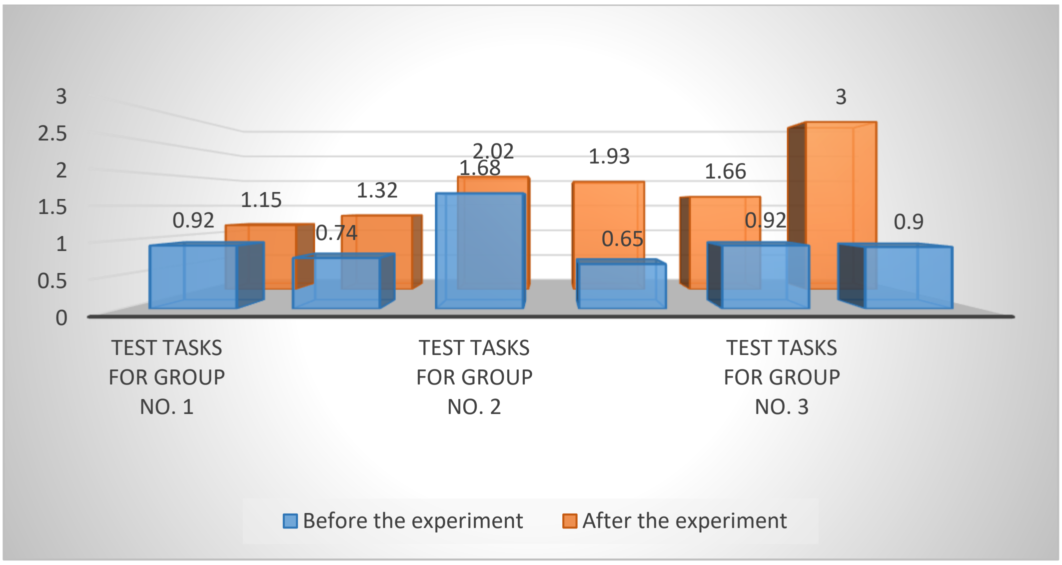
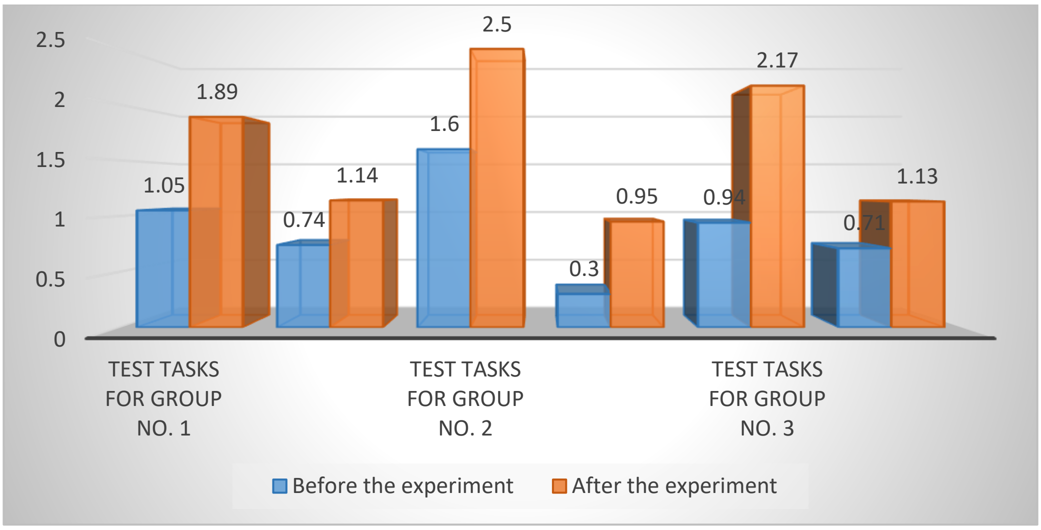


Figure 8

The Formedness of Tribological Knowledge in the Experimental Group of the Formative Stage of the Experiment



According to the data obtained in the study, t_{ps} – perception of problem expression, t_{HR} – hypothetical reasoning and t_{HP} – the perception of the proof of the hypothesis are calculated, respectively. Comparison of critical student distribution number based on the number of degrees of freedom $n_1 + n_2 - 2 = 20 + 20 - 2 = 38$, and the reasonable error rate for probability have been accepted as 0.01. In pedagogical statistics, the critical value is calculated using appropriate software. The average value calculated before the experiment was 0.014, ± 1.710, (m = ± 0.010), while the mean value calculated after the experiment was 2.035 ± 0.035 (m = ± 0.025). The number of degrees of freedom (f) is 1. t – criterion of the students is 9.286. The value of the critical t – criterion for the student's designated degree of freedom is 12.706. As long as there is tobs<tcrit, the differences for the value p = 0.068 remain statistically insignificant. The important criterion here is that the value t

for a given degree of freedom and the acceptable probability of error is at least 9.286. It turns out that in Kazakhstan the value we calculated with a calculation accuracy of 99% is higher. Since a probability of error of 0.01, 0.02 or lower would mean that the result is scientifically sufficient, the main idea we put forward in our hypothesis has been confirmed.

3.2. Discussion

The results we have obtained from our analyses clearly show that we have achieved the result of the training development that we propose in our hypothesis, which is our main goal. Therefore, we can decide that the methodology we have developed has increased the interest of university students in tribology. A superior level of knowledge has developed in the field of tribology, and this knowledge has also developed the ability to apply it in the performance of research tasks.

While the correct answer rate was between 50% and 75% in the first test, the correct answer rate was between 85% and 95% in the last test, as presented in Table 1. The measured increase is more than 20%, and this is a very good percentage of success, but our educational experience tells us that when the difference in knowledge level in the range of 50%–75% is met with the difference of 85%–95%, the difference in high volume is much more important than the difference of 20% in the lower slices. This means that after the implementation of the educational model, there is a huge increase in the level of knowledge of students in the field of tribology. The same effect can be seen from deviations between CG values and EG values before and after the experiment (Table 2).

In Figure 7, a visible representation of the formation of tribological information of the control group in the formative group of the experiment can be seen. It is clear that the formation of information is interactive and random.

In Figure 8, a visible demonstration of the formation of the tribological knowledge of the experimental group in the formative group of the experiment is shown. What is seen is that the formation of knowledge increases in a completely systematic way.

4. Conclusion

In the physics departments of universities, the inadequacy of the students' knowledge about surface forces, such as friction forces tribology knowledge, has emerged. This indicates the existence in the literature of shortcomings in the number of educational materials and textbooks directed to certain important topics and the necessity of including tribology and important subjects in the training of future physics teachers. In this study, as a solution to the findings mentioned above, a model has been created to teach tribology physics of university students within the scope of compulsory and elective courses by including all the necessary components such as content, method, teaching and objectives. The inclusion of the principles and concepts of tribology as a department in the general physics courses of the universities 'molecular physics', 'mechanics', 'fundamentals of thermodynamics and statistical physics' and 'electricity and magnetism' were programmed, and the teaching methods were defined for the students and the necessary tools were created by including digital technologies to make the application correctly.

In addition to the aforementioned programme, a textbook covering the most important parts of tribology, including teaching, research and development studies, has been determined and published to help the future physics teacher. A physical workshop consisting of three laboratory works has been developed, which is carried out on the basis of the research centre of the university's 'Surface Engineering and Tribology' and by its scientific staff. We conducted a pedagogical study that confirmed our hypothesis. According to the results of the experiment, it is seen that the use of the training method we propose, as presented in Table 1, will contribute to the understanding of the tribology of physics education.

4.1. Future work

There is much more to be done in the field of tribology, especially at the postgraduate level. In particular, the determination of the factors affecting the friction mechanism between two bodies and the formation of the friction coefficient between surfaces is important in terms of producing new material with the desired feature (Godet, 1990; Popov, 2018). The superlubricity subject has also great interest in the nanostructure dimensions to study at the graduate level (Dienwiebel et al., 2004, Filippov et al., 2008).

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Data availability statement

Data confirming the conclusion of this study are available upon request of the corresponding author.

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