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Article

A Virtual Reality Lab for Automotive Service Specialists: A Knowledge Transfer System in the Digital Age

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Abstract: Under the influence of the COVID-19 pandemic, there is an accelerated transition from the traditional form of knowledge transfer to online learning. Our study of 344 automotive students showed that the success of this transition depends on the readiness to introduce special digital tools for organizing knowledge and conducting practical forms of classes. In this regard, a modern digital form of organizing and transferring knowledge to automotive service engineers in the form of virtual laboratories was developed and presented in the article. The work scenarios, functionality, and minimum technical requirements of virtual laboratories as software systems are described and reviewed in the paper. The rationale for the effectiveness of the application, based on the results of using 109 university students in training practice, is presented as a result of the research. An analysis of the distributions of the student survey results and their training progress revealed differences at the $p = 0.05$ significance level. This confirmed the hypothesis that the use of methods for teaching engineers special disciplines and language skills using VR technologies is much more effective than the traditional one. An increase in students' interest in learning was revealed, and their performance improved markedly. This proves that the immersive nature of VR technology makes it possible to better assimilate the studied material, increase the level of motivation of future car service specialists, and also allow the organization of the transfer of knowledge online. The very process of knowledge transfer becomes the point of acquiring new digital competencies necessary for high-tech industries.

Keywords: virtual reality; lab; automobiles; service; knowledge transfer

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1. Introduction

The "informatization of society" is being replaced by the digitalization of the economy, which is positioned by experts as "technonomics". In this sense, the development of engineering and technology creates an environment for the rapid evolution of the economy, but the implementation of these opportunities requires highly qualified specialists, both in terms of professional skills and competencies as well as efficiency in personal development. In today's society, young people must be ready to work in a constantly changing information environment. Under these conditions, one of the most important competencies of a modern specialist is the ability to use digital technologies in their professional activities, to carry out effective interpersonal communication, to actively master and process huge flows of information, and to be ready for constant self-education [1].

Businesses need engineers qualified to design, build, and operate complex technical systems. It is not always possible for a company to find a full-time employee in the same location where the organization is based. However, the improvement in the quality of communication, the development of information, and communication technologies made it possible to circumvent this limitation. In the context of globalization and an increase in sharing remote employment formats, the design and development of products by international teams is becoming a natural feature of modern engineering. The new realities of digital transformation, changes in the nature, and forms of labor relations have resulted in the formation of the so-called gigonomics, which refers to the situation when an employee implements his professional skills in different companies located anywhere in the world through digital (electronic) services [2]. Of course, in addition to high professional competencies, this model requires the knowledge of international languages, most often English. Thus, knowledge of the language makes it possible to implement communication skills, and, in addition, provides the opportunity for another soft skill—working with information, since in order to remain competitive in the labor market, a specialist needs to be aware of and analyze various foreign sources and experiences in the area of his professional interests.

All these aspects impose new demands on knowledge systems engineering. The knowledge representation system for engineering education has been improved in recent years through the use of new e-learning opportunities using special platforms, including distance learning technologies. The forced rapid transition of universities to this format of knowledge transfer during the pandemic required the active introduction of new digital resources, methods, and technologies of remote communication. At the same time, engineering students require significant efforts, both during their studies and in their subsequent professional activities, as equipment and technologies become more complex. Under these conditions, the problems of the attitude of the students themselves to new formats of interaction also need to be actualized. It became clear that the traditional model of knowledge transfer is disintegrating, and it is also impossible to focus only on online learning technologies. It is necessary to search for new formats and tools that provide both the exchange of engineering knowledge and the improvement of the linguistic skills of the future engineer.

2. Problems and Features of Knowledge Transfer in Modern Conditions of Digital Transformation

Knowledge engineering is a set of models, methods, and techniques aimed at creating systems that are designed to solve problems using knowledge. In fact, knowledge engineering is a theory, methodology, and technology that covers the methods of extracting, analyzing, presenting, and processing expert knowledge. Here, knowledge is understood as a set of information, concepts, and ideas about something received, acquired, and accumulated as a result of teaching, experience, the process of life, etc., and usually implemented in activities.

At a high level, the knowledge engineering process consists of two steps. (Figure 1):

1. Knowledge extraction is the transformation of “raw knowledge” into organized knowledge.
2. Knowledge implementation (incorporation) is the transformation of organized knowledge into operational knowledge.

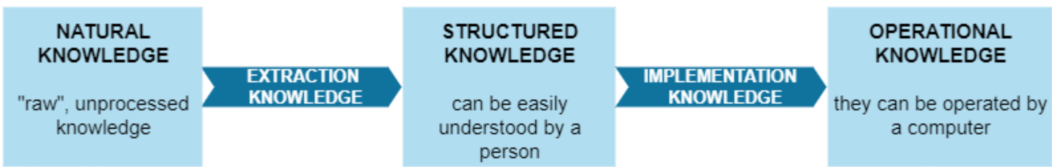


Figure 1. Process of knowledge engineering.

The content and purpose of the knowledge transfer concept in the context of education is the acquisition and development of the student’s ability to apply the acquired conceptual and procedural knowledge and skills in authentic professional contexts. In the area of knowledge transfer, various tools and models have been created to effectively manage knowledge and its representation in order to achieve the stated goal. Thus, there is an extensive review [3] devoted to the analysis of the main factors influencing the transfer—characteristics of the student, the design and conduct of the intervention, and the influence of the working environment.

The so-called deep meaningful learning has received wide development. It is understood as thinking and development of a higher order through a variety of active intellectual activities aimed at building meaning through pattern recognition and association of concepts [4]. It includes research, critical thinking, creative thinking, problem solving, and metacognitive skills. Due to the high degree of elaboration, this theory is successfully applied in improving the process of knowledge transfer at all education levels to achieve the application of knowledge in authentic contexts.

For the transfer to take place, it is necessary to organize learning as an active and dynamic process, which is influenced by the motives of students. Given the rapid and continuous development of technology in all areas and the dominance of the lifelong learning concept, knowledge transfer is considered a top priority in continuing professional development and corporate training programs.

The existing realities require a revision of the traditional methods. The development of information and communication technologies has led to the emergence of new opportunities for the representation of knowledge and its processing and use. The subject of modern knowledge engineering is interaction with the information field, which allows not only the exclusion of a person as a source of natural knowledge without losing the quality of knowledge data transfer, but also allows the significant expansion of the experience of the learner. The range of technology possibilities is growing, and using them during the educational process, we can simulate a large number of different situations that the learners may have to face in their professional activities. At the same time, it is necessary to reconsider the concept and essence of the representation and transfer of knowledge, which itself sets the context of the description and is a holistic description of the situation, formed as the result of generalizing information and establishing certain patterns in any subject area that let us set and solve problems in this area. Knowledge is a resource based on the practical experience of specialists and on the information that exists in the enterprise. When creating a modern information field of knowledge, it must be taken into account that information and communication technologies allow the embedding in a computer of a mechanism for both acquiring and deriving knowledge based on facts and relationships contained and organized in a computer environment. However, new opportunities opened up by the use of information and communication technologies have also identified new problems and challenges.

It was suggested that, with a certain level of sophistication, practical exercises can be replaced by virtual reality laboratories, so the use of specialized virtual laboratories is necessary.

3. Background: Digital Technologies and Virtual Laboratories as a New Form of Knowledge Transfer

3.1. Digital Technologies in the Modern System of Knowledge Transfer

Despite all the obvious extremely negative aspects of the COVID-19 pandemic, the crisis has led to the discovery of new dimensions in the online teaching of engineering courses and has made it possible to use various digital knowledge transfer tools.

Currently, there are many tools and methodologies in the field of engineering education. Technologies such as virtual and augmented reality, digital twins, and smart education provide the improvement of the educational environment, increasing the motivation of students and preparing them for life in the digital age [5]. Modern digital technologies allow training based on virtual classrooms and remote laboratories, games, and gamification while also increasing the motivation and interest of students in their studies.

The article [6] describes the technique of gamification in the study of geosciences as an innovative teaching method for students of engineering specialties. When using this technique, students are divided into small groups and perform group tasks during the semester. Assignments were rated in points, and a table was drawn up showing the current performance of each group. At the end of the semester, student questionnaires were conducted, and the answers showed that gamification can improve students' learning motivation and increase interest in the subject.

Gamification is increasingly used in the educational process and in e-learning. The article [7] shows how the reward system in gamification affects the motivation of students during the semester. The use of gamification is analyzed using the Kahoot gaming educational platform. The results of the study showed that students were interested in this educational online tool, as evidenced by the increase in their final performance.

Game methods in the educational process contribute to a deeper understanding of the essence of real processes, increase the interest and motivation of students, provide a detailed analysis of technological processes and risks, and also contribute to faster adaptation of young professionals in the workplace.

Currently, there are more and more studies devoted to the best practices in the educational system based on distance learning technologies. The article [8] describes the use in the educational process of the remote laboratory VISIR (Virtual Instrument Systems In Reality), based on a network of virtual cooperation between universities. VISIR is a state-of-the-art laboratory using real equipment, measurements on which are made using real instruments, with the possibility of remote control. VISIR systems are installed in thirteen different higher education institutions from eight countries (Argentina, Austria, Brazil, Georgia, India, Portugal, Spain, and Sweden) and successfully integrated at different levels of education. The PILAR (Platform Integration of Laboratories based on the Architecture of VISIR) project, by providing access to a remote laboratory to other educational institutions, expands the opportunities for practical training at a higher level of digital integration.

An analysis of applied forms of knowledge transfer shows that blended learning has advantages over both traditional learning and e-learning. For its successful implementation, a single information and educational platform is needed that allows the development of educational content, the management of the educational process, and delivery of the opportunity for virtual communication [9].

The study [10] presents a knowledge transfer model that uses the YouTube video repository for engineering courses. The proposed standalone model with video storage is highlighted as the best alternative to improve student satisfaction and performance. Students prefer the video repository over other educational tools due to its flexibility. They also note the convenience of the model when preparing for exams, as videos can be viewed anytime and anywhere compared to a model that is transmitted "live" over the Internet, with the possible difficulties of a poor Internet connection. The authors believe that the results of the study can be used to develop hybrid teaching models.

The article [11] describes the transition from face-to-face to blended learning in the Master's program in engineering by adding a parallel online group, which had a positive impact on learning outcomes and ensured the continuity of the master's program. Live streaming of lectures allowed online students to interact with students in the classroom as if they were in a regular classroom session. Interaction between the teacher and students, as well as between students, is provided through online chat, interactive tutorials, face-to-face lectures, and discussion forums. In addition, collaboration has been enhanced using state-of-the-art OpenBIM-based software, which has improved the quality of communication and the teamwork of students as well as their interaction with their teacher. An analysis of the final grades showed that the new methodology significantly improved the average student grades, although no significant differences were found between the two groups. The proposed "anytime, anywhere" approach to knowledge transfer with supporting materials and student monitoring has contributed to the improvement of the educational process.

The author of the study [12] proposes to use the Moodle system in remote content transfer technology, in which the theoretical lecture material is duplicated. The proposed new approach combines two types of education: classical (in classrooms and laboratories of the university) and self-education (distance learning outside the university). Theoretical materials and local tests on each topic, uploaded to Moodle, contribute to the successful development of knowledge and skills by students in any place and at times convenient for them.

The remote communication format and related technologies have become an integral part of the modern knowledge engineering system [13]. The authors of the article [14] believe that efficient technologies are necessary for the successful implementation and support of distance learning. In their study, they propose a new technology solution for video conferencing using webRTC technology as a replacement for applications that still rely on flash memory technology. According to the results of the tests, the system is user-friendly and can be recommended for use.

Modern knowledge engineering should, on the one hand, meet the needs, interests, and aspirations of students as much as possible, and, on the other hand, provide high-quality training for engineers who are ready to solve production problems in the digital economy. Undoubtedly, the digital educational environment, influencing the various senses of students, should stimulate their interest and develop motivation for learning.

VR is a relatively new, high-tech, and cutting-edge technology that can be used as a powerful knowledge transfer tool. A lot of evidence has appeared in the press about the successful introduction of virtual reality technologies into the educational process during the pandemic and lockdown. It is widely implemented in educational institutions for the training of medical doctors [15,16], workers in various industries [17–19], simulators for pilots [20] and drivers [21,22], and for the training of engineers [23,24].

3.2. Virtual 3D Models for Studying the Design and Properties of Complex Technical Systems

Replacing real physical objects studied in laboratory and practical classes in the traditional form with their computer 3D models in conditions of social distancing has become the only worthy alternative and an opportunity to consider in detail their structure and understand the principles of functioning [25,26]. With the help of engineering modeling, it is possible to create educational content with easy-to-understand visualizations to maintain a quality educational process.

3D models, often one of the key elements of the digital environment, can be created using CAD programs or 3D computer graphics software. Searching for the required digital content in an engineering subject can be a significant effort, so it seems promising to create public resources for downloading and importing the developed 3D models.

However, it should be noted that the creation of physical models using the virtual reality environment is a complex task and requires both knowledge of the subject area itself and experience in software development. In some cases, this is a deterrent when teachers decide to switch to a new format. Therefore, it is relevant to develop simple tools that can help inexperienced developers convert educational content into digital format [27].

3.3. Creation of a Virtual Environment for Studying Technological Processes

The second direction is the use of virtual laboratories to study technological processes. Since augmented and virtual reality technologies allow a deeper understanding of the essence of real processes and demonstrate both the main steps of the process and possible critical situations [28], new approaches and achievements in the field of online education based on the use of these technologies are not just relevant but the only possible ones to ensure the required quality of the knowledge transfer process.

Thus, the engineers who design the car will be able to check its maintainability as well as conduct a crash test to assess the safety of the designed car. Engineers who design processes can test their safety and ergonomics on a model as well as analyze their effectiveness. Engineers who are involved in maintenance can check on the model that equipment and tools will be safer and more ergonomic.

The use of virtual reality laboratories also makes it possible to solve the problem of safety and security. This way, students can work out the technological processes of repair associated with increased danger, such as the maintenance of gas-balloon cars, for example, which is associated with the risk of leakage or even the explosion of gas fuel.

The article [9] presents a model of interaction in the creation of training courses based on technologies of virtual and augmented reality using the project approach. The implementation of the proposed virtual training system of the 3D reality laboratory creates unique opportunities for training specialists in the field of project management for IT. The digital twin technologies proposed in the studies [29,30] together with the cloud simulators can also be successfully integrated into curricula for automotive engineering departments.

The authors' work [31] presents a description and practical application of a remote container-based virtual laboratory (CVL) related to cybersecurity. The lab is based on Linux Docker virtualization technology, which allows the creation of realistic scenarios for student learning. The proposed laboratory was highly appreciated by the students, who noted such properties as usefulness and ease of access and application.

Of particular interest in modern engineering education is modeling based on the integration of augmented and virtual reality (AR/VR) with traditional engineering simulators. The study [27] proposes a simple and flexible methodology for integrating AR software with technical content such as animation, 3D models, and engineering simulations. The digital instrument developed in this work is available online.

In [32], there is an example of how the intensive practical group design engineering course "Design and Innovation of Medical Equipment" was effectively adapted. All previously scheduled face-to-face lectures were held remotely via Zoom. Instead of in-person tours, medical device companies were taking virtual tours of their facilities, showing their design, manufacturing, and inspection processes. Of the students surveyed, 82% were satisfied with the quality of remote lectures. Student feedback also demonstrated that it is more difficult to establish personal communication in the distance learning format. The challenges of communication and networking were particularly evident in the virtual tours of medical device companies, where 44% of students said that they did not have enough opportunities to meet and interact with engineers. However, the main problem from the point of view of training a good specialist is not the lack of full-fledged communication.

Laboratory and practical classes had to be rethought and replaced. Practice and internships at the sites of employers have almost disappeared. Some parts of the education sector have done a great job of addressing this variety of problems with things such as digital artifacts, virtual labs, proxy remote control [33], but it should be noted that the problem has remained largely unresolved.

3.4. VR Technologies for Acquiring Linguistic Skills

Teachers who transfer knowledge and skills in the field of languages also faced a problem during the COVID-19 pandemic. To solve this problem, the authors of the article [34] resorted to the creation of SMART textbooks for teaching students the Russian language, which can also be used to teach other languages. SMART textbook is a type of electronic textbook with interactive tools, the possibility of interaction with other students, and the ability to connect various additional devices of VR and AR technologies. The SMART textbook is intended for use in the classroom as well as independently by students. The main function of such a textbook is to make learning more entertaining, and to instill in the student an interest in the subject. Thus, the remote transmission of content, with a competent approach to its use, can contribute to the development of students' language competencies.

The authors of the article [35] also faced the problem of the inability to conduct face-to-face Chinese classes due to the pandemic, and they tried to solve this problem by switching to remote knowledge transfer, yet more and more students lost engagement in the knowledge transfer process and became underachievers. In this regard, the question arose of the advisability of using VR-, AR-, and MR-technologies. The authors note that with the use of these technologies, the threshold for beginners to enter the complex process of knowledge transfer is noticeably reduced. The holographic display of the interlocutor helps better understand the diction of a native speaker of a foreign language. Interactive images can help pick up associations and remember words better, and the sound accompaniment helps students to memorize and understand the tones of the Chinese language correctly. The transfer of knowledge becomes more playful and exciting in order to attract the interest of students.

The authors of the article [36] found out that that 3D visualization of various technical objects using AR and VR technologies allows the teacher to interest students and attract their attention and present educational material more clearly, and students learn foreign language terms more easily and quickly and master speech patterns for professional communication. By using 3D visualization technology in foreign language classes for future specialists, the authors do not fundamentally change the teaching methods, but simply expand the possibilities of a printed textbook. Visualization of objects increases the attractiveness of the process of knowledge transfer for a generation accustomed to the constant use of electronic devices since childhood.

In the article [37], the authors analyze virtual online platforms in order to introduce these technologies for studying foreign languages in universities. After analyzing the demand for these technologies, they argue that the use of these technologies is a promising direction, list the most popular online platforms with VR technologies, and describe their functionality.

Engagement and assimilation of the material are important components of acquiring the required competencies, and, besides, the virtual reality environment is good because it can simulate real situations in which students may find themselves, which allows them to better prepare for future professional activities. The authors of the article [38] have developed a virtual reality system for their students. The goals of this program are to improve the level of English proficiency and systematic immersion in situations, with the subsequent solution of professional problems. The game method purposefully involves the student in actively conscious cognitive activity. The sequence of the exercises is important because VR CUSTOMS has a plot of an educational "game", where the user acts as one of the characters from a virtual point of view, and as a student from a real point of view.

3.5. The Use of VR Technologies in the Automotive Industry

A car is a complex technical system, and its quality requires coherence and optimality of processes at all stages of its life cycle: from market research and consumer preferences, to product design and manufacturing technology, production, product promotion, operation, and maintenance to disposal. This requires that engineers have different competencies, possessing relevant knowledge, methods, and technologies. Digital transformation is changing all sectors of the economy, providing ample opportunities for digital tools to improve processes. Pandemics like COVID-19 are becoming a catalyst for this process, too.

Despite the great relevance of this area, the great attention from the international scientific and educational communities, and the large number of publications that have appeared in the results of research, many questions remain unresolved.

When virtualizing the knowledge transfer process, the student in the process must believe in what is happening, the object models, the environment, and the atmosphere, all of which should imitate the real world in its laws and physics as much as possible, while it should also be maximally optimized in order to be accessible to the maximum number of current and potential students. This will increase the availability of the software product, as well as ease of use, which positively affects the involvement in the process of knowledge transfer and, consequently, the assimilation of the material. In the article [39], the authors solve problems with the processes of optimizing the creation of a three-dimensional space, texturing 3D objects and setting up scene lighting. They concluded that it is possible to use the methods of the video game industry to improve the performance of mobile virtual reality applications in the educational field.

Working with a VR headset takes time to master and get used to the technology, as untrained users can become disoriented, which in turn leads to a loss of balance and injury. However, if the application in the virtual environment is poorly optimized, then various negative visual effects can bring discomfort to experienced users. In order to avoid this, it is necessary to set tasks for optimizing VR applications. The authors of the article [40] dealt with such optimization problems. In their work, the authors decided to turn to game development industry tools to optimize locations. Their research covers the practical application of these tools in such areas as topology of 3D models, rationalization of texture maps, and working inside a game engine. To achieve the tasks set, the authors proposed a methodology for creating and processing models and the environment, as well as technologies and tools that were used to develop a VR application for learning English.

There are excellent examples of virtual labs where scripts are implemented to manipulate the main parts of a four-stroke internal combustion engine [41,42] or the center console of a car [43]. However, despite the technical problems in the virtualization of the process of knowledge transfer in general, the system of knowledge engineering for the operation of vehicles has not implemented the primary task—a full-fledged replacement of practical classes through the use of virtual laboratories. Despite the extensive search, we could not find any works that present examples of the introduction of virtual laboratories into the educational process that implement an experiment with a full-fledged technological process of car repair. Therefore, the creation of such laboratories is an urgent agenda for today.

3.6. The Use of VR Technologies in Knowledge Transfer

VR technologies provide knowledge engineers with unique opportunities to recreate reality. The reliability of duplication is so high that it is sometimes called miraculous [44].

Foreign language teachers can, using the capabilities of a virtual laboratory, recreate real situations, which can be quite problematic, especially in conditions of distance learning and the absence of fellow students. The recreated virtual environment allows users to literally create the effect of presence, playing the scenario not just in words but immersing entirely in the situation and experience. This gives an almost faithful recreation of the production context.

In addition, when studying technical objects, the use of virtual reality technology makes it possible to reduce the student's tension associated with the fear of violating safety precautions and damaging expensive equipment or being injured himself. Process simulation allows circumvention of the limitations associated with the lack of safety of the process or the system being studied for an unprepared and untrained person. All of this contributes to a more active and easy immersion of the student in the process being studied.

All of the above turns out to be an undeniable advantage over other tools for implementing the transformation of knowledge in the modern digital era. However, the agenda for researchers of the possibilities of virtual reality is a serious task as they have to demonstrate the transfer of both content and strategies beyond the gaming environment. For example, in work [45], the author studied the predictive effect of self-regulated learning model variables on transfer after several gaming sessions in a science-oriented game-learning environment in a fifth grade classroom. The author noted the potential of such games as changes in knowledge were found to be an important predictor. This suggests that the students who made the most progress in learning in the game were also the ones most likely to pass on their knowledge outside of the game. Earlier studies also indicated that transfer significantly correlates with game performance: students who complete play also score significantly higher in transfer performance [46].

In addition to being used as a learning component, a virtual environment can also take on the functions of an LMS system. For example, in [47], a new driving system based on virtual reality (VR) is presented. It is capable of recording eye gaze, pupillary dilation, heart rate, and learner driving performance data. Thus, the authors propose to use the capabilities of the environment for measuring neurocognitive load in order to classify users. This can be used to improve the efficiency of knowledge transfer.

In [48], the authors proved the viability of using virtual reality environments to transfer knowledge in such unsafe conditions as training mining personnel in emergency evacuation procedures. The use of the underground mine fire evacuation simulator for all three metrics (simulator performance versus real experience, accuracy score, and platform learning value score) showed the presence of learning transfer, suggesting the viability of proxy metrics in cases where performance testing in real conditions is impossible.

In any case, when using virtual laboratories for automotive service specialists, it is necessary to evaluate the effectiveness of knowledge transfer.

4. Materials and Methods

4.1. Methodology for Identifying Problems Associated with the Transition to a Remote Format of Knowledge Transfer

In the context of the lockdown caused by COVID-19, there has been a massive transition to distant forms of knowledge transfer. A new mode of interaction has brought the degree of digitalization to a new level. To identify the problems associated with the issue, we conducted a survey in June 2020. The questionnaire consisted of 84 questions, grouped into 4 blocks: socio-demographic information, organization of the educational process, students' vision of the learning process organization and the implementation of educational competencies, students' assessment of the satisfaction and motivation degree with the educational process when using distance technologies. The content of the questions in more detail is described in [49]. In the course of the study, we used an online survey (GoogleForms). The survey participants were undergraduate (85.1%) and graduate engineering students (14.9%) from the Naberezhnye Chelny Institute of Kazan Federal University. The study aimed at identifying the attitude of students to remote technologies of digital methods of knowledge transfer. In total, 344 full-time students took part in the survey (Figure 2).

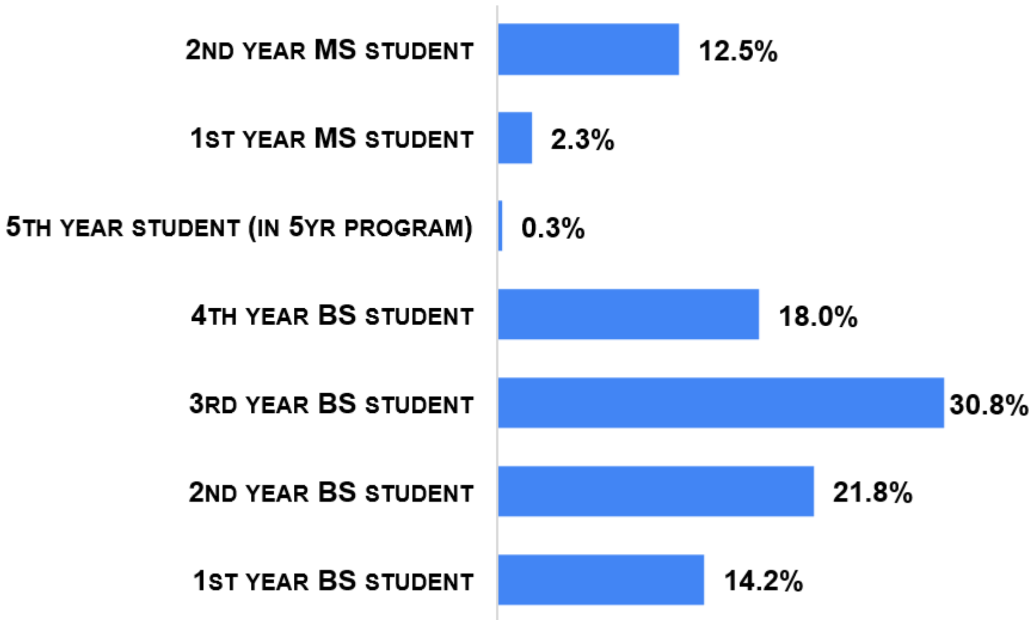


Figure 2. Distribution of students by courses of study.

The age structure of the respondents differed as follows (Figure 3): 19 years and younger—25.6%; the category of 20–25 years old was the most numerous and amounted to 70.3%; 26–30 years old—1.7%; and over 30 years old—2.3%.

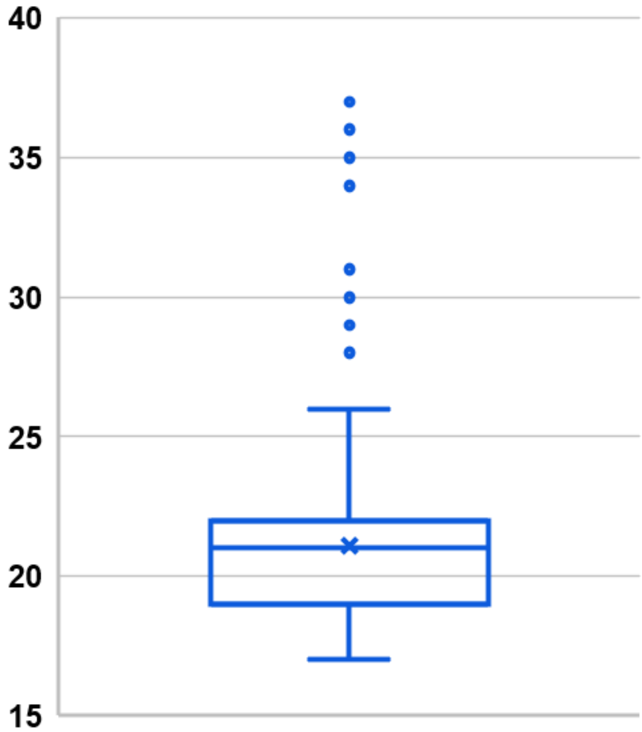


Figure 3. Age composition of the students.

We also analyzed the results of the examination session of these students.

4.2. VR Lab: Target Audience, Duration, Learning Process, and Activities

To overcome the limitations associated with the remote form of transferring practical knowledge, a virtual laboratory was developed at the Naberezhnye Chelny branch of Kazan Federal University for students of the speciality, "Repair and operation of transport and technological machines and complexes". Now, the students are able to practice various operations and procedures both on real machines and in a virtual reality environment. At present, a typical model of VR equipment for balancing work has been developed, and laboratory work has been tested. During the implementation of this work, students study the purpose of the balancing machine, the device, and the principle of its operation, working out the steps of the technological process of balancing car tires and disks.

Students are given an initial safety briefing. The student is put on a helmet and controller straps. Under the supervision of the teacher, the process of the lesson begins.

First, the student needs to install the wheel on the shaft of the balancing machine, not forgetting to open and close the protective cover. Next, the parameters of the installed wheel are set. The balance of the wheel is checked by running the wheel, and according to the obtained unbalance values, it is necessary to install the weights. The wheel balance is checked by restarting the machine. This completes the lab. The purpose of the work is to achieve the required values within the permissible variation. The students do the entire described scenario in the developed VR laboratory (Figure 4).

The duration of this practical work is determined by the duration of the technological process and depends on the type of wheel: for a passenger car, the process of balancing by a professional mechanician is 2 min, for a truck—5 min. Due to the minimalism of the virtual environment, the performance of the virtual laboratory is high even on relatively weak machines, so we can count, that interaction with the environment occurs instantly and is determined only by the qualifications of the performer. An untrained student can spend up to 15 min balancing a wheel for a car and 20 min for a truck.

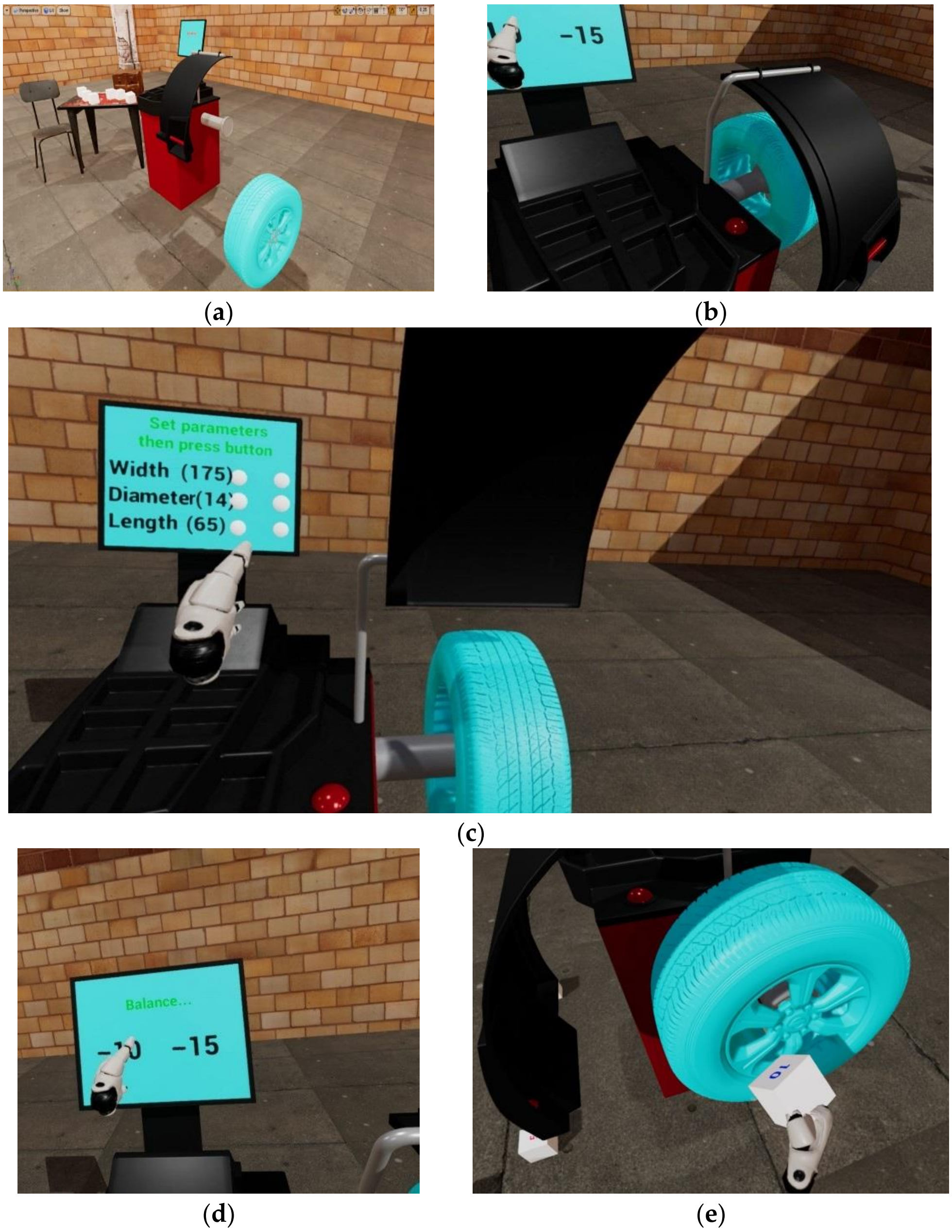


Figure 4. View of virtual laboratory: (**a**) before the wheel is installed on the balancing bench; (**b**) after installation; (**c**) wheel settings; (**d**) wheel needs balancing: 10 grams on the left and fifteen on the right; (**e**) installing weight on the right rim.

To develop the linguistic skills of engineers, this laboratory was finalized. We have applied the same immersive method of getting acquainted with models of equipment and car components with the addition of a dictionary and instructions in foreign languages. The idea is that students in the process of performing laboratory work in a virtual reality environment see a description of the processes and instructions for performing in English. For each stage of the process, each piece of equipment and/or tool is accompanied by a description in Russian and English.

The current project has an environment where the student is located together with several interactive objects for learning. Figure 5 shows the disc brakes of the vehicle.

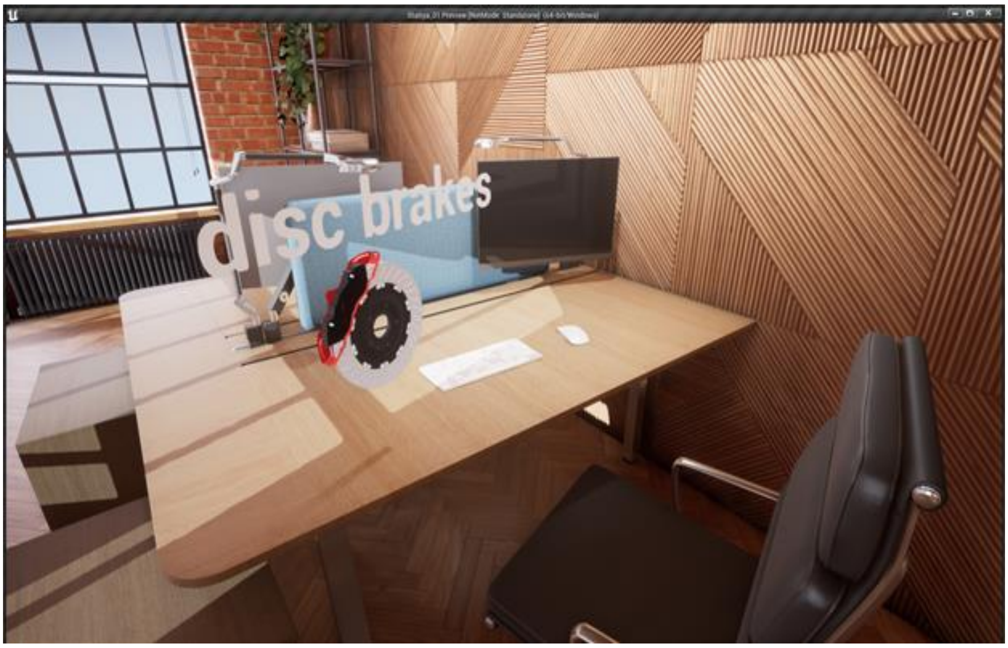


Figure 5. Screenshot of the environment of the object under study and its translation into English.

It is planned to add items such as a two-fork lift and a car battery. A screenshot from the project with models of the objects under study is shown in Figure 6.

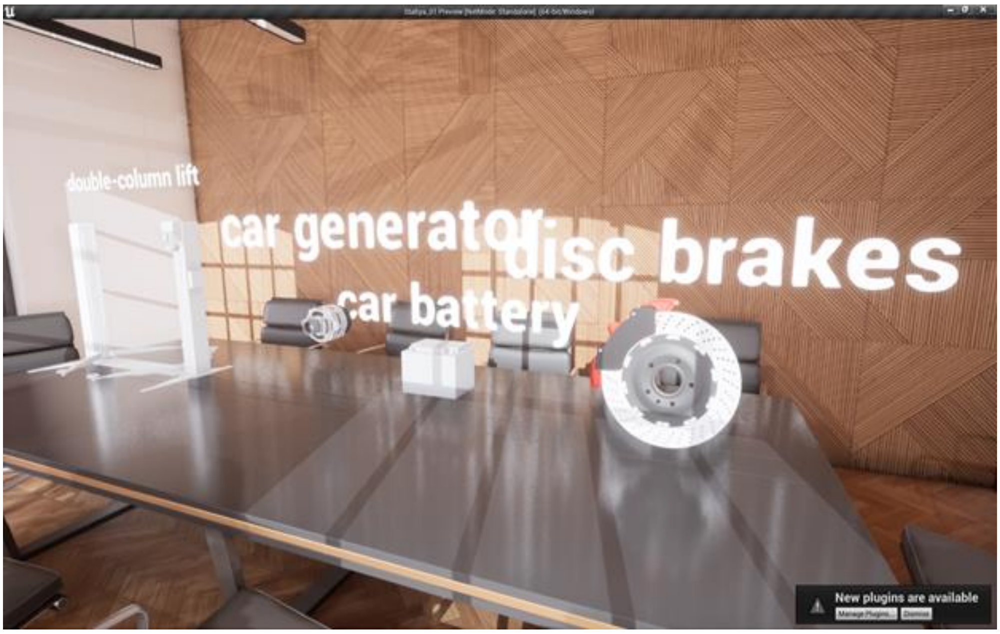


Figure 6. 3D object models.

Interaction with a bilingual virtual laboratory is carried out as part of the training of undergraduate students with the specialities "Service" and "Operation of Transport and Technological Machines and Complexes" on the discipline "Introduction to the Specialty". The aim of the course is to familiarize students with the benefits of virtual reality and gain hands-on experience with available technology and improve their foreign language proficiency. The students were offered a training scenario in which they needed to get acquainted with the tools and details in a limited time. During the introduction, the name of the subject in English is shown. In addition to studying the translation of the object itself, you can parse it and show the translation of the constituent parts of the component.

After studying the technological process, students are asked to take an exam both for professional skills and for knowledge of English terms. Thus, by completing these exercises, students will be able to study specialized, technical English in depth, which will help them improve their general level of education, and will also allow them to communicate in English with foreign colleagues.

The student's movements are minimal, as there is a space of 2×2 m. This will allow the student to reach the wheel, the controls of the machine, and get loads from the table. The virtual environment has been configured to match the real work with this wheel balancing machine as much as possible. This task was set within the framework of the pedagogy of problem-based learning in order to promote the development of knowledge that could be used during real work.

In addition to working in virtual reality mode, one can work without a helmet. All it takes is a keyboard to navigate and a mouse to interact. This method of interaction allows the transfer of knowledge to be organized remotely only if one has a computer. This format is a convenient way to conduct a lesson, even if the student or teacher is separated in space and time. Listening to the lesson, interacting with the virtual space and group tasks are performed. Such activity gives a sense of presence and blurs the boundaries that usually arise when transferring knowledge via videoconferencing.

The transition to learning from the real world to the virtual world works if the simulated objects and their properties exactly correspond to the real ones. The more accurately the properties of the real world are transmitted, the better the virtual learning contributes to the transfer of knowledge and provides an understanding of the system from the real world [50,51]. This development corresponds to situational learning and is aimed at creating a contextual, realistic, and interactive environment. This will allow the student to simulate real work experience at the enterprise, which has been confirmed by previous studies [48]. We also performed a transfer assessment using the methodology described in Section 4.4.

4.3. VR Lab: Development Methodology, Software Stack and Technical Requirements

A feature of the used method creation of a virtual laboratory is the creation of digital content and virtual models of equipment similar to those used in the industry by university staff, including with the involvement of computer students. This approach allows the organization of joint projects to solve real problems using the same modeling environment that is used in production. At the same time, within the framework of the collaboration of teachers and students of several areas, there is an exchange of experience and knowledge in an environment similar to a real professional one.

We have analyzed 2 environments for creating virtual reality laboratories (Table 1).

The choice of a development environment was made in favor of Unreal Engine. At the time of the development of the VR lab, UE had a visual programming technology called Blueprints, and Unity also had a similar technology, although it was paid and had to be installed additionally.

Blueprints has been a key technology that simplifies the development and programming process. It allows you to do everything visually: drag and drop nodes, set their properties in the interface, and connect their "wires" instead of writing code line by line. In addition to rapid prototyping, they also simplify the creation of scripts.

We used the Unreal Engine version 4.27. We used the standard license, which is free to use by teachers and students for non-commercial projects [52]. To create virtual locations, models that are in the public domain were used.

Table 1. Comparison of environments for creating virtual student learning tools.

Parameters	Unity Game Engine	Unreal Engine
Coding	C#—Also 'Prefab' is used for encoding according to each scene.	C++—Also used in BluePrints without coding with drag-and-drop logic.
Cost	The most basic plan (Personal) is free to use, but more expansive and business-oriented plans cost $399 annually per account or more.	The platform is free to use, but includes a royalty system that takes effect as soon as the app monetizes, bringing the company (Epic Games) 5% of the profit.
Graphics	Physically-Based Rendering, Global Illumination, Volumetric lights after a plugin installed, Post Processing	Physically-Based Rendering, Global Illumination, Volumetric lights out of the box, Post Processing, Material Editor
Performance	Does not scale well, unlike Unreal Engine	Has support for distributed execution
Visual programming	Unavailable at the time of development	Blueprints is an Unreal Engine visual scripting system. It is a quick way to create game prototypes.

Due to the simplicity of working with this engine, it was possible to develop a demo version ready for use in the classroom in the shortest possible time.

Due to immersive capabilities, the developed knowledge transfer systems impose significant requirements on the hardware. Minimum hardware requirements are: 64-bit processor, such as Core i5-7500/Ryzen 5 1600, 12 GB RAM; and a 6GB video card, such as GTX 1060/RX 580. In addition, a virtual reality helmet is required. This is a significant limitation when distributing the laboratory for private use, for example, in residential areas with a full lockdown.

During the development, virtual reality devices were used, which students will work with in the future. These are HTC Vive and HP WMR. The kit includes the glasses themselves and the controllers as well as the base stations for tracking with the HTC Vive. Table 2 shows the comparative characteristics of the presented devices.

Table 2. Comparative characteristics of virtual reality devices.

Title	Display Resolution	Field of Vision	Update Frequency, Ghz	Other Sensors
HTC Vive	2160 × 1200	110	90	Proximity and position sensor
HP WMR	2880 × 1440	95	90	Front motion cameras Inside-out

4.4. Methodology for Evaluating the Effectiveness of Using the Proposed VR Lab

Estimating the transfer of the educational process between the simulated and real environment is a difficult task. Indirectly, it can be measured by the correlation between professional training and performance, but it is usually determined by the degree of improvement in the performance of tasks (in reality) after completing training (in a virtual environment) [53]. The parameters for evaluating such a transfer can also be measures of technical and behavioral compatibility between these environments as well as individual characteristics, such as the reaction of students, acquired knowledge, motivation for learning, behavioral changes in participants as a result of training, and improvements in organizational work [54,55]. To confirm or refute the hypothesis of whether practical training can be replaced by virtual reality laboratories, we compared knowledge transfer using real physical equipment and a virtual laboratory. At the same time, it was important for us to evaluate both the quality of knowledge transfer when using the new methodology and the assessment of the course by the students themselves. Therefore, we used a combination of student surveys and the results of their examination session.

We conducted a mini-survey of students learning the repair and operation of transport and technological machines and complexes. In the Fall of 2021, we interviewed 3 groups of students who studied this course in the traditional form in 2017–2019 (27 students who studied the course in 2017, 23 students in 2018, and 24 students in 2019), and 2 groups of students who studied the course using a virtual laboratory (18 students in 2020 and 17 students in 2021). These students are among those who participated in the distance learning survey described in Section 4.1. We used Google Forms to collect the data. The questionnaire included the following statements:

1. I am more motivated by the prospect of acquiring new knowledge, skills and abilities than by the grades that I can get.
2. I feel that I have gained new experience that will be useful to me in my future professional activities.
3. I enjoy attending classes in the subject and try not to miss them without a good reason.
4. I am not distracted by foreign objects in the course of the work.
5. I believe that there is a lack of new digital technologies in the scope of the materials in this discipline.

Thus, with the help of the first question, we measure the student motivational level and also his desire to acquire knowledge, which, with the proposed methodology for transferring knowledge, includes, in addition to professional knowledge, digital knowledge and skills. The second question enables the assessment of the students' feelings about the quality and usefulness of the acquired knowledge in their professional activities. The third question shows the level of a student's interest in the course with traditional and proposed technology of knowledge transfer. We use the fourth question to compare the levels of a student's self-discipline and self-organization in the course with traditional and proposed knowledge transfer technology. The fifth question allows us to directly get a student's assessment regarding the adequacy of the use of digital technologies in the course.

We asked students to rate their degree of agreement with each statement on a 5-level Likert scale, where 1 is "strongly disagree" and 5 is "strongly agree".

We used ANOVA to compare the results of surveys of students' groups studying according to different methods over several years. In total, of the 109 students in the automotive direction, 74 students trained using physical equipment and 35 using virtual. At the end of the training, the examination tests results of the studied groups were also compared.

The formation of the student's assessment for the exam is influenced by the speed of the task and the number of mistakes made. Based on the assessment, we can draw conclusions about the change in the quality of knowledge transfer using the virtual laboratory.

Questions 1–4 of the questionnaire make it possible to assess whether the transfer of knowledge with the proposed methodology is deep and not superficial. At the same time, we mean by deep learning the understanding by students of the course place in the overall educational trajectory and the course usefulness in the short or long term [4,56].

In addition, to assess the degree of compliance of the developed laboratory with real conditions, we also asked questions to 4 full-time teachers who lead disciplines in vehicle repair and maintenance, and 2 invited teachers who combine teaching activities with work at automotive service enterprises:

1. I feel that the environment and scene in the virtual laboratory is similar to the real physical environment in the enterprises of the vehicle service.
2. I feel that the scenario laid down in the virtual laboratory corresponds to the technological process of balancing the vehicle wheel.

We instructed teachers on the rules of interaction with virtual reality equipment, conducted work sessions in a virtual laboratory, and then asked them to evaluate the degree of agreement with each statement on a 5-level Likert scale, where 1 is "strongly disagree" and 5 is "strongly agree".

5. Results

5.1. Analysis of the Problem of the Knowledge Transfer Process at Kazan Federal University during the COVID-19 Lockdown

The results of the survey, conducted according to the method of Section 4.1, revealed useful results from the point of view of the trends discovered and used in the future for the development of knowledge transfer methods.

Among the main difficulties in the remote format of knowledge transfer, students identified the impossibility of conducting laboratory classes (56.1%), the inability to take into account the personal characteristics of students (32.6%), limitations in obtaining practical skills (49%), low quality control of knowledge (29.1%), and difficulties in assimilation of the material (37.5%) (Figure 7).

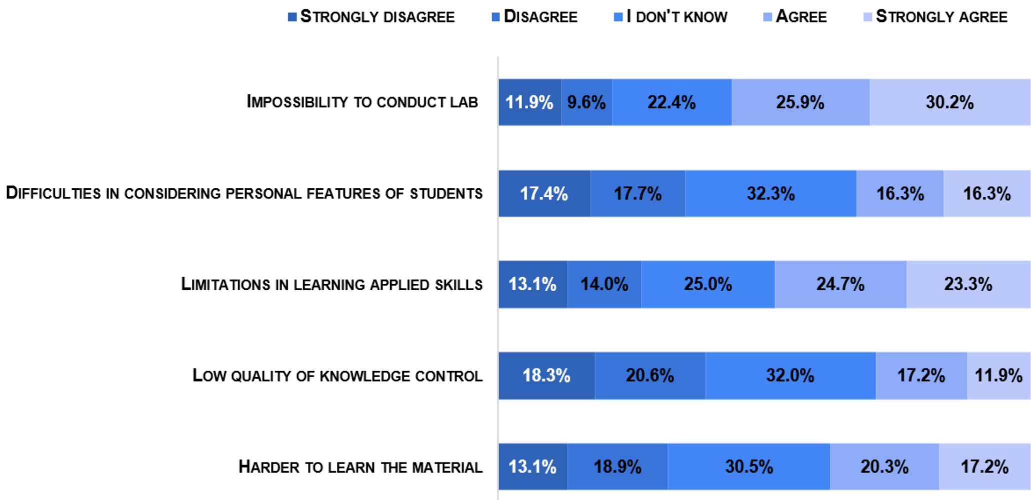


Figure 7. Difficulties in the remote format of knowledge transfer.

The most popular methods for mastering educational materials were the instructions of the university (62.8%), instructions on the Internet (56.4%) and video materials provided by the university (40.4%) (Figure 8). At the same time, teachers helped to find the listed educational resources and methods for development of 33% of the students; fellow students shared their experience in 32% of the cases; students who mastered it on an intuitive level comprised 32.2%; and those who "failed to master" comprised 2.8% of the students.

The majority of students agree with the statement that modern education should combine distance technologies and traditional educational practices (68.9%), and the skills acquired in the distance learning format will be useful to them in their future professional activities (57.8%). In general, 65.7% of the students who took part in the study confirmed their positive attitude towards the distance format: almost 58% noted positive changes in their ability to learn independently, 52.9% mentioned an increase in the quality of knowledge transfer, and almost 50% noted increased amount of free time and positive changes in educational motivation.

The results of the survey revealed a low degree of student satisfaction with the quality of laboratory classes in the remote format of knowledge transfer using existing tools.

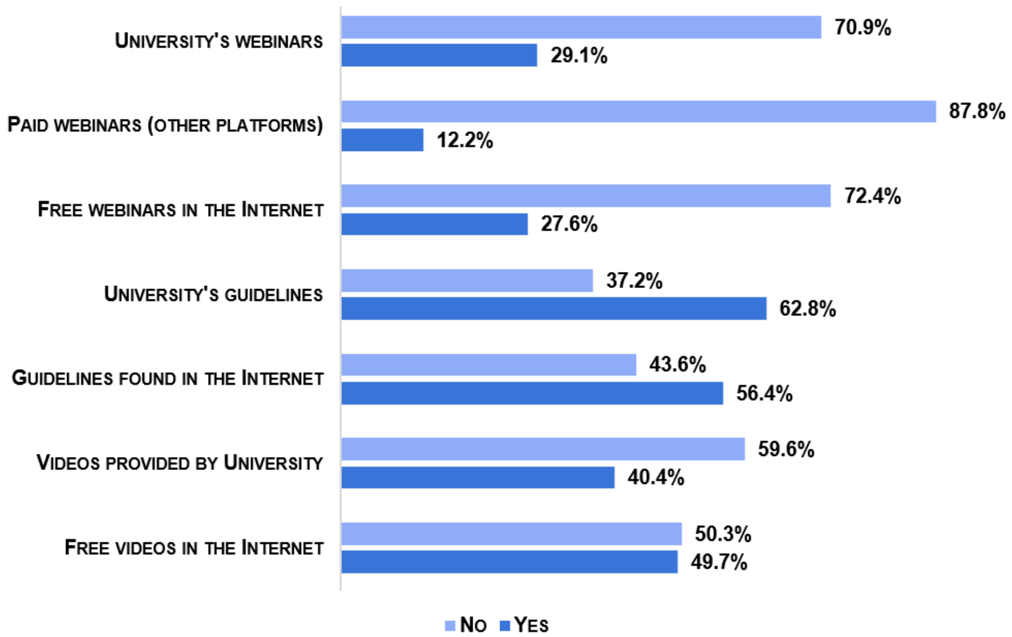


Figure 8. Methods for mastering educational materials.

The analysis of the session also showed that the expediency and effectiveness of online classes is higher for a lecture course while personal communication between the student and the teacher is necessary to obtain Practical Skills. The average score for the theoretical (lecture) part of the Natural Sciences turned out to be higher than for the Implementation of Practical Tasks (Figure 9). The numbers in the center of the graph (for example, 1191111) indicate the number of the student group.

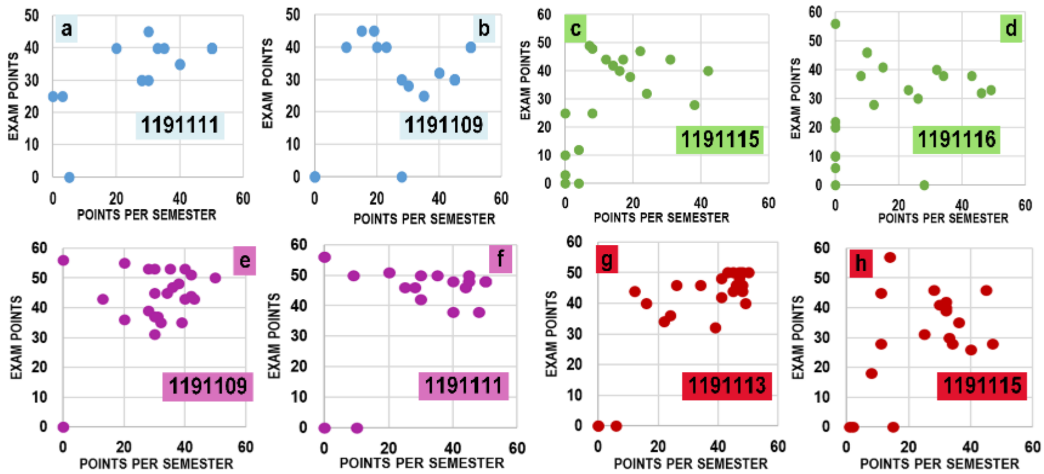


Figure 9. Exam results in Maths ((**a**,**b**)—teacher 1, (**c**,**d**)—teacher 2) and in Structural Materials Technology ((**e**,**f**)—teacher 3, (**g**,**h**)—teacher 4).

Held in 2020, a questionnaire survey also showed that students had problems with finding and using educational materials, which indicates the need to address questions about the effectiveness of using distance technologies in teaching disciplines that include the acquisition of practical skills. Students of the first cluster note problems with the use of teaching and methodological materials, which makes it necessary to solve the issue of using online technologies for courses related to obtaining practical skills. On the other hand, the problems specific to foreign languages are explained by the complexity of organizing paired language practice when using some distance platforms, or by the lack of an opportunity as such. The survey question “How satisfied are you with the quality of teaching foreign languages?" allowed us to reveal the degree of satisfaction. The results of the survey conducted after the remote period showed slightly lower grades compared to the fall semester of 2019–2020, conducted in the traditional form.

An analysis of the results revealed significant problems in organizing practical courses in special engineering subjects and foreign language courses. The existing digital means of transferring knowledge of the automotive profile are insufficient to stimulate educational motivation, especially for students with a low initial level of training. In addition, in engineering education, online content transfer cannot completely replace laboratory and practical classes that take place in the traditional form. The educational content that existed at the time of the lockdown could not provide the proper level of quality for the transfer of knowledge and an understanding of the essence of real processes. The results of the survey and analysis of the sessions confirmed the relevance of developing tools that allow students to gain knowledge in the field of design features of vehicle components and parts [57], the principles of operation of mechanisms [58,59], technological processes of repair and transportation [60,61], and for more efficient active cooperation and successful acquisition of the necessary engineering competencies.

5.2. Results of Using Virtual Methods of Knowledge Transfer

The development and use of a VR laboratory is the solution to the current situation. In addition, this solves the budget problem, since due to the limited university funding and the constant expansion of the equipment, tools, and accessories model range, it is impossible to ensure timely renewal of the material and technical base for laboratory and practical classes. The current stage of development of virtual laboratories is sufficient to conduct a test to determine the effectiveness of this method of studying engineering knowledge and a foreign language.

The survey confirmed the effectiveness of the use of virtual laboratories in the transfer of knowledge in comparison with the use of traditional teaching materials and real repair equipment for students of the automotive faculty for the specialties, "Operation of Transport–Technological Machines and Complexes" and "Service". Students, overall, were more motivated (Figures 10 and 11).

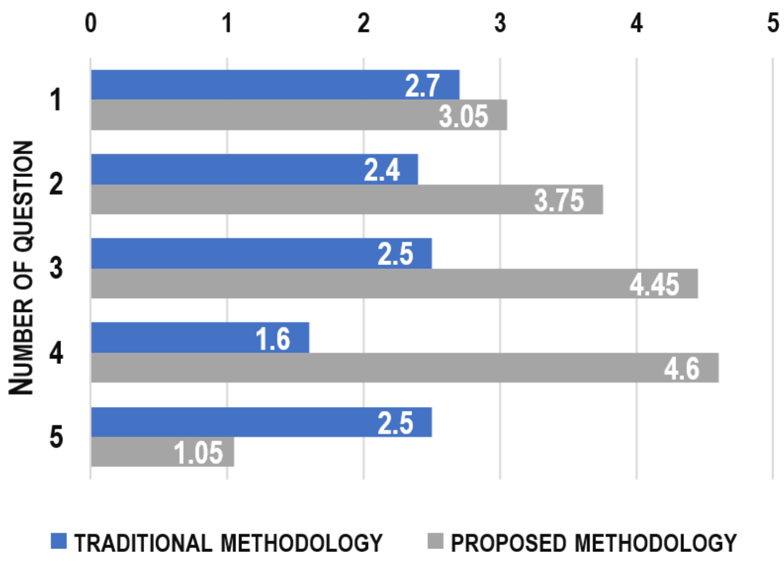


Figure 10. Survey results.

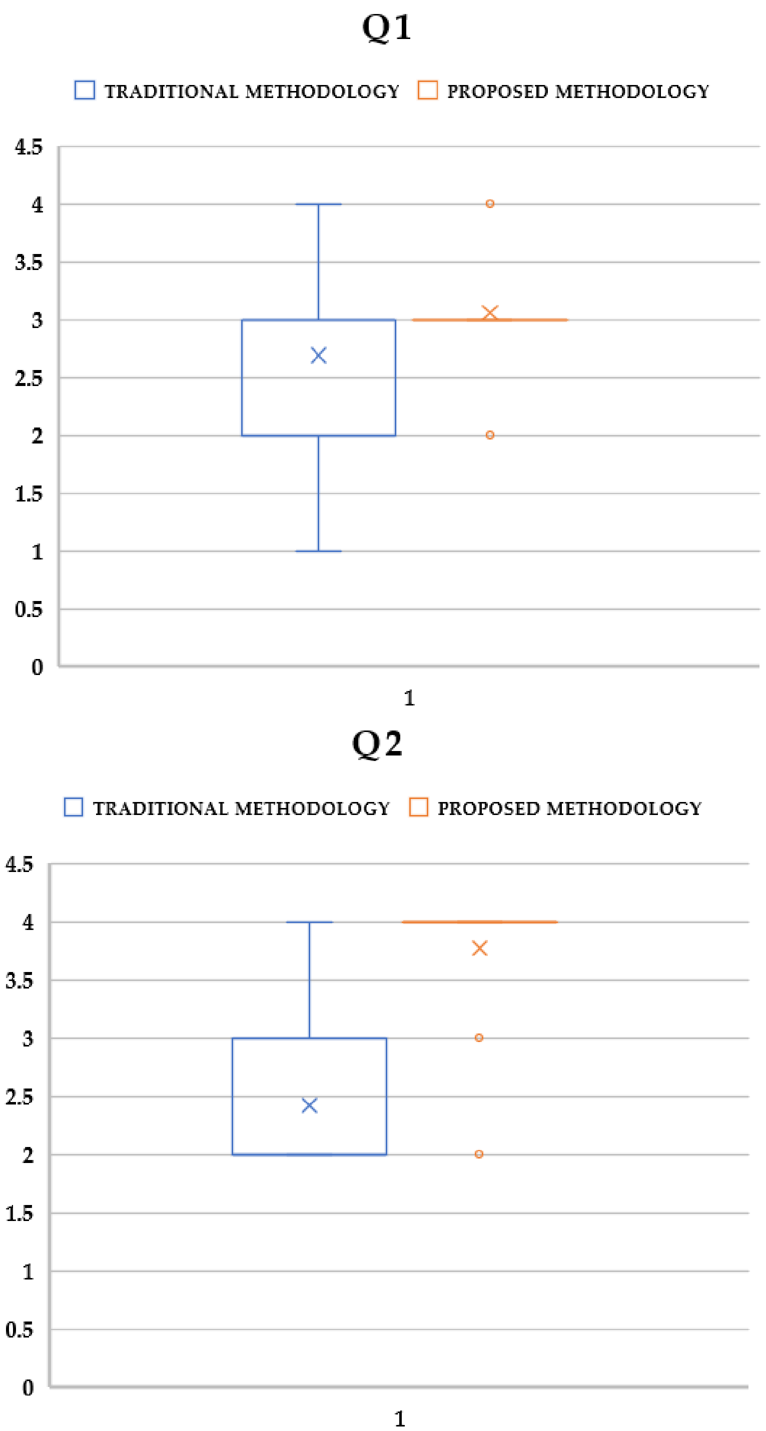
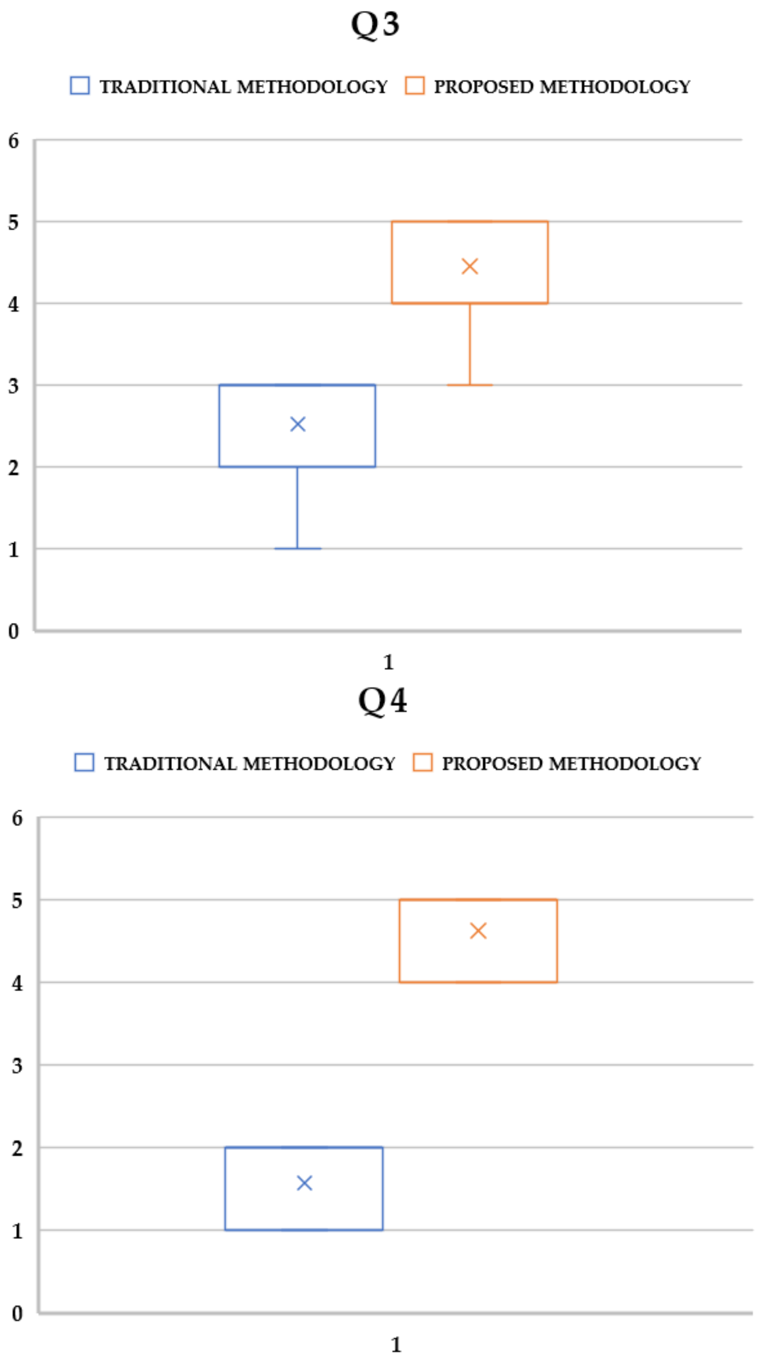


Figure 11. *Cont.*



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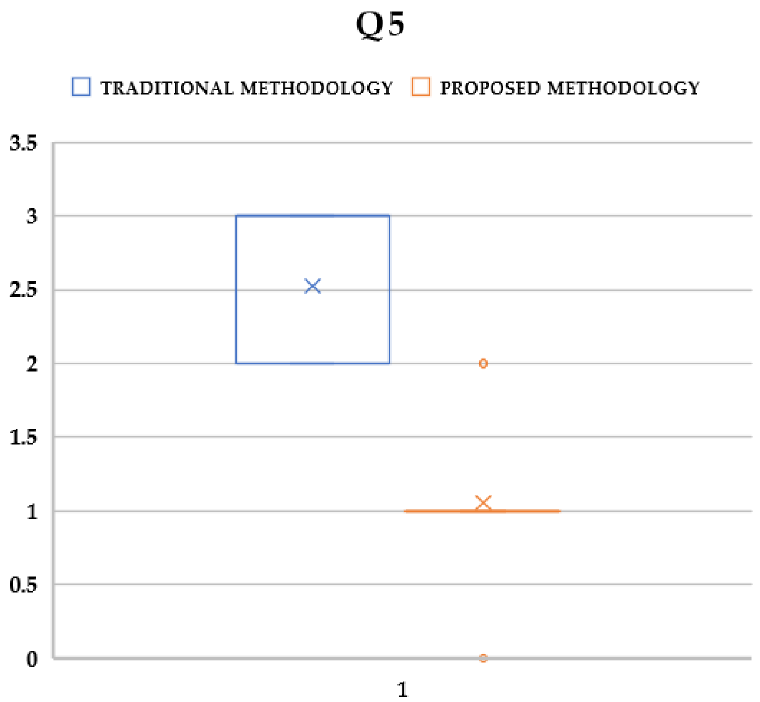

Figure 11. Distributions of answers to questions.

The analysis of variance confirmed the significance of the teaching methodology factor at the $p = 0.05$ significance level (Table 3).

Table 3. The results of the dispersion analysis of the survey.

Question Number	F	*p*-Value
1	10.84617	0.001342456
2	165.0139	2.05886×10^{-23}
3	230.2754	1.95939×10^{-28}
4	901.7582	6.01913×10^{-54}
5	225.7624	4.04072×10^{-28}

Increased motivation led to a higher level of academic performance (Figures 12 and 13).

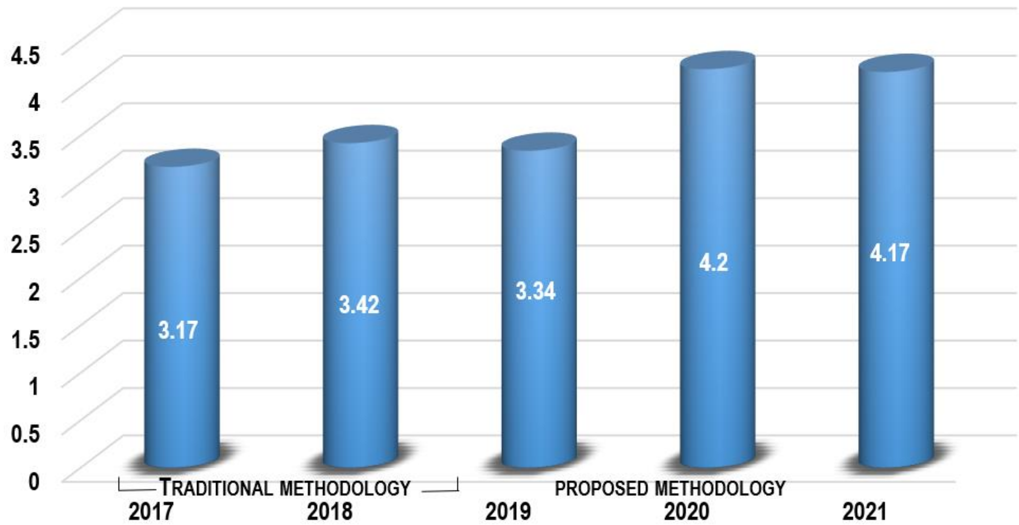

Figure 12. Exam results—average score obtained by students.

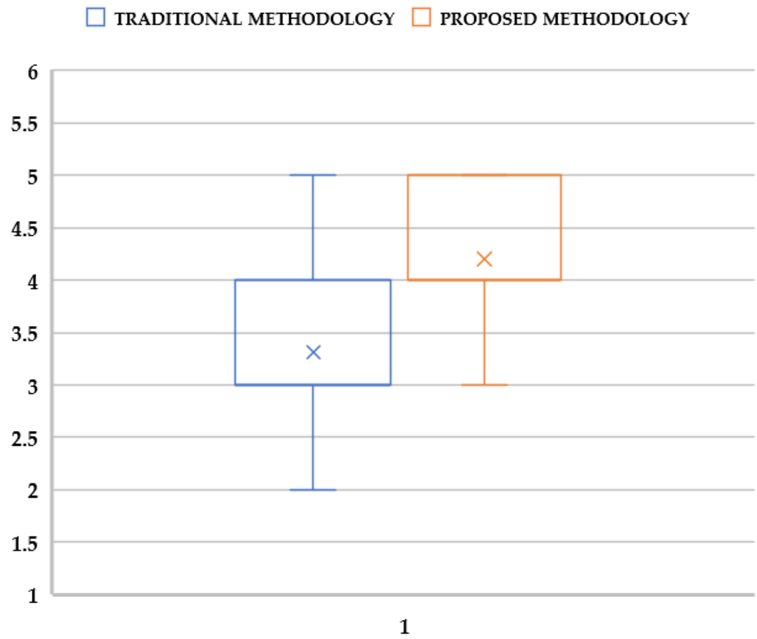

Figure 13. Distribution of exam results.

The results of a teachers' survey allows us to say that the environment and the scene in the virtual laboratory are similar to the real physical environment at vehicle service enterprises, and the scenario laid down in the virtual laboratory corresponds to the technological process of balancing a vehicle wheel (Figure 14).

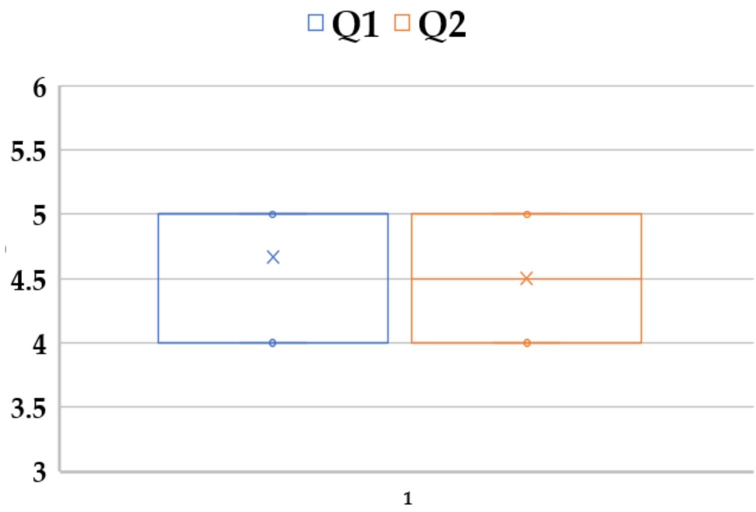

Figure 14. Distribution of teachers' survey results.

6. Conclusions

The growth in the rate of development of engineering and technology exacerbates the problems of the technical literacy of specialists. The main resources for the development of companies are increasingly becoming people and the knowledge they possess, intellectual capital, and the growing professional competence of personnel. Today, new methods of knowledge transfer based on the intersection of information technologies and engineering approaches are required, which will allow a synergistic effect from their interaction to be obtained. This creates new challenges for knowledge engineering. In particular, this concerns the system of training technical specialists in the operation of vehicles, which should overcome inertia, a decrease in student motivation, insufficient funding for the re-equipment of laboratories, and increased requirements for teachers.

Currently, society is moving along the path of the digitalization of all spheres of life. One of the reasons for this was the COVID-19 pandemic, which has radically affected the world and all aspects of education, leading to social distancing and technological changes in the form of knowledge transfer and the development of practical skills. In the context of the lockdown due to COVID-19, educational institutions were faced with the task of transforming educational material from the traditional form of delivery to the remote one while maintaining the quality of its development. When developing new methods of knowledge transfer, it is necessary to consider how best to meet the academic intellectual and emotional needs of engineering students. In this sense, the virtual way of transferring knowledge is the only possible one. After the removal of the COVID restrictions, the prospects for the development of virtual laboratories have not decreased, since they are often a good alternative to physical laboratories in the traditional form of face-to-face classes, especially in the case of the potential danger of the experiments being carried out.

Experience gained during the COVID-19 pandemic shows that the use of new methods of knowledge transfer in engineering education contributes to the development of competencies required for high-tech industries. To do this, it is advisable to use the virtual reality learning environment, which motivates students to engage in engineering professions and improve not only their professional but also their linguistic skills. Without educational laboratories, it is impossible to implement the formation of practical skills in any area of engineering training. They allow students to participate in various stages of experiential learning, including conceptualization and experimentation, followed by reflection, analysis, and interpretation of the data obtained. Similarly, the traditional ways of learning languages are increasingly receding into the "background" and therefore the applications of new technologies can increase the efficiency of working with languages. Virtual reality has entered our personal and professional lives and is becoming an effective means of intercultural and professional communication.

As part of this study, it was found out that the use of methods for teaching engineers special disciplines and language skills using VR technologies is much more effective than the traditional one; after tests and surveys, an increase in students' interest in learning was revealed, and their performance improved noticeably. It was possible, on the one hand, to increase the involvement of students, and, on the other hand, to provide a safer learning environment. The introduction of a virtual simulation system allows students to practice real actions on virtual workstations.

It is planned to finalize the project, increase the interactivity of objects and their number, optimize the application to increase productivity. Blended learning needs to be added. If circumstances arise that interfere with attending a class, the student is given the opportunity to attend it remotely. Remote monitoring of what is happening in the classroom is observed as well as the participation in the lesson and interaction with groupmates and the teacher.

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