THE EXPERIENCE OF INTRODUCING DIGITAL TWINS INTO THE EDUCATIONAL PROCESS ON THE EXAMPLE OF TRAINING IN THE REPAIR OF AIRCRAFT EQUIPMENT UNITS

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ABSTRACT

The utilization of digital twins in education is a promising approach that offers novel possibilities for delivering theoretical and practical knowledge. Digital twins transform the way users interact with devices, allowing for experimentation and innovation without the fear of damaging expensive hardware. Aircraft repair training is a complex and costly process that requires innovative educational tools and technologies. In this study, we developed a training software that utilizes an adaptive interval repetition method based on H. Ebbinghaus, P. Pimsler, and S. Leitner's methods to train learners in aircraft repair. We utilized 3D models created in SolidWorks and Blender3D software packages and implemented the program script in the Unreal Engine environment. To evaluate the effectiveness of the mechanism, we collected feedback from participants and analyzed learning outcomes in both experimental and control groups. Our training software employs an asynchronous approach to information acquisition, enabling learners to create personalized learning trajectories. Our results demonstrate the effectiveness of the proposed mechanism for educational systems and virtual reality technology in general. This innovative approach is not limited to aviation but can be applied in other engineering disciplines as well.

Keywords: *Digital Twins, Interval Repetition Method, Virtual Reality, Training Software, 3d Model, Higher Education*

1. INTRODUCTION

The constant evolution of technology brings education to a new level, which becomes much more attractive to students, makes it possible to use new tools, which in turn leads to the evolution of the learning process [1]. As a result of the spread of computers and the development of the Internet, information systems have become an indispensable tool that supports the educational process. In recent years, they have definitely strengthened their position not only as an effective and efficient tool

that complements traditional methods and tools used in education, but also as a primary source of knowledge and the formation of professional competence [2-5]. More and more educational centers around the world are beginning to introduce powerful new technological tools that help them meet the needs of various groups of students. It is well known that the use of information and communication technologies improves the attitude of students towards learning [6-8].

The current state of digital technology encourages the use of more advanced methods to ensure the most effective learning. One of the currently available modern tools used in the educational process are digital twins. Over the past few years, the digital twin, which is an interactive computing environment, has moved from gaming to professional development. This technology, due to the high level of immersion and involvement of various senses, the need to focus on the activities performed, allows you to develop the skills to solve various problems and problems. In this way, people make fewer mistakes in real life because they gain experience in solving problems they might face in real life using the digital twin [9].

The studies carried out so far show that the user, being in an immersive environment, effectively acquires knowledge [9-10]. Due to its advantages, VR technology is widely used in research, industrial and educational fields [11]. Today, technology that was once too expensive or impractical for consumers is now readily available. The relative cheapness of modern virtual headsets makes it possible for even low-budget educational institutions to provide proper hands-on training [12].

Virtual environments can be widely used as engineering training simulators. The digital twin gives engineer a better understanding of a facility's design and helps them make changes when needed. The vast majority of training stands for aviation instruments, systems and assemblies currently used in the Republic of Kazakhstan are outdated, as well as the aviation equipment to which they relate. Ordering training stands that meet modern requirements costs the same as a real aircraft unit, device or system. The use of digital twins will make it possible to create virtual training stands that meet modern requirements for the training of aviation technical personnel, to multiply them with minimal costs only for virtual reality equipment. However, a review of the literature in this area on the example of existing solutions shows that this topic is quite new, and there are not so many didactic solutions

for the development and use of software based on digital twins.

Thus, there was a need to develop an effective mechanism for training curricula as a modern, promising learning tool. The aim of the study is to develop a mechanism for a training software tool using the example of repair of aircraft equipment units, implemented using digital twins, and to evaluate its effectiveness when introduced into the educational process. The resulting training software will provide an opportunity to gain practical skills in the learning process in those areas where it is difficult due to the high cost or difficult availability of the necessary equipment.

2. LITERATURE REVIEW

The aviation industry has strict requirements for the level of qualification of specialists, which requires paying special attention to the quality of the content of educational programs. Modern educational technologies improve the quality of education, while being able to reduce the operating costs of training organizations [13]. The introduction of an interactive component into the educational process significantly increases the percentage of assimilation of the material [14]. One of the technologies leading to innovative learning tools is the digital twin, which offers 3D computing environments with advanced forms of interaction that can increase motivation in the learning process. According to [15], the digital twin can be used to make learning more interesting and fun in order to increase motivation and attention, reduce costs when using the target and the real environment, no matter how expensive the simulation costs. The digital twin provides the opportunity to learn with a real situation, but artificially created, facilitating the visualization and feeling of interaction with the object of study.

Virtual learning is close to reality through the use of virtual and augmented reality and technologies that try to create the most accurate digital twin in the display, as well as manage and move it in a three-dimensional environment and in real time [16]. When we cannot get real experience, the digital twin is indispensable. The simulation of the digital twin also allows us to find ourselves in difficult and dangerous situations that are usually not available in the real world. In addition, the digital twin makes it possible to convey difficult learning topics to students that are sometimes impossible to show.

In [17-18], some key features of virtual reality, augmented reality and combined reality, as well as the differences between them, are explored. Aspects

of the possible use of digital twins in the modern world are considered. The attachments to augmented and virtual reality that exist and are used in the modern educational process are considered. The need for special technical equipment and a special virtual laboratory is indicated for the introduction of virtual and augmented reality systems into the modern educational process.

[19] conducted a study to illustrate the effect of VR when used as a learning tool. The purpose of this study is to improve the abilities of medical students by creating digital twins. The group of students was equally divided into two different groups, virtual and non-virtual. According to the results of this study, students who studied using VR developed themselves more than students who worked with traditional methods. In the same vein, in [20], a group of authors conducted a study on improving the social abilities, attention and functioning of young people diagnosed with a high level of autism. The possibility of using digital twins to improve the learning process of students with disabilities is also presented in [21]. The use of digital twins in the process of teaching disabled students at minimal cost will help improve the educational process.

[22] state that learning in an artificial environment is successful because learners can cognitively create knowledge for themselves by interacting with the virtual environment and observing the consequences of their actions. As a result, the brain can make judgments and connections faster when the learner is interacting in their virtual environment than when learning takes place in a largely decontextualized, non-immersive setting.

[23] demonstrated that learners prefer learning with elements of virtual reality to traditional observational approaches. As a result of the study, it was shown that participants in experimental training using VR tools have a higher information retention rate than in traditional training.

In addition to learning motivation, [12] summarized ways in which interactive learning environments can support self-regulatory skills. He stated that features such as menus and navigation controls can support the use of metacognitive skills such as scheduling learning activities. Built-in questions that require a response from the student can help to remember previous knowledge, thereby improving the use of rehearsal skills.

According to [24], the greatest memorization (90%) is observed when students perform real or imitating actions. Virtual reality is based on a hands-on approach and therefore provides a powerful learning tool.

A good overview of virtual and augmented reality applications for engineering education using digital twins is presented in [25]. The aim of the study was to present tools that will engage users in a way that is more familiar to them due to their age, motivate them by incorporating game elements, and at the same time transfer the knowledge and practical skills necessary for their future career.

[26] introduced a digital twin to promote education in electrical engineering. They designed and developed online labs that students could access remotely using virtual reality. These projects allowed students to use virtual mockups and virtual instruments to complete simple electronic labs. The created application contained realistic digital twins of models of all equipment, as well as the corresponding electrical components for experiments.

A more interesting approach was presented in [12], where the authors presented a digital twin of the mechatronics laboratory. The goal of this project is to enrich the curricula by introducing a virtual reality-based tool for teaching mechatronics in higher education institutions. The digital twin of mechatronics provided a virtual reality space where students could experiment with simple equipment that allows them to make mistakes and learn from them without real consequences.

VR also enhances engagement by giving learners a stronger sense of presence and immersion compared to traditional learning environments. In digital twin modeling studies [27–28], low-achieving students improved academic performance more than traditional learners, even more than their high-achieving counterparts. The availability of virtual reality gives students the ability to construct and manipulate digital twins to represent knowledge, something traditional teaching methods lack [28].

Unfortunately, no scientific papers have been found on the development of software tools for digital twins that are effective in terms of memorizing educational information. In most cases, the digital twin serves as a learning and practice tool, but tests and exams are still written. Digital twin exams are still an area of distance learning. Thus, there is a need to create such an application that can report on a student's progress or eventually lead to a final test/exam with automatic scoring. For example, the authors of [29] proposed guidelines for educational applications of digital twins based on user research and interviews with experts.

Let us find out what methods of controlling the cognitive activity of students are used in traditional education technologies. Management of the learning process of the subject occurs on the principle of feedback. Training tasks, explanations are developed by the teacher, based on the purpose of training, based on a comparison of the model of the required knowledge and the model of the current knowledge of the student. The model of the trainee's current knowledge is formed in the teacher's mind on the basis of monitoring the results of the trainee's performance of educational tasks by comparing them with the correct results [30]. In the general case, the activity management process includes the following steps [31]:

− formulation of management tasks;

− description and analysis of the initial state of the control object;

− selection and determination of the nature of control actions on the control object;

− implementation of control actions (executive devices);

− assessment of management results (measurement);

− introduction of corrective control actions.

The prototypes of software tools with automated control of cognitive activity can be considered foreign language teaching systems that can be used in distance learning. The main method of memorizing information in such systems is the repetition method. The repetition method appeared at the end of the 19th century, when the German psychologist Hermann Ebbinghaus published an article in which the curve of forgetting information was described in the form of a meaningless series of syllables. Since then, various modifications of this method have appeared, proposed mainly by linguists [32]. Over time, many applications have appeared that implement the repetition method, united by one task: to calculate the very ideal moment in time for repeating the learned information. However, the memorization schemes proposed in [33-35] in their pure form are not suitable for VR technology, in which the skill is memorized.

Thus, a preliminary study of literary sources on the introduction of digital twins in the educational process confirmed the relevance of the chosen direction of research. By itself, the use of digital twins does not guarantee the quality of education. The effectiveness of training depends on the quality of pedagogical software products. An analysis of the literature data showed that:

− the introduction of digital twins in engineering education to obtain practical skills improves the quality of education and increases the student's memorization rate;

− there is no conceptual approach to the presentation of the mechanism of the VR tutorial, which includes both the training and testing components;

− it is necessary to develop a mechanism for managing the student's cognitive activity in the digital twin software tool that implements an adaptive variation of the repetition method.

3. METHODOLOGY AND RESEARCH METHODS

As a result of the study of ways to develop digital twin applications and existing software, the authors determined the procedure for using specialized software tools (SolidWorks, Blender3D, Unreal Engine). The procedure for using these software tools for developing a digital twin program is presented in detail [36].

The current article focuses on the logic implemented by the training software. This logic is based on the interval repetition method. The essence of the interval repetition method proposed by H. Ebbinghaus is the assumption that there is some ideal moment for repeating previously learned information. If you do this earlier than you should, then it is likely that the student will simply spend extra time. If you do it too late, then there is a possibility of forgetting the material, you will have to learn everything again. The ideal moment for repetition is when the learner is about to forget the information. The task of the computer program is to calculate this moment and remind in time of the need to repeat what has been learned. With each timely reminder, knowledge is stored in memory for a longer period of time, that is, it will take more time to forget what has already been learned. Consequently, the intervals between repetitions increase. Thus, the program fixes the time component of training and assigns the next session accordingly [32].

An alternative approach [33] suggests that if information is repeated just before it is completely erased from memory, the time after which a person begins to forget it again will increase exponentially. To date, no repetition scheme has been proposed for practical skills training programs; the authors propose an approach based on the S. Leitner system. The essence of the method is to classify the material into three categories [34]:

− new or very complex information that is difficult to remember;

− information already known, which is supposedly well deposited in memory;

− information that is fixed in memory with 100% probability.

The article proposes a scheme for operating with the indicated three categories of complexity, which makes it possible to form an individual learning trajectory.

Not an unimportant task for the implementation of the first training software for digital twins was the choice of units and technological processes in view of the complexity of digitizing 3D models and the laboriousness of scripting. The study and systematization of technological processes intended for implementation into a digital twin was carried out jointly with JSC Aircraft Repair Plant No. 405. The choice of units and their digital twins for implementation in the software was carried out according to the principle of the greatest significance while reducing the influence of the human factor on the risks associated with maintenance and repair. Since the list of components is extensive, the authors used an automated method of forming the content of academic disciplines of specialization of maximum utility for implementation in the professional field, described in [37].

The developed training software was tested in the groups of the educational program 6B07101 "Technical operation of aircraft and engines" in the study of the discipline "Maintenance practice". The effect of implementation is determined by:
− based on the analysis of feedback forms, which were filled in by students who took part in the experiment;
− based on the analysis of learning outcomes in the experimental and control groups.

4. THEORETICAL BASIS

First of all, let's look at the definitions of the main concepts. By a learning system using digital twins, we mean a hardware and software environment in which the states and processes of functioning of complex systems are visualized, aimed at increasing the efficiency of student learning. The main goal of such a learning system is the active involvement of students in the learning process.

A 3D model is a three-dimensional object of a part or assembly that is displayed and used in a software application for demonstration as a digital twin.

In the process of developing any software, it is necessary to highlight the main components. Although digital twin experts list various components, there is a small pool of traditional components that are recommended for a VR

system. The authors chose the structure proposed in [38–39]. Table 1 illustrates the content of the components of the digital twin training software for studying the repair of aircraft assemblies and assemblies.

Table 1. Components of the program of digital twins for the repair of aviation equipment

System Components	Aircraft repair software
Learning objectives	The use of a digital twin of a 3D simulator to hone the skills of performing aircraft repair operations will allow students through virtual learning to develop conceptual understanding, manage their learning, and perform operations in automatic mode.
Input and interactivity	It is supposed to perform operations of disassembly and assembly of units/assemblies of aviation equipment. Identification and development of digital twins of the most valuable units / nodes for training.
VR activity	The user, choosing a unit/assembly for training, goes through three training modes: the mode of viewing the execution of operations in automatic mode; training mode, for self-fulfillment with tips; test mode, to control the memorization of the process. The studied units require the repeated execution of operations according to the interval repetition scheme, specially designed for this project.
Software	Development of realistic digital twins - a set of programs SolidWorks and Blender3D. Development of system scripts - Blueprint editor of the Unreal Engine package. Storage of user input and output data - MySQL database.
Hardware	Minimum specification PC: Gigabyte G5 GD, Intel TGL i5-11400H, RTX 3050 4Gb, 144Hz IPS, 8x2Gb, M2 512Gb, Win10Home 64. Additional equipment: Oculus Quest 2 headset.

The digital twin training tool is a scalable system to which training modules can be added for units

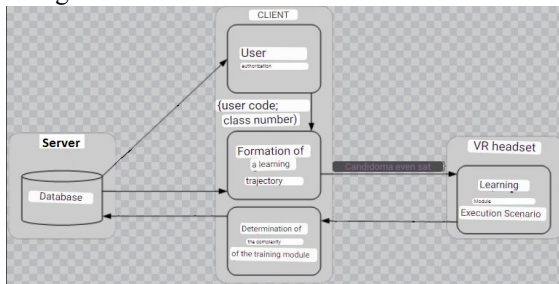and assemblies. The software architecture is shown in Figure 1.

Figure 1: Software architecture

The presence of a learning trajectory formation module allows you to create an asynchronous type of information acquisition. The asynchronous type allows you to create a schedule for the passage of the studied material individually, despite the fact that the process and learning material is the same for all students.

After authorization, the user is offered training modules for study. In accordance with S. Leitner's system, all modules are classified by complexity L={0, 1, 2}, where 0 is the weakest complexity, 2 is the highest level of complexity. For each new module, the complexity is defined as L=0. After the first completion of the training module, the individual complexity of the component is determined for each student, depending on the number of mistakes made. Figure 2 shows a macro scenario for the execution of each training module.
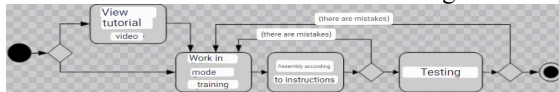

Figure 2: The scenario of the training module execution

Each training module implements three modes: training, training, testing. In the training mode, the student views the execution of operations in 3D. The training mode allows you to independently perform operations using the input headset. Testing allows you to evaluate the practical skills acquired by students. Testing of practical skills is carried out in two stages: execution according to the instructions; independent operations. In case of student's mistakes at the stage of testing performed according to the instructions, the software tool rolls back to the training mode. Thus, the student will have to consolidate the studied operations in various modes at least three times, provided that all three times are performed without errors.

Depending on the number of mistakes made by the student in the training and testing modes, the training module is assigned an individual level of difficulty for each student. The formation of the difficulty level value can be represented as a function L=f(L0, It), where L0 is the initial level of the module (set to 0 for each new module), It is the number of iterations of the training and testing modes during the next repetition.

$$f\left(L_0,\,It\right)=\begin{cases} L=0,\ if\ \left(\left(L_0=0\ or\ L_0=1\right)\ and\ \left(It=1\right)\right) \\ L=1,\ if\ \left(\left(L_0=0\ or\ L_0=1\ or\ L_0=3\right)\ and\ \left(It=2\right)\right) \\ L=2,\ if\ \left(\left(L_0=0\ or\ L_0=1\ or\ L_0=3\right)\ and\ \left(It>2\right)\right) \end{cases}$$

The list of modules is automatically sorted and presented to the user in an orderly fashion: first, topics that are ready for testing (partially completed or required to be repeated); then topics learned and ready for training; topics not explored further; fully completed topics are placed at the end of the list. Such an organization provides the convenience of using a large number of topics in the curriculum, and also helps in the effective management of the individual educational process of each student.

Thus, during the next lesson, students are offered a new module for learning, as well as repetition of training modules of varying complexity in accordance with the accepted scheme of interval repetition. The authors propose to use for such software the following scheme of interval repetition of training modules with complexity L for the next moment of the educational process N in the total number of visits T:

If (L=0) and (N mod (T div 2) ==0)
If (L=1) and (N mod (T div 3) ==0)
If (L=2) and (N mod (T div 4) ==0)

Let's say that training is supposed to be once a week for one semester. Then T=15, since in Kazakhstan there are 15 academic weeks in one semester, and N=1,…,15. Depending on the complexity of the module according to the scheme, the need to re-study it in the next visit is determined. If during the process of repetitions the complexity of the module has changed, then the repetition rule for it also changes.

5. RESEARCH RESULTS

Using an automated method for forming the content of academic disciplines of maximum utility specialization [37-38], the authors chose five topics for the experimental implementation of digital twins in a training software tool:

− disassembly/assembly of the valve H-5810-270, consisting of 7 parts;
− disassembly/assembly of check valve 636100, consisting of 7 parts;
− disassembly/assembly of the GA-192T air crane, consisting of 13 parts;
− disassembly/assembly of electromagnetic brake EMT-2M, consisting of 28 parts;
− disassembly/assembly of the MV-1200 electric motor, consisting of 36 parts.

In the future, it is planned to replenish the software tool with other units with various technological processes of digital twins.

In accordance with the developed concept, for each unit under study, the status of the modes for each component of the training software is displayed (Figure 3).
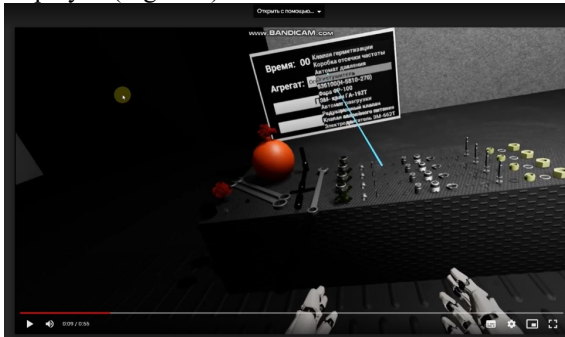

Figure 3: Fragment of the user interface after authorization

Selecting an unlearned unit in the training mode allows you to view a 3D video of the disassembly/assembly of the corresponding product. In training mode, in addition to the implement and tools, a tablet with instructions for the operations performed is displayed in the user's field of vision. Fragment of the training on assembly of the containment valve 242-5800-10, i.e. The virtual workplace in the digital twin software is shown in Figure 4. Erroneous user actions are accompanied by a sound signal.
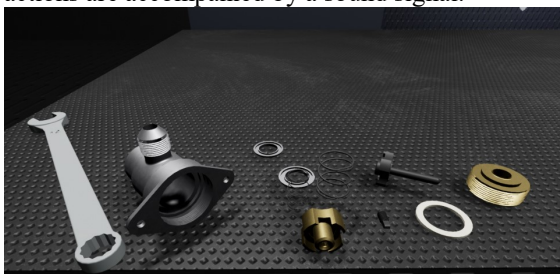

Figure 4: Fragment of training in the digital twin software tool

In the "assembly according to the instructions" testing mode, a tablet with instructions for operations is also provided to the user, only there is no sound signal for erroneous actions. The final test, the student must disassemble / assemble the unit without any prompts. A fragment of the final testing is shown in Figure 5. During testing, the user can see a scoreboard with the time of operations.
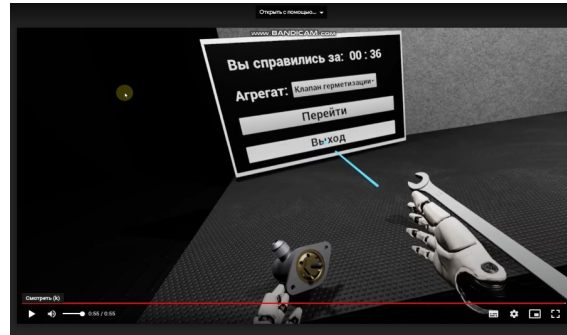

Figure 5: Fragment of the final test

An experiment on the introduction of digital twins software into the educational process was carried out at JSC "Academy of Civil Aviation". The didactic environment for the introduction of digital twins is based on the typical layouts of classrooms in JSC "Academy of Civil Aviation" (Almaty, Republic of Kazakhstan). Traditional equipment in the form of tables, chairs, projectors, blackboards and computers does not significantly affect the layout of classrooms. However, the introduction of digital twin technology forces the development of new prerequisites for classrooms that guarantee the freedom and safety of users in VR. Taking into account the fact that not all content and activities can be completely transferred to the digital twin environment, the prepared classroom concepts should be universal in nature, ensuring the implementation of classes in a hybrid form, that is, based on traditional solutions and digital twin technology. For this purpose, the concept of universal training rooms was developed. The hybrid class scheme is shown in Figure 6.
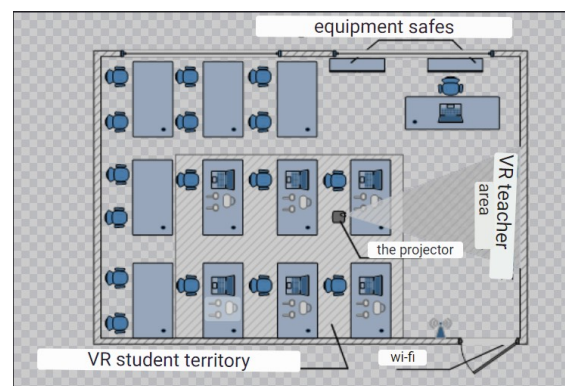

Figure 6: Hybrid class diagram

The concept allows the work of laboratory groups of up to 22 people. In a dedicated workspace, multiple users will be able to simultaneously test virtual reality solutions using four base stations. Students use stationary stations equipped with virtual reality glasses, and the teacher, who manages the virtual reality learning

process, can selectively observe the actions of students on his computer. The proposed approach allows you to effectively use the audience and smoothly switch between virtual and real environments during classes. This allows you to effectively use the various teaching methods and resources available today.

The laptops have a learning system using interactive virtual reality technologies. This software component accesses the database located on the server to receive input and output data. The logic of interaction between software components was presented in the article [36]. The database stores information about students (login, password, full name, group) and data characterizing the learning environment in the software (the state of knowledge of each learning module). After connecting the headset, students are authorized and have access to educational materials, in accordance with the saved results of the last successful session.

In the prepared classroom, six students worked simultaneously in virtual reality, and 10 students used traditional methods to solve problems while waiting for their turn. For the work, a laboratory room measuring about 5 m × 7 m was used. The working area VR was 3 m × 4 m (Figure 7).

Figure 7: Image of the educational process using digital twins

After six weeks of training, students from the experimental group filled out specially designed feedback forms containing the following questions:

"Was it convenient to use the virtual reality system?"

"Was there enough time allotted to complete tasks in VR?"

"Do you think that the virtual reality system has contributed to better learning?"

"Did it take you extra time to get used to the real environment after doing the tasks in the VR system?"

"Do you think VR is the least labor-intensive form of learning compared to traditional?"

In five questions, the trainees noted the level of satisfaction with the work with the digital twin

program in a five-point system (1 - completely dissatisfied, 5 - completely satisfied).

Comparing traditional and VR learning required an additional control group. Conclusions about the effectiveness of this or that training were built on the analysis of final control scores presented in a 100-point system.

6. THE DISCUSSION OF THE RESULTS

In the experimental group, 85% of students experienced the experience of using VR technologies for the first time. On average, each student used VR for 43 minutes per day. An analysis of the feedback forms filled out by VR users is presented in Table 2.

Analyzing the results presented in Table 1, it can be seen that students do not have any serious problems using a solution based on digital twin technology. Obviously, the decisive factors were: the presence of previous experience with digital twins or the support of the instructor, as well as the openness and positive attitude of young people to new solutions and experiences.

Table 2. Analysis of feedback forms with participants of the experimental group

Questions	Satisfaction levels					Average rating
	1	2	3	4	5	
Q1. Was it convenient to use the virtual reality system?	0 [0%]	1 [3%]	10 [29%]	14 [41%]	9 [26%]	3,9
Q2. Was there enough time allotted to complete tasks in VR?	0 [0%]	0 [0%]	8 [24%]	10 [29%]	16 [47%]	4,2
Q3. Do you think that the virtual reality system has contributed to better learning?	0 [0%]	1 [3%]	8 [24%]	16 [47%]	9 [26%]	4
Q4. Did it take you extra time to get used to the real environment after completing tasks in the VR system?	0 [0%]	2 [6%]	10 [29%]	14 [41%]	8 [24%]	3,8
Q5. Do you think VR is the least labor-intensive form of learning	0 [0%]	2 [6%]	10 [29%]	11 [32%]	11 [32%]	3,9

compared to the traditional one?						

Considering session duration score (Q2) and ease of use (Q1), a low percentage of students (3%) felt little discomfort. None of the subjects experienced significant discomfort. For most, using digital twins has been a positive experience.

It is important to note that the answers to question Q4 about the need for additional training in the use of digital twins were distributed in such a way that a comparable number of participants believed that such training was necessary and that it was not required. Presumably, this was due to the same reasons as mentioned above. A certain group of students needed additional time to get used to the real environment after working with digital twins in virtual reality. Obviously, this group was not very large; however, with this in mind, further research into the impact of the VR environment on its users should be considered in the future.

The answers to questions Q3 and Q5 were very important from a didactic point of view. The above answers indicate that the vast majority of students (73% - Q3) believe that digital twin technologies contribute to better learning, and 62% (Q5) are convinced that the digital twin system is less labor intensive than the traditional one. This result is due to the fact that in traditional education, acquaintance with the units is carried out only theoretically, without the possibility of obtaining practical skills.

Obviously, the reliability of the examination depends on the consent of the respondents in the assessment. In [26], various criteria for assessing the consistency of respondents in point scales are given, and as the best solution, an integral criterion for assessing unanimity is proposed - Cronbach's alpha statistics. The standardized Cronbach's alpha can be calculated using the following formula:

$$\alpha = \frac{n}{n-1} \cdot \left(1 - \frac{\sum_{i=1}^{n} S_i^{\,2}}{S_{сум}^{\,2}} \right)$$

where $S_i^{\,2}$ is the sample variance of the *i*-th statement, $S_{сум}^{\,2}$ is the sample variance of the total rating scale (total rating of the respondents).

The calculations carried out according to the estimates of the respondents for all questions (*n*=5) made it possible to obtain *α*=0.972. The result obtained at a level close to 1 indicates a high unanimity of the respondents and confirms the reliability of the educational research. Figure 8 shows a diagram of the range of respondents' ratings for each question of the questionnaire,

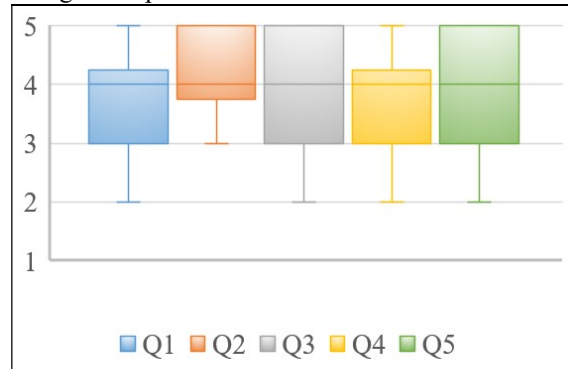which allows them to be compared by average ratings and spreads.

Figure 8: Graph of the span diagram on the feedback questionnaire questions

The analysis shows the correctness in the organization of study time when working with the application of digital twins, since the smallest spread of estimates is observed on the second question "Was there enough time allotted to complete tasks in VR?". According to the presented average satisfaction ratings for each question, one can generally conclude that VR has a positive impact on the learning process. The lowest average value was determined for the third question (3.8), which indicates the presence of a certain adaptation period for students when implementing digital twin training programs. The key benefit for students is that they gain confidence before heading into the work environment.

In the next step, comparisons were made between different forms of learning used in the learning process. The main comparison criterion was the final score for the module being studied, obtained by students in the experimental group (learning with the application of digital twins) and the control group (traditional learning). To obtain more objective results of the analysis, the students of both groups were divided into three subgroups according to the level of overall performance during the entire study at the university: "90-100" - the level of "excellent students"; "75-89" - the level of "good students"; "50-74" - the level of "triples". The results of the study conducted on the same experimental group of students and an additional control group are presented in Table 3 and Figure 9.

Table 3. Results of module training in the traditional form and using the VR module

Groups by overall performance	Control group			Experimental group		
	Number of persons	Average score in the discipline	Average deviation of the result from the overall performance	Number of persons	Average score in the discipline	Average deviation of the result from the overall performance
90-100	9	94,2	-0,7	10	95,0	3,6

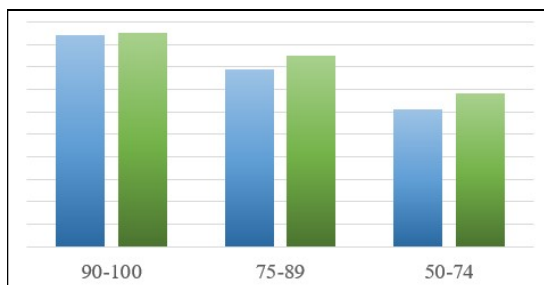|						
75-89	7	78,9	-1,4	16	85,1	1,9
50-74	5	61,2	-2,2	8	68,1	5,4

Figure 9: Learning outcomes in different performance groups (control (blue) and experimental (green) groups)

The histogram in Fig. 9 clearly shows the comparison of learning outcomes in the control and experimental groups. In the subgroup of "A" students, the learning outcomes are almost identical, however, in the larger subgroup of "B" students and the subgroup of "C" students, there is a clear advantage of using an innovative software product.

An additional study of learning outcomes showed interesting results. For each student, the deviation of the learning outcome from his overall performance was calculated. Table 3 presents the average values of this indicator for various subgroups. During the use of the digital twin program, it is obvious that students of all subgroups have a better learning outcome than is typical for them. A particularly better result is observed in the subgroup of "three students" (on average, the module score is 5.4 points higher than the overall academic score). While in the control group, the results are slightly worse (on average, the module score is 1-2 points lower than the student's overall performance score). This fact can be explained by the fact that in virtual reality, students had the opportunity to assemble and disassemble units much more often, to see each part and check them in the context of the entire machine. Moreover, students overwhelmingly noted that classes using engaging virtual reality didactic methods were more memorable than traditional ones.

7. CONCLUSION

The current state of digital technology is forcing educators to use more advanced methods to deliver the most effective teaching. Virtual reality is a medium whose boundaries are still being explored, so through thoughtful pedagogy and innovative experiences, the digital twin will facilitate the integration of education and production.

VR is a powerful tool to support and facilitate learning and teaching. In education, instead of expensive instruments and laboratories, it is more economical to use their digital twins in the form of 3D models with identical physical properties transferred to VR technology. VR-environment allows you to conduct training activities that are difficult to implement in conventional laboratory classes. 3D visualization and interaction realized by VR technology can be used to obtain tangible learning outcomes:

− development of skills for solving real production problems;

− studying engineering tasks in various modes that cannot be organized in a traditional classroom or laboratory due to various reasons, such as cost or safety;

− support for the creative approach of students, as this provides an opportunity for understanding innovative technologies.

An analysis of the possibilities of using virtual reality in education made it possible to identify a conceptual approach to the implementation of the mechanism of the educational application of digital twins for the repair of aviation equipment, based on the interval repetition method. The presented mechanism can be applicable to the development of training software for digital twins in other areas.

The experience of introducing virtual reality into the educational process has shown an advantage over traditional learning technologies, since the student is active and can improve his skills on a prototype of real practice.

8. ACKNOWLEDGMENT

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