HARDWARE-SOFTWARE COMPLEX OF INTERACTIVE TRAINING PROGRAMS ON AIRCRAFT REPAIR PROCESSES BASED ON 3D AND VR

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ABSTRACT

Inspection and maintenance processes in the field of aircraft repair are characterized by a high percentage of manual operations, small batch sizes, and a wide variety of handled components. The learning process in this field is complex and expensive. New educational tools and technologies need to be introduced to provide effective education. The paper proposes a mechanism of educational software tool on the example of aircraft equipment units' repair, implemented with the help of VR and 3D-modeling technologies. As a result of the experiment the effectiveness for the educational system of the proposed mechanism and the VR technology in general was proved the number of errors decreased and the time of operations execution increased. The benefits of the implementation of VR in the educational process were noted by 69% of students. The described innovative approach can be useful not only for the preparation of educational VR solutions in aviation, but also in other branches of engineering.

Keywords: *Virtual Reality, Learning Tools, 3D Model, Aviation Equipment*

1. INTRODUCTION

The main purpose of education is to prepare students for life, work, and citizenship by developing their knowledge and skills that are considered essential in society. The educator's task is to enhance the qualifications, competencies, and skills of the graduates in the process of learning [1]. Practical activities in engineering education are mostly based on specialized research equipment and should be performed under supervision. Consequently, students cannot set up laboratory equipment on their own, and even more so there is no opportunity to practice and catch up outside the lab schedule [2]. More and more educational centers around the world are beginning to adopt powerful new technological tools to help them meet the needs of diverse student populations. It is well known that the use of information and communication technology improves student attitudes toward learning [3-5].

The current state of digital technology encourages the use of better methods to provide the most effective learning. Over the past few years, virtual reality, which is an interactive computer environment, has moved from the realm of gaming to the field of professional development. Kirner C.

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Siscoutto R [6] defined virtual reality (VR) as an enhanced user interface for accessing computer-based applications that allows for real-time display, processing, and interaction with the user in three-dimensional computer environments.

Advanced educators have already begun to use virtual reality for teaching, as the technology is quickly becoming mainstream. In particular, VR can:

- lead to increased student engagement in learning;
- provide active, constructivist learning;
- provide an educational experience for the student commensurate with his or her personal life manifestations;
- provide reinforcement of skills through experiential activities;
- provide opportunities for students to be creative;
- provide a platform for visualization of abstract concepts [7].

Today, technology that was once too expensive or impractical for consumers is now readily available. Virtual reality technology is poised to become breakthrough and extremely influential - market researchers predict that the industry will grow to a trillion dollars by 2035 [7]. The relative cheapness of today's virtual headsets gives even low-budget educational institutions the ability to provide proper hands-on training [8].

Virtual environments can be widely used as simulators for engineering training. Virtual reality gives engineer a better understanding of an object's design and helps them make changes when necessary. The overwhelming number of training benches of aviation devices, systems and units currently in use in the Republic of Kazakhstan are outdated, as are the aviation equipment to which they belong. Ordering training stands that meet modern requirements costs as much as a real aviation unit, device or system. The use of three-dimensional models and virtual reality technologies will make it possible to create virtual training benches that meet modern requirements for the training of aviation technicians, to multiply them with minimal cost only for virtual reality equipment. In addition, the conditions of pandemic and finding educational institutions in quarantine on distance learning, the significant project becomes the organization of virtual internships, practical and laboratory classes to ensure the practical competence of future specialists.

Thus, there is a need to develop VR training programs as a modern prospective training tool. The use of VR in the learning process is of particular interest, as it gives completely new opportunities for providing information and gaining both theoretical and practical knowledge. Virtual reality completely changes the way users interact with the device, gives them the freedom to experiment and come up with bold, innovative applications or prototypes without worrying about damaging expensive equipment [9].

The aim of the research is to develop a mechanism of training software on the example of aircraft equipment units repair implemented with the help of VR and 3D modeling technologies and assess its effectiveness [10]. This will accelerate the development of VR training programs in other areas.

2. LITERATURE REVIEW

Learning is currently one of the most popular areas of virtual reality research. Safe virtual environments can be used to simulate real or predictable environments that are too dangerous, difficult, or expensive to train. Virtual reality-based training is particularly well suited for situations where cognitive and spatial skills are important [11]. For educational purposes, virtual platforms usually simulate a classroom or laboratory, and sometimes they provide a safe environment for testing scenarios that would be too difficult or dangerous to perform in real life.

The article [12] explores some key features of virtual reality (VR), augmented reality (AR) and unified reality (MR) as well as the differences between them. Aspects of the possible use of reality technologies in the modern world are considered. Considered existing and used in the modern educational process attachments to augmented and virtual reality. The article points out the need for special technical equipment and a special virtual laboratory for implementing virtual and augmented reality systems in the modern educational process.

The authors of [13] demonstrated that students prefer learning with the elements of virtual reality to traditional approaches based on observation. As a result of the study, it was shown that the participants of the experimental training with the use of VR tools, the rate of memorization of information are higher than in traditional training.

A good overview of virtual and augmented reality applications for engineering education using gamification elements is presented in [14]. The aim of the study was to present tools that would attract 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 impart knowledge and practical skills necessary for their future career.

The authors of [15] presented a VR application to promote education in electrical engineering. They designed and developed online labs that students could access remotely using virtual reality. These

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projects allowed students to use virtual layouts and virtual tools to perform simple electronic lab work. The application created contained realistic prototypes of 3D models of all the equipment, as well as appropriate electrical components for experiments.

A more interesting approach was presented in [8], where the authors presented the Virtual 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 Virtual Mechatronics Lab 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 increases engagement by giving students a strong sense of presence and immersion compared to traditional learning environments [16-17].

In research on simulated virtual world creation, low-achieving learners have improved academic performance more than those who learn through traditional methods, even more than their high-achieving counterparts. The accessibility of virtual reality gives students the ability to construct and manipulate visual objects to represent knowledge, something that traditional teaching methods lack [18].

Unfortunately, there are very few scholarly works describing the process of testing knowledge in a virtual environment. In most cases virtual reality serves as a tool for learning and practice, but tests and exams are still written. Virtual reality exams are still an area of distance learning. Thus, there is a need for an application that can report on a student's progress or eventually lead to a final test/exam with an automatic grade. For example, the authors of [19] proposed guidelines for virtual reality educational applications based on user research and expert interviews.

Thus, a preliminary study of the literature on the implementation of VR in the educational process confirmed the relevance of the chosen direction of research. The analysis of the literature showed that:

- the implementation of VR in engineering education for practical skills improves the quality of learning and increases the memorization rate of students;
- there is no conceptual approach to presenting the mechanism of VR tutorial, which includes both teaching and testing components.

3. HARDWARE AND SOFTWARE COMPLEX OF INTERACTIVE TRAINING PROGRAMS

The vast majority of training benches of aviation devices, systems and units currently used in the Republic of Kazakhstan are outdated, as are the aviation equipment they belong to. The cost of a training stand that meets modern requirements is equivalent to the cost of a real aviation unit, device or system. The use of three-dimensional models and virtual reality technologies will make it possible to create virtual training simulators that meet modern requirements for the training of aviation technical personnel, multiplying them with minimum expenses only on virtual reality equipment.

Hardware-software complex of interactive training programs on technological processes of aircraft repair using 3D and VR technologies includes (Figure 1).

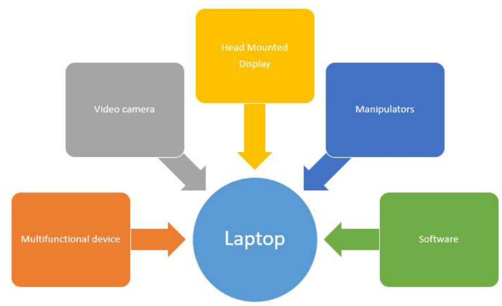

Figure 1: Hardware and software complex of interactive training programs

The software includes:
- Collection module;
- Display module;
- Database (Figure 2)

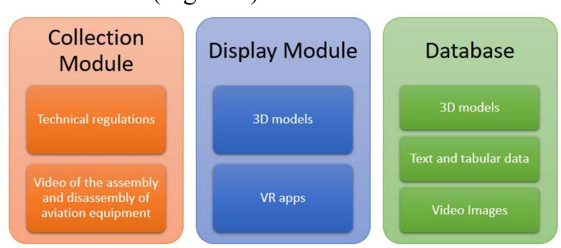

Figure 2: Software

The following requirements are imposed on equipment reliability:

- as hardware platforms should be used means with increased reliability;
- the use of hardware appropriate to the class of tasks to be solved;
- hardware and software complex should be able to recover in case of failures.

Reliability of hardware and software must be ensured through the following organizational measures:

− preliminary training of users and developers;

− timely performance of preventive maintenance and diagnostics processes;

− compliance with the rules of operation and maintenance of software and hardware;

− timely performance of procedures for data backup.

Reliability of the software Set shall be ensured by:

− carrying out a set of measures for debugging, searching for and eliminating errors.

− Keeping logs of system messages and errors by subsystems of the Complex for further analysis and configuration changes.

4. MATERIALS AND METHODS OF RESEARCH

As a result of the study of ways to develop VR applications and existing software [20-22], the order of use of specialized software tools was determined. At the first stage, a database of 3D models of parts for each unit is formed. The creation of the 3D model is carried out in the SolidWorks program. This program for three-dimensional design allows simulating products of any degree of complexity and purpose. Obtained 3D models are saved in *.stl format. At the second stage, to make the model realistic, smoothing and scanning is performed in the Blender3D program. This program was chosen because the format of the files created in it is compatible with the VR development program Unreal Engine. In addition, it is a free open-source 3D modeling engine, which can then be used to automate the processing of models. The finished VR application containing all the 3D models in the main scene is implemented through the Unreal Engine. This program has a wide range of development tools. The key criterion in favor of Unreal Engine turned out to be Blueprint, a visual scripting editor, without the need for programming.

Five topics have been selected for experimental implementation in the tutorial software, each of which deals with learning the operations of one of the units:

− disassembly/assembly of the H-5810-270 valve, consisting of 7 parts;

− disassembly/assembly of check valve 636100, consisting of 7 parts;

− disassembly/assembly of GA-192T air valve consisting of 13 parts;

− disassembly/assembly of EMT-2M electromagnetic brake consisting of 28 parts;

− disassembly/assembly of an electric motor MV-1200, consisting of 36 parts.

Students’ satisfaction with the VR software tool was assessed using feedback forms containing the following questions:

“Is this your first experience with VR technology?”

“Evaluate qualitatively the duration of the session”

“Evaluate qualitatively the comfort of using the VR complex”

“Evaluate qualitatively the usefulness of VR learning”

A comparison of traditional and VR training required the identification of an experimental and control group. Conclusions about the effectiveness of one or the other training were based on the analysis of the final control protocols. The following information was recorded in the final control protocols for each student: disassembly time of the unit, assembly time, number of mistakes made, and the examiner's evaluation.

5. THEORETICAL FOUNDATIONS

First of all, let us consider the definitions of the basic concepts. By learning system using VR, we will mean a hardware and software environment that visualizes the states and processes of functioning of complex systems, aimed at improving the efficiency of student learning. The main purpose of such a learning system is to actively involve students in the learning process.

A 3D model is a three-dimensional object of a part or unit that is displayed and used in a software application for demonstration in VR.

Let us consider a learning system using interactive virtual reality technologies. After analyzing existing virtual reality systems, it can be summarized that a typical system includes four main elements:

1) an input device to simulate work behavior;

2) an output device that allows the user to be in a virtual environment;

3) a graphical software system that creates simulated scenarios;

4) a database of storage of various conditions to simulate the working environment.

Figure 3 shows the placement of the main software components on the hardware nodes and the logic of their interaction. The database placed on the computer contains information about the students and data characterizing the learning environment in the software environment. After the headset is connected, the students are authorized and access the learning materials according to the saved results of the last successful session.

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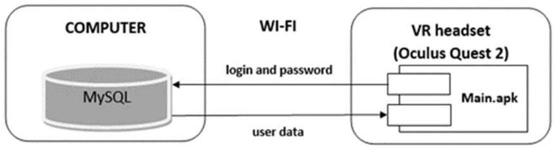

Figure 3: Placement and interaction of the main software components of the VR educational software tool

The software tool provides an interface with a selection of training topics to be studied in three modes. They are teaching, training, and testing. In training mode, the student views the operations in 3D mode. Training mode allows the student to perform operations independently using an input headset. Testing allows you to assess the practical skills acquired by the students.

After performing each mode, the student's status is memorized and marked in the visual interface with a special marker. The list of topics is automatically sorted and comes out to the user in an ordered form: topics ready to be tested first; then topics studied and ready for training; then topics not studied; 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, as well as helps in effective management of the individual learning process of each student.

As a result of experimental development of VR software tools, the authors developed the concept of a training software tool mechanism on the example of repair of aviation equipment units, presented in Figure 4.

According to the concept presented, after watching a 3D training video, the training mode is performed until all necessary operations are performed without errors. Practical skills testing are performed in two stages: execution according to instructions; independent execution of operations. If the student makes mistakes during the instructional testing phase, the software tool rolls back to training mode. Thus, the student will have to reinforce the learned operations in different modes at least three times, provided that all three times are performed without errors.

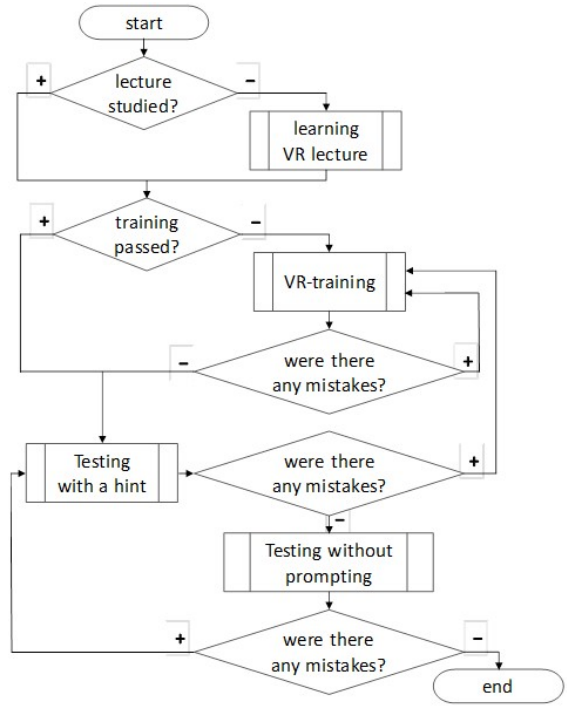

Figure 4: Training software tool mechanism

6. PRACTICAL RESULTS OF SOFTWARE TOOL IMPLEMENTATION

Research and systematization of technological processes intended for implementation in VR was carried out jointly with JSC "Aircraft Repair Plant #405". The selection of technological processes for implementation in the software tool was carried out according to the principle of the greatest importance while reducing the influence of the human factor on the risks associated with maintenance and repair.

A 3D model is a three-dimensional object of a part or unit that is displayed and used in a software application for demonstration in VR.

The list of components is extensive, for each model presented above is applicable. In addition, a number of stages due to the large number of operations are actually separate technological processes. Thus, there was a need to limit the boundaries of the study. As a result of discussions with the employees of JSC "Aircraft Repair Plant #405", five products with the implementation of technological processes of collection and disassembly were selected for preliminary implementation. In the future, it is planned to add other units with different technological processes to the software tool. Virtual user interface is shown in Figure 5. In accordance with the concept presented above, the status of the modes is displayed for each unit under study. The software tool currently contains five training topics, each of which examines

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the disassembly/assembly operations of one of the units: valve H-5810-270; check valve 636100; air valve GA-192T; electromagnetic brake EMV-2M; electric motor MV-1200.

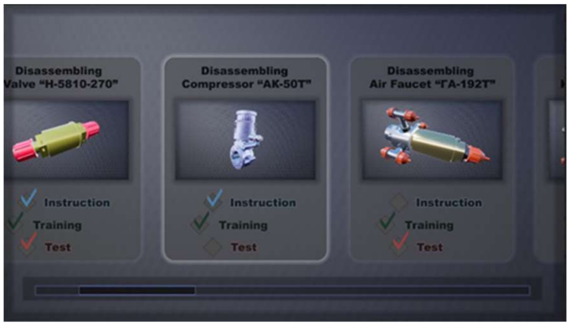

Figure 5: Virtual user interface

Selecting an unexplored unit in the training mode allows you to view a 3D video of disassembly/assembly of the corresponding product. Figure 6 shows a fragment of a 3D training video on disassembly of an air tap "GA-1927".

Figure 6: 3D training video fragment

In training mode, in addition to the machine and tools, a tablet with instructions on the operations to be performed is displayed in the user's vision area. A fragment of the training in the VR software is shown in Figure 7. Erroneous actions of the user are accompanied by a sound signal.

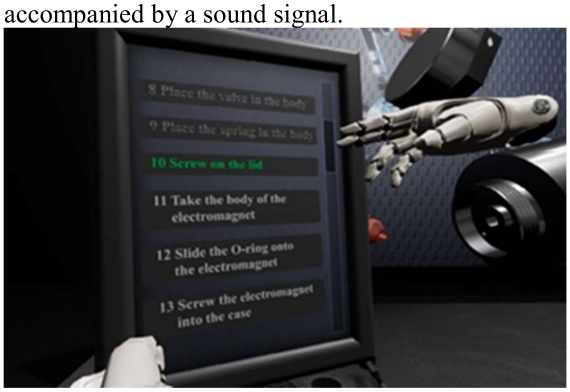

Figure 7: Fragment of training in the VR software tool

The user is provided by the tablet with instructions in the first stage test mode, only there is no sound signal in case of erroneous actions of the user. At the second stage of the test, the trainee must perform disassembly/assembly of the unit without any prompting. A fragment of the test of the second stage is shown in Figure 8. During testing, the user can see a scoreboard with the time of operations.

Figure 8: Virtual user interface

7. DISCUSSION

The Civil Aviation Academy is conducting an experiment on the use of VR software in the educational process. Photos of the learning process using the developed VR software tool are shown in Figure 9.

Figure 9: Photos of the learning process using the developed VR software tool

During the virtual reality sessions students were asked to fill out specially designed feedback forms, the results of which are presented in this article. 85 percent of students experienced VR technology for the first time. On average, each student used VR for 43 minutes per day. An analysis of the feedback forms completed by VR users is presented in Figure 10.

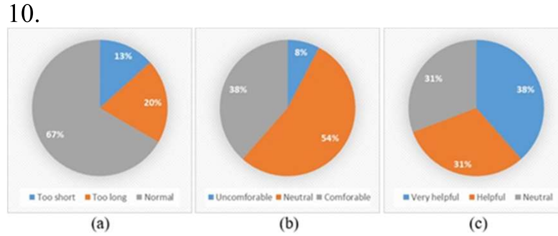

Figure 10: Analysis of feedback forms filled out by VR users: (a) – session duration assessment; (b) – comfort of using the VR complex; (c) – the usefulness of VR training, which precedes experience in a work environment

Considering the assessment of session duration and comfort of use, a low percentage of students

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(8%) felt little discomfort. None of the subjects experienced significant discomfort. For most, using VR was a positive experience. A key benefit for students is that they gain confidence before going into the work environment - 69% indicated that VR learning helped or helped a lot.

As part of the study, it was decided to test the difference in skills gained by students through VR learning compared to traditional learning. To this end, a control group and an experimental group were formed. The experimental group of 13 people was trained through the developed VR software tool. The number of training and testing for the experimental group was not limited. For the control group of 7 people a supervisor from the staff of JSC “Aircraft Repair Plant #405” was allocated. Under his guidance the students had an opportunity to disassemble and assemble one by one 5 approved units (001 - valve H-5810-270; 002 - check valve 636100; 003 - air valve GA-192T; 004 - electromagnetic brake EMV-2M; 005 - electric motor MV-1200). Accordingly, the students could observe the performance of the same operations by their classmates.

The final assessment of the skills acquired by the trainees was carried out on the basis of JSC “Aircraft Repair Plant #405”. Students had to disassemble and reassemble 5 types of installed units. The examiner noted in the protocol the time of the operation and the number of mistakes made by the student. After the unit operations were completed, academic performance was graded on a 100-point scale on the task control. Table 1 shows the results of exam protocol processing:

Table 1: Exam protocol processing results

№	TYPE OF UNIT	NUMBER OF ELEMENTARY (NON-DISMOUNTABLE) PARTS IN THE UNIT (UNIT.)	AVERAGE TURNAROUND TIME (SEC.)		THE AVERAGE GRADE FOR THE PERFORMANCE (100 POINT)	
			EG *	CG**	EG*	CG**
001	THE VALVE H-5810-270	7	32	31	100	100
002	CHECK VALVE 636100	7	55	55	100	100
003	AIR TAP GA-192T	13	125	127	95	93
004	ELECTRIC MOTOR MV-1200	28	403	451	90	84
005	ELECTROMAGNETIC BRAKE EMV-2M	36	534	606	87	80

*EG – Experimental group.
**CG – Control group.

Before and after testing result, analysis can be observed that both virtual reality and traditional enterprise training have a positive effect on the knowledge of the subject. However, as the number of details increases, the speed of operations in the experimental group is significantly more effective than in the control group.

The score is directly related to the number of errors made during operations. The results of the analysis of the errors made during the exam by the experimental group and the control group are shown in Figure 11.

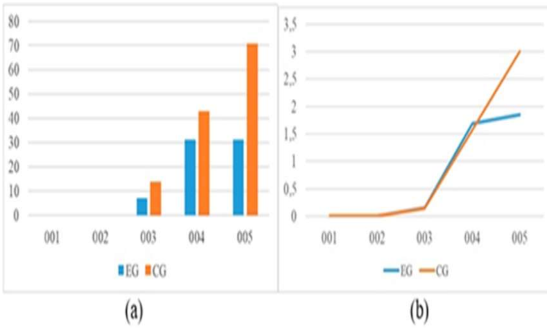

Figure 11: Mistake analysis made during the exam by the experimental group (EG) and control group (CG): (a) – the percentage of students who made mistakes; (b) – average error rate

The analysis showed that the proportion of students making mistakes when performing operations in the control group and the exam group increased consistently with the increase in the number of parts in the unit. However, in the experimental group the percentage of making mistakes is much lower, and this difference is especially noticeable when assembling the most complex unit 005. The average number of errors when working with a complex unit was also significantly lower in the experimental group.

In virtual reality, students had the opportunity to assemble and disassemble units much more frequently, to see each part and check them in the context of the entire machine. The factory cannot provide the opportunity for a large stream of students to practice as often as the process of building practical skills requires. Moreover, students overwhelmingly noted that lessons using attractive didactic methods of virtual reality were more memorable than traditional ones.

8. CONCLUSION

The current state of digital technology is forcing teachers to use better methods to provide the most effective learning. Virtual reality is an environment whose limits are still being explored, so through thoughtful pedagogy and innovative experiences, virtual reality will facilitate the integration of education and production.

VR is a powerful tool to support and facilitate learning and teaching processes. In education, instead of expensive tools and laboratories, it is more economical to use copies of them in the form of 3D models with identical physical properties transferred to VR technology. VR-environment enables learning activities that are difficult to implement in conventional laboratory classes. 3D visualization and interactivity implemented by VR technology can be used to produce tangible learning outcomes:

− developing skills in solving real-world manufacturing problems;

− study of engineering problems in different modes, which cannot be organized in a traditional classroom or laboratory due to various reasons, such as cost or safety;

− support of students' creativity, as it provides an opportunity to understand innovative technologies.

Analysis of the possibilities of virtual reality application in education allowed highlighting the conceptual approach to the implementation of the mechanism of VR training application on repair of aircraft equipment. The presented mechanism can be applied to the development of VR educational software tools in other areas.

The experience of implementing virtual reality in the educational process has shown an advantage over traditional learning technologies, as the trainee is active and can improve his skills on the prototype of real practice.

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