Development of an Interactive Mobile Platform for Studying Radio Engineering Disciplines Using Augmented Reality Technology

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Abstract—Currently, we are witnessing the active introduction of modern digital technologies in the field of education. One of the main reasons for this was the transition to distance learning due to the global COVID-19 pandemic. More and more virtual labs, virtual textbooks, as well as educational platforms that allow students to acquire the necessary skills and abilities remotely using the Internet, are being used in the educational process. The most promising educational platform is an interactive mobile learning platform. It has several advantages, among which one can especially single out the convenience of learning due to its interactivity and organization of the studied material. The application of augmented and virtual reality allows for increasing the effectiveness of classes. These technologies provide another level of interaction and material perception by students. However, VR and its high level of immersion require special equipment and more actions from the user while AR is cheaper and more affordable, but still interactive and has great visual aids. The aim of the paper is to demonstrate how augmented reality can be used for radio engineering disciplines on the example of an interactive mobile platform. This article discusses the process of developing a mobile platform that allows studying the material of radio engineering courses using augmented reality technology. The work also contains the results of a survey conducted among the students who used it as a part of their class activities. In addition, sections of the article contain a description of the project development process, its structure, international experience, and the conclusions.

Keywords—mobile interactive platform, mobile application, augmented reality, Unity3D, physics, radio engineering disciplines

1 Introduction

The forced accelerated transition to distance learning stimulated the online education market, but also made it possible to see all the weaknesses of educational systems almost all over the world. The costs of such a situation were the increased level of stress among academic staff, as well as conflicts within families [1], caused by the need for parents to act as teachers. This affected the perception of educational material by students and had a negative impact on their performance.

In the higher education system, the problem is no less critical. The transition to a remote format has especially affected the majors of the technical and natural spheres [2]. Thus, for the remote study of the humanities and social sciences, a computer and access to the Internet are enough. To study the natural and technical sciences, in addition to theoretical training, it is necessary to acquire practical skills. They are gained as part of laboratory work and various experiments, which require specially equipped laboratories and devices. When switching to distance learning, students were deprived of the opportunity to gain such experience. The current situation has demonstrated the need for alternatives to laboratory equipment, including digital solutions.

Most of the knowledge that a student gains during training is theoretical, but this is not enough to train technical specialists [3]. Conducting laboratory tasks and experiments is one of the few types of practical work within educational institutions.

The prerequisites for the introduction of virtual laboratories were the rapid development of ICT and the general digitalization, as well as the lack of equipment in some universities due to its high cost or other reasons. Therefore, to provide students with the necessary practical experience over the past twenty years, electronic educational resources have been used to gain real experience in a virtual environment.

Virtual labs are interactive electronic systems in which a user can perform tasks of laboratory workshops that require real equipment. The use of this kind of software has several advantages over the traditional approach, which requires the availability of appropriate equipment and space where it can be installed [4].

The use of such technology as augmented and virtual reality (AR and VR) switches the virtual lab work approach to another level since students have the opportunity to work with virtual models of the equipment in detail. For example, AR allows working with and investigate each piece of equipment separately when the realistic 3D models of different devices are placed in the students' own environment. This is highly important for radio engineering courses, when students work with a set of different devices where real interaction is highly appreciated. However, it should be noted that for the full use of VR special expensive helmets are required, whereas for AR only a smartphone is enough.

This paper is dedicated to the mobile educational platform that can be reached from different devices such as PCs, laptops, smartphones, and tablets. Based on the device a user gets access to a particular version of the platform. Thus, the user with a mobile phone gets the AR version of the laboratory. If the user accesses the platform using a PC, the desktop version is available. If he or she somehow does have a special VR headset, then the VR version of the lab work can be used. But the main target is still smartphone users and AR, since this approach makes the interaction with the developed system more affordable, as there is no need for additional purchases and devices. This lets us gain more audience and make the educational process simpler with the use of the technologies.

2 Related works

To study radio engineering courses, one of the key skills is experience with various types of measuring equipment. Many research groups are engaged in the development of virtual laboratories for acquiring this kind of skill.

For example, the work [5] presents the results of developing a piece of software consisting of two modules: UA-LAB (Universal Analog LABoratory) and CV-LAB (Capacitance & Voltage LABoratory). The first module is designed for voltage measurements and the second for laboratory testing with high sensitivity and accuracy of voltage and capacitance measurements. Both modules are universal, which means that students are not limited to performing any specific set of actions. In this way, they can study electrical, thermal, chemical, or biochemical processes.

Volovyk et al. [6] consider the process of developing a spectrum analyzer on the LabView platform. It allows you to study the spectral characteristics of different signals using the virtual panel of the device, which displays all the necessary information.

The developers of the project [7] describe the experience of developing and using the created virtual laboratory in physics. The authors note the interest of students when working with this software since it is possible to complete tasks in a virtual laboratory even without experience. Following the instructions, users perform the necessary task, and then, after getting acquainted with the functionality of the laboratory, they follow their own algorithms of actions. The authors consider virtual labs as a tool to ensure a quality level of education, especially during the pandemic.

In [8], the experience of developing and performing virtual labs for the study of materials science and microelectronics is given. The authors incorporated random errors and delays typical of real measuring devices into the behaviour of the equipment, which made it possible to make interaction with virtual devices close to reality. As a result, the use of the laboratory proved that such an immersion environment provides the ability to interact with virtual objects and tools much more efficiently.

The use of virtual laboratories in the educational process belongs to the concept of electronic learning (e-learning). The use of mobile devices for learning is described by the notion of m-learning: e-learning and mobility [9]. Within this learning format, El-Hussein et al. distinguish 3 main concepts, such as mobility of technologies, mobility of learners and mobility of learning processes and information [10].

Research on the readiness and acceptance of mobile learning in universities is presented in papers by Park et al. and Ismail et al. [11, 12]. These studies have shown the benefits of mobile learning and the willingness to use mobile technologies in education. Factors influencing the successful implementation of m-learning technology are discussed in the article [13].

With the development of wireless technologies, the main advantage of the mobile learning format is the independence of both students and teachers from personal computers. With m-learning, educational content can be accessed at any time and from anywhere, provided that the mobile device is connected to the Internet. For example, El-Sofany et al. (2013) discuss those educational services that can be moved to a mobile platform and present a system prototype and architecture of a mobile educational platform [14].

An increase in responsibility and self-organization in the process of m-learning was demonstrated by students in the study [15]. The experiment made it possible to identify key aspects of consumer demand for distance education based on how participants perceive the benefits and effectiveness of mobile learning. M-learning is described as a simple, convenient, interesting, innovative, and modern learning method compared to traditional classroom learning.

The article [16] is devoted to the development of mobile learning platforms, as well as the advantages and disadvantages of each approach. This paper provides an overview of learning platforms from a design implementation point of view to help educators implement a quality model for their projects. Also noteworthy are the works of El-Sofany et al. (2014) and Antic et al., which also consider various aspects of the development of mobile educational platforms for Android and iOS operating systems [17, 18].

Examples of mobile applications using AR aimed at practice-oriented learning are described by Gurevych et al. [19]. It is concluded that AR stimulates the educational process and motivate students to further study the material. An analysis of VR and AR that are adapted to STEM courses is presented in [20, 21]. The use of VR and AR in mobile applications makes it possible to simulate learning in a three-dimensional environment [22], thereby improving the quality of the learning process [23, 24].

This paper will present the development of a mobile educational platform for the study of radio engineering disciplines using AR technology.

3 Problem statement

To solve the problem of limited access to expensive high-tech equipment due to its absence or impossibility of using it in the educational process at a convenient time, the authors decided to develop a mobile educational platform for students of "Radio Engineering, Electronics and Telecommunications" academic program to study the special radio engineering courses. At the initial stage, the following functional requirements for the platform were formulated.

The educational platform should include various educational materials, as well as virtual labs. A user must have unlimited access to all educational content on the platform. The computer models of modern high-tech measuring instruments included in the platform must have a realistic interface and imitate the full functionality of their real counterparts. This will allow users to gain practical skills in working with measuring equipment while performing laboratory work.

Virtual and mixed reality is increasingly being used in the field of education. However, special VR devices are still not able to replace devices that are more accessible to users – smartphones and computers. In this regard, the platform being developed should work not only on a personal computer but also on mobile devices.

4 Web platform implementation

The created platform consists of two components: a web platform and virtual labs, which are part of it along with the educational material.

Web application orientation eliminates the need to install software or additional components on users' devices. This saves user resources, simplifies interaction with the main program, and makes all developed software easily upgradeable and expandable.

The developed software is based on a modular structure. It implies the independence of each element of virtual labs and the possibility of reusing the same modules (for example, models of measuring instruments) in various laboratory works. Therefore, to describe the instrument models, the system of objects inside the Unity game engine was used, and to develop the model software, Microsoft Visual Studio and the Qt library were applied. The choice of Unity to develop the platform made it easy to implement elements of AR, bringing realism to lab scenes and game elements that are known to have a positive impact on the learning process.

The independence of each of the models makes the project more flexible and scalable. So, to create a new laboratory work, which involves already developed device models, you only need to import them from the created library.

The created project is an educational platform that simplifies the interaction between teachers, students, and educational material. To make the system convenient in operation, several software requirements were presented to it:

- implementation of three types of users: student, teacher, and administrator;
- support for materials of various formats, including for ensuring the operation of virtual labs based on Unity;
- availability of basic functionality to ensure the workflow between a student and a teacher.

To provide users with the necessary functionality, the project implements three types of users, each of which has its own set of available actions. Figure 1 shows the use case diagram of the mobile educational platform with three actors. The operations are accessible for the users based on their role. For example, the platform administrator controls users, course content, and groups. The teacher has access to the evaluation of student work, and course management. The student has access to courses, their content and submission of assignments.

As a result, the platform has the following set of operations, the availability of which differs depending on the user role:

user authorization and authentication;

management of students and groups;

management of courses and materials;

student attendance management;

access to course materials, downloading assignments.

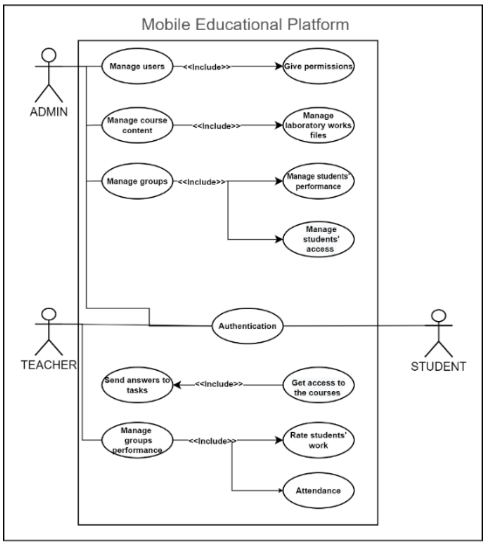

Fig. 1. The use case diagram of the interaction of different types of users with the platform

The following figures show screenshots of the running system. Figure 2 displays the students enrolled in one course. You can see what functionality the platform administrator has. Thus, for example, he or she can add new users, change user data, get additional information about profiles, and see user roles on the course.

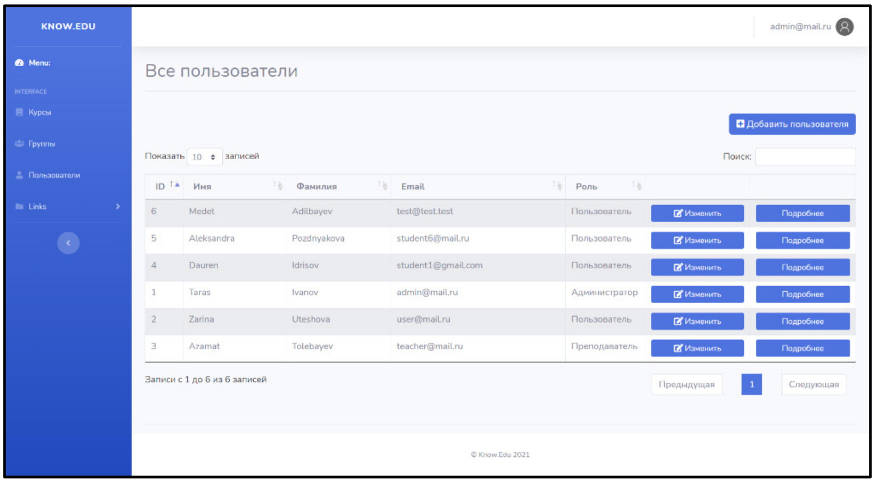

Fig. 2. Students enrolled in a course on the platform

Figure 3 shows a screenshot demonstrating the process of making changes to the course task. The following can be changed: title, description, task number in the course, and additional files necessary for work.

Since the project is a web application, its development process consists of two main parts: developing the logic of processes occurring on the system side (the backend) and demonstrating the results of these processes to the user in a convenient format. To implement the backend, the Laravel framework was used that simplifies the development of the basic functionality of such systems: authorization, authentication, and data control. Another advantage is its support for the MVC (Model-View-Controller) architectural model. Thanks to this approach, the load in the application is distributed among three structural objects. The model responds to user actions, the controller changes the system depending on these actions and displays them using a view in a user-friendly way.

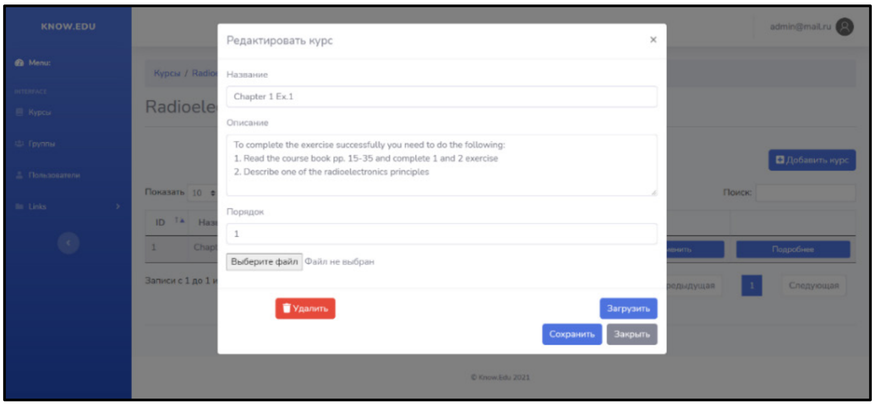

Fig. 3. Editing a course by a teacher on the platform

To implement the user side of the project, the Vue.js framework was used, which provides easy work with dynamic data and is widely used to develop user interfaces for both mobile devices and personal computers.

The Unity game engine has become the environment for developing virtual labs. With Unity, it is possible to deploy applications using WebGL technology. In addition, the platform has rich functionality and a wide range of additional modules – assets that can be connected if necessary. All this combined: the possibility of cross-platform development, user-friendly interface, simple work with 3D models, as well as support for third-party libraries to implement additional functionality, became the rationale for choosing this engine.

Figure 4 shows a component diagram that reflects the main components of the project, as well as the technologies used to implement them. So, for example, it shows how the user receives data, and what tool is used for this. The diagram also describes the interaction of all components with each other.

Thus, the data that the user receives is available to him through VIEW. They are obtained through MODEL, which has access to the database. These two components communicate with the CONTROLLER, which responds to user requests and instructs the model. The results of this chain are displayed through VIEW.

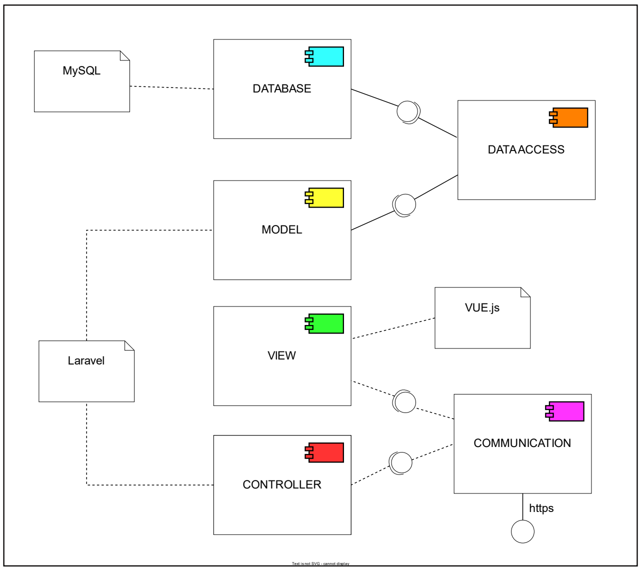

Fig. 4. The component diagram of the platform

5 Development and integration into the platform of virtual labs

Any lab included in the developed platform involves the use of measuring equipment. The models of the measuring instruments within the platform are made with a realistic interface. It allows students to gain primary skills in working with these devices. In addition to the appearance, the models of virtual instruments have realistic functionality. Working with them comes down to pressing buttons and selecting the appropriate menu items on their screens in full accordance with the rules for working on real equipment.

During the 3D implementation of the models of measuring instruments, previously developed software was used to create autonomous laboratory works [25]. This allowed us to reduce development time and reuse previously written code.

The computer models in terms of exterior and functionality were based on the actual equipment. Such realism is necessary in order to allow users to get a real experience when working with a virtual model of a device. In the future, it will be easier for students to start working with physical equipment.

To provide a digital copy of the equipment with the appropriate operational functionality, a program code was developed that determines the behaviour of this equipment. Already developed software was taken as a basis. However, it was necessary to adapt the existing developments, namely, rewrite the code from C ++ to C #, since the current project is being developed in the Unity game engine environment. In case of code incompatibility due to different specifics of existing developments and the current project, a new code was written that implements the desired functionality. As a result, these labs were implemented in a 3D environment, while performing the necessary functions. Another upgrade of the virtual labs for the web platform is the ability to switch some labs into AR mode for those users who work on the tasks via smartphones. The AR version of the labs differs in the way of interaction with the labs since smaller screen resolutions limit users' experience. In AR mode a user needs to place the equipment onto a flat surface and set it up that requires additional effort form the user.

As a result, models of widely used measuring instruments from Rohde & Shwarz company, such as the ZVA-40 vector network analyzer (Figure 5) and the FPC-1500 spectrum analyzer (Figure 6), were created and included in the web platform. It can be seen from the figures that the user interface of the created instrument models fully corresponds to the real analogues. This allows users not only to carry out the necessary measurements but also to gain primary skills in working with real equipment.

Fig. 5. 3D model of a vector network analyzer

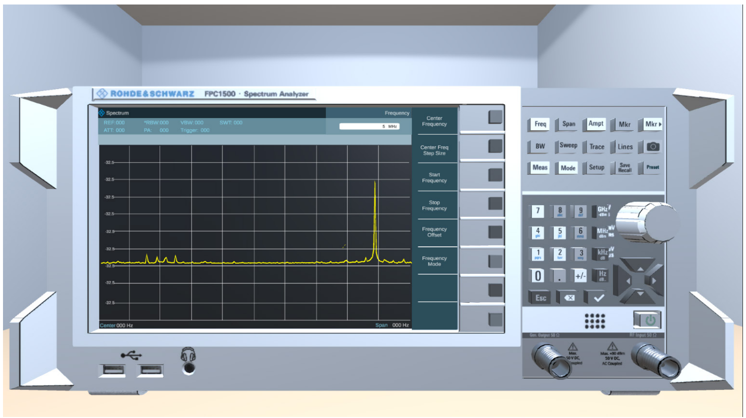

Fig. 6. 3D model of a spectrum analyzer

These measuring devices are widely used in real life. For example, vector spectrum analyzers are widely used to study various radio engineering devices, examine their transfer characteristics, and measure the parameters of S-matrices. And the study of the transmission of various radio signals, and types of modulation without the use of spectrum analyzers is simply impossible. Therefore, the development of models of these devices in the first place and their introduction to the mobile platform made it possible to create several virtual labs. They are aimed at studying physical laws and gaining skills in using high-tech measuring equipment. All created device models (for example, RC filter, microstrip resonator, microwave filter based on a rectangular waveguide) are built considering the previously developed approach and can be connected to the appropriate measuring equipment (for example, to a vector network analyzer model) to study their characteristics.

The development of each of the labs was carried out according to one algorithm. To begin with, realistic 3D models were developed, and then, depending on the device, a program code was written. To tie it all together in the Unity environment, it is necessary to "attach" the scripts that determine the behaviour of devices to user input. In our case, these are pressing buttons on the devices, changing the depth of immersion of the filter pins on a rectangular waveguide, or changing the parameters of the RC filter. Depending on this, the information displayed on the device screens in the virtual scene of the lab changes.

The scene of the lab studying the filter on a rectangular waveguide is shown in Figure 7 and the same lab in AR mode is given in Figure 8. The AR tool that is used in the project is Easy AR SDK. It has a special package for Unity game engine, that makes its integration easy and convenient. Surface tracking mode was used in the mobile version to ease the interaction of the students with the application since it does not require any image or object markers and can be used by a variety of the devices. So, the virtual equipment of the lab can be placed into the mobile environment after targeting the smartphone onto the flat surface. This approach does not require additional effort from students, as well as there is no need to use AR markers or any other additional educational material except the platform itself.

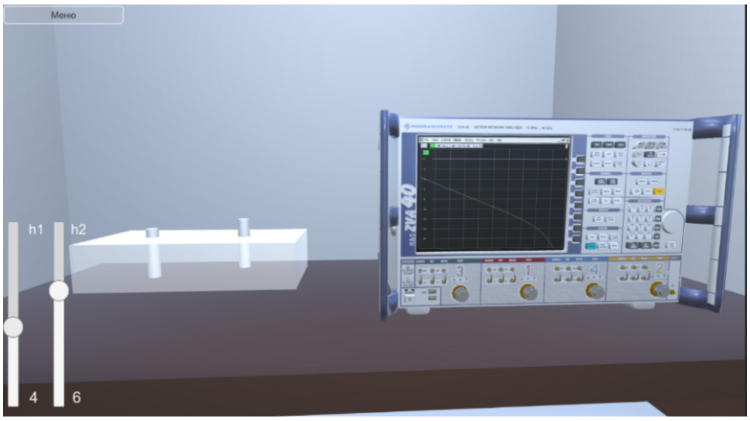

Fig. 7. Microwave filter on a rectangular waveguide

The lab work includes a filter on a rectangular waveguide and a vector network analyzer. The user, immersed in a virtual environment, can change the resistance and capacitance values, and observe in real-time the change in the frequency response of the filter on the screen of the vector network analyzer. The main functionality of the measuring device is also available to the user. So, for example, the user can change the viewing range, or the amplitude characteristics of the displayed parameters, and use the measuring line and markers to measure the S-parameters of the device being studied. However, the students must be familiar with the procedure of the experiment. They must know what parameters need to be measured and how to use the analyzer, otherwise the lab work execution will not be completed.

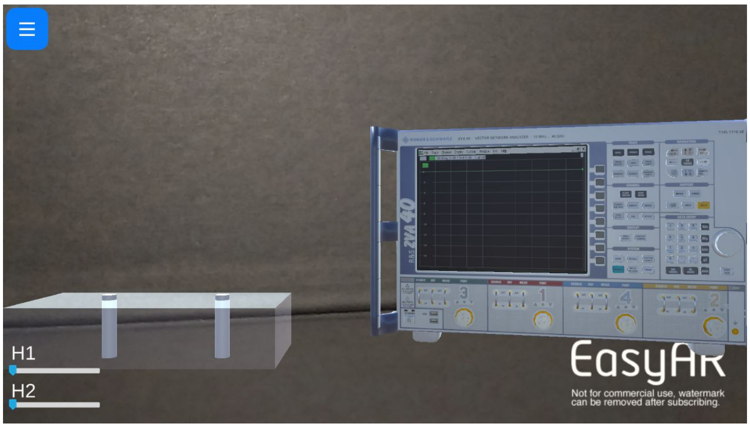

Fig. 8. Microwave filter on a rectangular waveguide in AR mode

The laboratory work, a screenshot of which is shown in Figure 9, is a visual representation that allows you to study how the energy budget is calculated from ground-based sources of radio emission, and what methods should be used to determine their coordinates for a radio monitoring system based on a small space device. The user can change the input parameters and observe how the output changes.

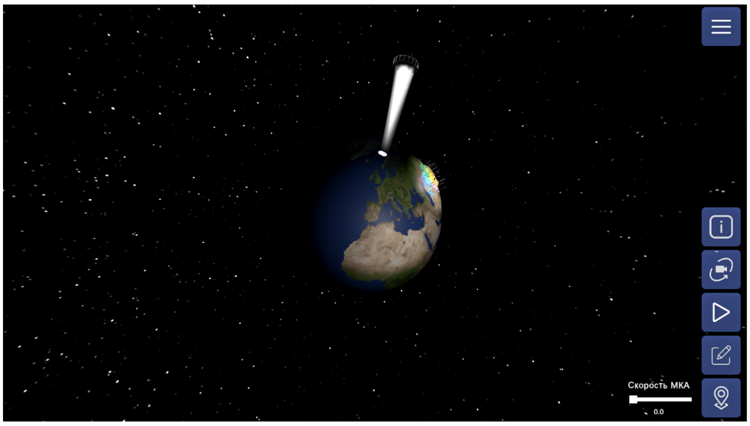

Fig. 9. Studying the functionality of a radio monitoring system based on a small spacecraft

6 The results of the learning experiment

To evaluate the effectiveness of any piece of software in the educational process, there are quantitative, qualitative, and mixed approaches. The work [26] provides a systematic review of the literature published between 2005 and 2018 to study the methodology for evaluating the effectiveness of m-learning. As a result, the authors concluded that most researchers used a quantitative approach. The same method was also applied by the authors to evaluate the results of the introduction of the developed project to the educational process.

The created platform was tested in the educational process of the International Information Technology University (Almaty, Kazakhstan). 48 students of the radio engineering academic program took part in the experiment. After studying the available material, conducting the labs on the mobile platform, and receiving grades, the students were asked to answer a questionnaire. The survey was done among the users who accessed the platform through their smartphones and applied AR version of the labs. The questionnaire was developed taking into account the best practices of evaluating the user interface and interaction experience with it. All questions were divided into several groups, each of which is devoted to a separate quality of the application: functionality, application interface, clarity, as well as usefulness. The questions to test the students' honesty and attentiveness were also included. The total number of questions was 37.

The results of the survey confirmed the effectiveness of using the created web platform and virtual labs.

Table 1. The results of the survey

№	Question	1	2	3	4	5
1	I would recommend the application to my friends	2	-	3	18	25
2	The application allows you to better understand the material	1	-	1	14	32
3	I learned the information better	-	2	1	16	29
4	The application makes it easy to run the processes I need	-	-	6	25	27
5	The application is useful	-	-	1	12	35

Some of the results of the survey are shown in Table 1. The students gave answers on a five-point scale, where 1 means "completely disagree", 2 means "rather disagree", 3 means "neutral", 4 means "rather agree", and 5 means "completely agree". These answers include the full range of opinions that can be met among users. The table clearly shows the positive response of the students to the use of the created mobile platform in the educational process. According to the users, the platform facilitates and simplifies the perception of the studied material. The respondents noted involvement in the learning process due to the visual demonstration and virtualization of the labs, the possibility of visual control of the experiment and the realism of the exterior of measuring instruments and devices.

Since the negative responses in the students' answers were the minority, we can conclude that the students are interested in such educational resources in general and the developed mobile platform and AR lab works in particular. Thus, the results of the learning experiment and the survey confirmed the need to develop and implement virtual labs and mobile learning in the educational process especially for radio engineering courses.

7 Conclusion

Digitalization is an integral part of our lives that has had a significant impact on education and has been accelerated by pandemic restrictions. During the period of using various ICT tools, it became obvious that they have a positive effect on the crucial factors of learning: perception of the material, its assimilation, and interest in the subject.

This work also proved that the development of educational materials based on the latest technologies has a beneficial effect on the quality of education, makes it more accessible and understandable, stimulates the independent study of the subject by students, which improves the quality of education in general. The use of AR within the project enriches the user experience as its interactive approach makes it more interesting and provides students with a higher involvement level.

However, along with this, virtual laboratory work is still an auxiliary tool and can be used as an additional tool to provide a combined type of training. Another disadvantage of this approach is that a virtual environment that allows repeating the same processes many times leads to the fact that students forget about the possible risks that may arise due to the mistakes made.

Giving more freedom to the user allows to avoid this issue and accelerates students' thinking process. That leads to better perception and understanding of the learning material. This approach was used in the presented work and based on the gathered results it shows a great performance.

The mobility of virtual laboratories and their independence from a certain place or equipment creates conditions for students in which they can act independently and draw their own conclusions and discoveries.

8 Acknowledgment

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