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# USING AUGMENTED REALITY TECHNOLOGY FOR VISUALIZATION OF EDUCATIONAL PHYSICAL EXPERIMENTS

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**ABSTRACT**

Augmented reality is a promising tool, which opens great opportunities for visualization. In the article a brief description of the augmented reality technology and an overview of some aspects of its application are given. The possibilities of using the augmented reality technology in teaching physics are described. An example of a developed application with the elements of augmented reality to study the phenomena of optics is presented. A free implementation of the library NyARToolkit and Unity 3D game engine were used for the project development. The results of the survey, test and interview conducted among the students before and after using the application clearly demonstrate its positive influence on the education process. It is shown that the developed application with augmented reality technology is effective and practically useful as an educational tool, especially in studying natural sciences.

**Keywords:** *Augmented Reality, Education, Physical Experiments, NyARToolkit, Unity 3D*

## 1. INTRODUCTION

Like any other area of human activity, education is affected by new information technologies throughout the world and in Kazakhstan as well. The worldwide Internet has open a new era in education [1]. It seems that teaching and learning methods, which are presently applied in higher education institutions, are especially affected by these changes. Indeed, lecturers can no longer teach students in the same manner as they did ten and even five years ago. Therefore, the informatization of the higher education in Kazakhstan is regarded as a high-priority task aimed at improving the domestic educational system [2].

The educational process can be improved through incorporating innovative teaching approaches and new methods of communication between lecturers and students. Nowadays, the teaching hours in all the universities of Kazakhstan consist of lectures and seminars for humanitarian courses and lectures, practical and laboratory classes for technical courses.

And often lecturers are limited by the time of their class hours to explain the given topics and interest students. Additionally, universities require, that the modern students should be more interested and directed in the learning process, and lecturers

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are responsible for this. At this situation, time distribution plays an important role for lecturers in order to meet these requirements.

And here, computer-aided teaching systems are particularly interesting. They are designed to help in preparing educational materials, presenting them, and testing the students. One of the examples of such teaching systems is Physics Virtual Laboratory, developed by the authors [3]. Such systems not only help to describe visually the complex physical processes, thereby saving the time for lecturers to give more additional material. These virtual laboratories allow increasing students' interest in the course. Such teaching systems like Physics Virtual Laboratory can contain their own tasks for laboratory works, which can interest students more in their studying process. Besides, such systems allow teachers to check the students' performance with the help of integrated test subsystems.

However, other opinions also exist. For example, according to the authors in [4], such systems have only cool graphics and interactivity that do not excite or motivate "right-brained" thinkers.

At the present time, one of the promising technologies that can be used as a next innovative approach within computer-aided teaching systems development is Augmented and Virtual Reality (AR and VR). Augmented and virtual reality are the highly demanded technologies in the modern world, that broaden the user's possibilities by bringing in various virtual objects into his/her field of perception in real time [5]. Interactivity, accessibility, realism and innovativeness can be named as the reasons of the growing popularity of AR and VR.

The augmented and virtual reality are widely used in various fields of science and technology, solving problems in fundamental scientific courses as well as in highly specialized application areas. The technologies of augmented and virtual reality is widely used in medicine, for example, for the visualization of internal organs of human body (tomography, ultrasound, X-ray, etc.). In industry it is a new stage of development of well-known systems of computer-aided design and simulation. In business these technologies are applied for the implementation of multi-functional tasks and their visualization in real time. Such approaches help to improve the efficiency of management and marketing activities. One of the most obvious applications of augmented and virtual reality is in entertainment. In education the use of augmented and virtual reality allows conducting lectures and labs clearly, showing students all the aspects of a real object or a process. It has a great impact on education in general, improving the quality of educational processes and decreasing their cost. Thus, application areas of AR and VR are limited only by fantasy.

In particular, it is worth noting the application of augmented and virtual reality for physics teaching and studying.

Physics is a science about the simplest and at the same time the most general laws of the nature. It studies matter, its structure and movement. The value of physics is determined by the dominant role of science and technology in the modern society. The laws of physics are the basis of entire natural science. However, the study of physics is not simple. It aims to explain the rationale and fundamental interactions in nature that govern the motion of matter. Thus, the technologies of augmented and virtual reality can be used for visualization and simulation of various physical phenomena in order to make the studying process more interactive, attractive and interesting.
But at the same time, despite all the benefits listed above there are also risks and negative aspects of using this technology in education. The use of this type of applications can entail the personal isolation of individuals from their peers [6]. Also introduction of new technologies is risk by itself, since the goal of new technologies is to help people to make life easier. That is why the level of their application and productivity, in every moment, must be high. Otherwise, there is no any sense of such technology implementation.

Furthermore, the investment amount also can be considered as a negative side of the augmented and virtual reality, and basically depends on the equipment. For example, in VR technology for simulation the illusion of the real or fictional world the most commonly used virtual reality headset that is worn on the head and motion controllers are Oculus Rift and HTC Vive [7]. The virtual reality headset and motion controllers installed on the mid performance computers or high-performance smartphones are the minimal equipment set in VR; while AR equipment set may consist of a computer or a smartphone only. Today almost every educational institution is equipped with modern computers; and their performance and software are enough to use basic functions of AR technology. This advantage of AR over VR makes it attractive for applying it in education.

In this article the authors present a software application, which is designed to teach physics in an interactive way using the augmented

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reality technology. The practical significance of the application is to increase the interest of students, pupils as well as any other interested people to study physics. The application is developed in the International Information Technology University (Almaty, Kazakhstan) in the Mixed Reality Laboratory.

## 2. LITERATURE REVIEW

Recently, universities around the globe have shifted from the traditional educational system to the system, based on information technology, including augmented reality. Such technologies can be introduced into various areas at all the training stages, like knowledge exchange, knowledge assimilation, testing and assessment. As evidence, in [8] a virtual laboratory is presented that is aimed at studying chemical processes based on augmented reality. Such approach is quite efficient, when dangerous, explosive, expensive or labor-intensive experiments need to be conducted.

Another application of augmented reality is the software Construct3D [9], which is successfully employed to study math and geometry in universities and high schools. This application inspires students to experiment with geometric constructions. Construct3D was declared as a simple learning tool. However, it contributed a lot to improve spatial abilities of students and maximize learning transfer. In [10] the authors present an application to teach painting to children. The sketch environment is based on the technology of augmented reality and computer vision. The sketch system provides such additional functions, as contour extraction, image processing and augmented reality rendering. In the work [11] an application to study geography is described. This application allows pupils to rotate the virtual 3D models of the Earth and the Sun and to study the constellations, planets, satellites and their interaction. The application Transparent Earth in [12] gives an opportunity to see the map of the world under your feet. In [13] a program that checks English proficiency is presented. A student is given ten cards with questions and four cards with answers. When he or she places a marker with a question in front of the camera, the application generates a virtual object, a question, related to this object, and possible answers. Then the student shows a marker with an answer to the camera, and the program compares the given answer with the correct one.

The development of AR technology also plays an important role in health service and medicine. It can be used in training future surgeons before major surgical procedures. Thus, a student first carries out an operation in a virtual environment without any risk to patient's health. Another application of augmented reality in medicine is conducting diagnosis of a patient using mobile devices. One of the examples of the medical applications based on AR is Palpsim [14]. This application allows students to "touch" a virtual patient with their hands. In order to make it possible, a complex system of sensory feedback based on the hydraulic mechanism is used.

Using AR, it is possible to facilitate complicated surgeries. Thus, an application Mikt Pille [16] is employed during a surgery to look inside a patient body. The program is developed by Cancer Research Center (Germany). Other applications of AR in medicine are tools against autism, in diagnosis of memory impairment, while getting rid of post-traumatic stress.

It can be said that augmented reality changes medicine. And the main advantage of AR technology application is reduction of medical errors.

The augmented reality technology is successfully applied in business as well. Many companies are interested in using AR to design and recognize physical parts of manufactured goods. According to Shelton [17], factories can not only construct an automobile in three dimensions, but create virtual comments, explaining to technicians what needs to be done or fixed.

In education, in particular in teaching physics the following works can be mentioned.

The work [18] presents an application to study physics of the magnetic field using AR. In this application the lines of the magnetic field are visualized as real magnetic distribution.

In [19] the application of technology of augmented reality in the research university laboratories is studied. The first-year students of the university took part in the research. The experimental results showed that the augmented reality technology significantly improves the students' laboratory skills and helps them to acquire the positive attitude towards physical labs.

In [20] the authors present the research, which analyzes the use of mobile augmented reality for increasing the interest in physics in secondary schools. Didactic possibilities of this technology have been examined using web and mobile applications. The results showed that the mobile augmented reality can increase the motivation and interest of pupils and can be successfully used in teaching physics in secondary schools.

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In [21] it is demonstrated that the augmented reality technology is an effective tool to improve teaching methods. The authors describe the development and evaluation of the system of augmented reality for explaining Euclidean vectors in physics and mathematics. The main goal of the application of this pedagogical tool was to facilitate in understanding of physical terms such as magnitude, direction and orientation and basic vector operations such as addition, subtraction, and cross product. The results of using this system showed its usability and good performance of learners. The system combines the real-world scenario with virtual elements controlled by interactive interface.

In [22] the application of mobile augmented reality technology for teaching physics is considered. The obtained results showed that AR is an efficient tool for physics teachers. In addition, it provides an opportunity to develop the necessary skills for teaching the natural sciences in the modern society of digital technologies.

In the [23] the authors studied a problem of merging their own devices with the technology of augmented reality in teaching. The work shows that using such integration it is possible to improve the quality of teaching at different stages of training of the high school students, students of the universities and children in different educational sections.

The application of AR technology for the teaching the natural science for the private college students was studied in [24]. According to the opinions of teachers and students, studying the subject with this technology was pleasant, easy and useful.

By the next authors in [25] the AR technology was considered in the study of mathematics, namely, the study of the rotation of solids. The decision to implement the concept, based on the vision of dynamic visualization, is supported by the idea of creating an impression of immersion. It is obvious that in the future the application of this technology will only expand, offering positive changes for the development of spatial visualization skills. The authors of this article are convinced of the advantages that AR technology can offer for the teaching mathematics and intend to use it to explain the calculation of the volume of solid bodies of rotation and other problems.

The main idea of research in [26] was studying the impact of the AR technology on improving students' performance and their psychological state. The study was attended by second-year students who were taught the subject "Presentation of information on computers" using two different technologies, such as augmented reality and the Internet. The results showed that both technologies contributed to improving students' performance.

The article [27] is devoted to the study of applying AR technology to support the software course and to test the various effects using interactive online and AR learning strategies. The data obtained demonstrated the potential of using the AR methods to support the motivation of student learning and interaction between peers. The interactive learning on the basis of augmented reality has become a trigger, encouraging students to participate more actively and improve academic achievements. It was concluded that in the stage of integrating applications with augmented reality into the course, technology developers should carefully study the target audience of the training, the amount of information displayed on the screen of the mobile phone and the availability of training equipment and classroom environments to achieve suitable learning scenarios.

In [28] the authors show the effectiveness of using the AR technology in lecture classes. It is demonstrated that this technology has a great positive impact on students, whose confidence and motivation to learn were growing.

In such a way, the technology of augmented reality is widely used in business and industry, as well as in teaching different subjects at all levels of education, from kindergartens to universities. Despite the wide application area, AR is mostly used as a supportive tool. And it has some subsequences. Developers have no approved standards and best practices, that forces them to create their traditions and set quality level. And partially because of it researchers frequently do not conduct works with users' feedback, that interfere to get an impersonal evaluation.

In the educational system of Kazakhstan, the field of development of new learning systems, based on information technology, is evolving as well. The projects, presented in the works [29, 30, 31 and 32] can be named. However, the use of augmented reality in teaching process is new for Kazakhstan universities.

In this article the authors present the application for physics study using AR, where students can not only watch the animation, but be a direct participant of the experiment. The additional problem sets and questions allow consolidating the past material in a game form.

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## 3. METHODS

Despite the fact that there are many examples of applications with AR in education, the optimal way of using AR in the complex fields of science like physics, which avoids the most of the risks of using AR and VR technologies in education is not worked out yet.

One of the important aspects of introduction of the new technology is choosing the right stage of the educational process, where its application is justified. For this purpose, among the students of the International Information Technology University a survey was conducted. The students were asked about AR technology, the reasons of using AR technology and in which cases they want to use it. Among all of the students participated in the survey (approximately 1700), over 94% of them know about AR and the differences between AR and VR. All of the students voted for introduction of AR technology into educational process. Among them only 8% voted for using AR only in lecture time, when the remaining 92% voted for applying AR during all class hours (lectures and labs). As the reasons of using AR technology most of the students pointed to uniformity of the current lessons and boring or old style of teaching and learning. Some of the students mentioned that the lectures of the different courses are similar, and they do not feel many differences between them. That certainly affects the students' perception and their achievements in the negative way.

The results of the survey had been taken into consideration by the authors before the implementation of the application. Its main goal is to help students to understand the complex physical laws and phenomena. And it can be used during physics lectures as well as labs.

The application was accomplished using the library NyARToolkit and the game engine Unity 3D. This choice was made taking into account the following factors [33]. First, the library and the engine are free and suitable for non-commercial use. Secondly, they provide wide opportunities for development of applications with augmented reality. In addition, the Unity 3D is very easy to use for programming of 3D visual elements, when it is difficult to imagine an object as a whole clearly. The entire library is written in C# programming language and can be imported into a new Unity project.

The NyARToolkit library uses a black-and-white square marker, inside which an identifier-pattern is inserted. Theoretically, it can be any pattern. But a conventional black-and-white marker of a simple form is used because of the limitations, such as webcam resolution, color rendering, lighting or computing power of a device used.

In [34] the principal types of markers, the comparison of the performance of different implementations and their recognition are given. The marker detection algorithm is as follows: the primary image → obtaining the threshold image (image binarization) → formation of associated components → defining the closed regions → selection of the marker borders and corners → coordinates transformation (image filling) (Figure 1).

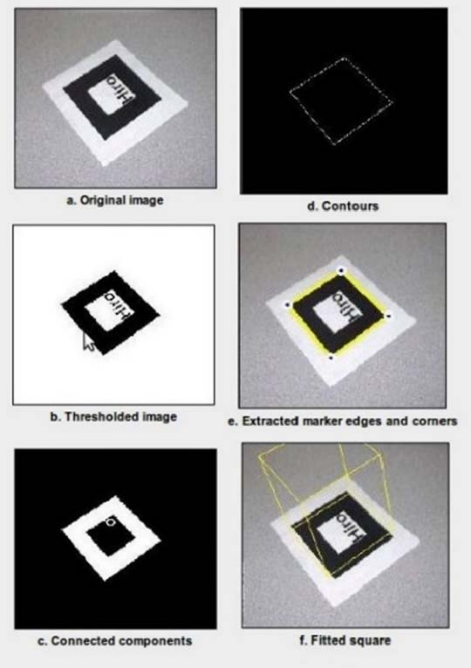


*Figure 1. The marker detection algorithm [35]*

The two-color marker consists of a square black frame and an internal pattern. The first stage of the recognition process is the detection of the black marker borders, i.e., the location of the connected groups of pixels below a certain gray value threshold. Then the contour of each group is extracted, and, finally, these groups surrounded by the four straight lines are labeled as potential markers. The four corners of each potential marker are used to calculate the homography to eliminate the perspective distortion. After the internal pattern is adjusted to the canonical front view, it is possible to form the grid of gray NxN values (usually 16x16

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or 32x32). These gray values form a feature vector, which is compared by correlation with known markers in the library of the existing feature vectors. As an output we can obtain a confidence factor. If this confidence factor is larger than the threshold, the marker will be detected.

## 4. EXAMPLE OF THE APPLICATION WITH AR FOR VISUALIZATION OF PHYSICAL EXPERIMENTS

With the help of AR technology an application that allows conducting a number of physical experiments was developed. The realization of the following experiments is available:

1) the study of the relationship between the angles of incidence, reflection and refraction of radiation at the boundary between two dielectric media;
2) the study of the phenomenon of total internal reflection from the boundary of an optically less dense medium;
3) the investigation of a thin lens with spherical surfaces;
4) the determination of the focal length of the thin lens;
5) the investigation of the interference phenomenon from two thin slits.

The application allows students to study various types of physical phenomena by turning training into a cognitive game. AR provides 3D visualization of the studied objects or processes. The developed programs analyze the incoming video stream using a web camera, recognize the corresponding marker and build the desired object or process. Moreover, students can not only observe the emerged image, but also change it by moving the markers in various directions. And each time the image on the screen of a device changes helping students to carefully examine the studied objects or processes from different angles and thereby deeply understand them.

One of the designed physical experiments presents the obtaining of the images of a converging lens. When a web camera of a computer, a smartphone or a tablet is moved on the specially created markers (Figure 2), the application shows an image, a burning candle and a converging lens on the screen of the device.

*a) The candle marker*

*b) The lens marker*

*c) The screen marker*

*Figure 2. The markers*

When the distance between the object and the lens or the image and the lens changes, the size of the image on the screen changes as well. In this case, the corresponding distances are displayed on the screen (Figure 3, a). A user has the opportunity to study the process of image constructing, to check the thin lens equation and to calculate the obtained image magnification (Figure 3, b and c).

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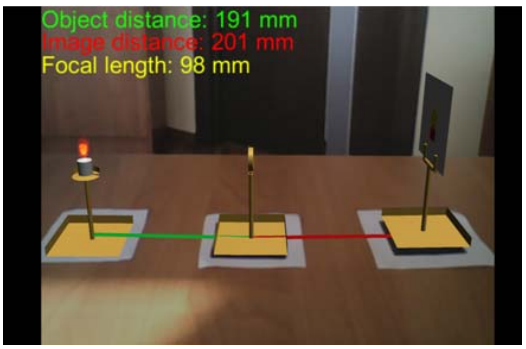
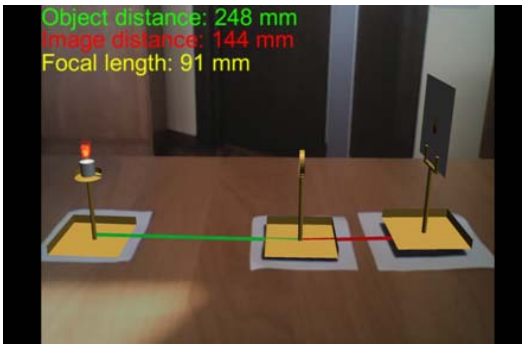
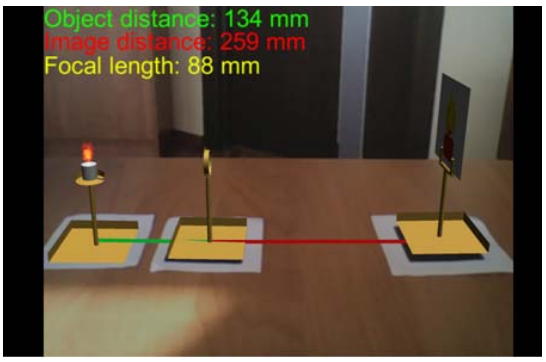



*a) The lens is in the middle between the object and the screen*




*b) The object distance is more than the image distance*




*c) The object distance is less than the image distance*

*Figure 3. Obtaining the augmented scene of the thin lens image*

The Figure 3 shows that when the lens approaches the object, the image magnifies (Figure 3, b), and when the lens is moved away from the object, the image decreases (Figure 3, c). Thus, the linear magnification of the lens can be calculated as:

$$M = -\frac{f}{d} \qquad (1),$$

where $f$ is an image distance; $d$ is an object distance.

To calculate the optical power of the lens the following equation can be used:

$$\frac{1}{f} + \frac{1}{d} = \frac{1}{F} = D \qquad (2),$$

where $F$ is a focal length of the lens; $D$ is a diopter or optical power of the lens.

In Figure 4 the flow chart of the application algorithm is shown. After the program is run, it checks web camera settings, the markers and the patterns in the memory. Then the incoming video stream is scanned to detect markers. The scanning process takes place every shot. As the marker is detected, the model is laid on it.

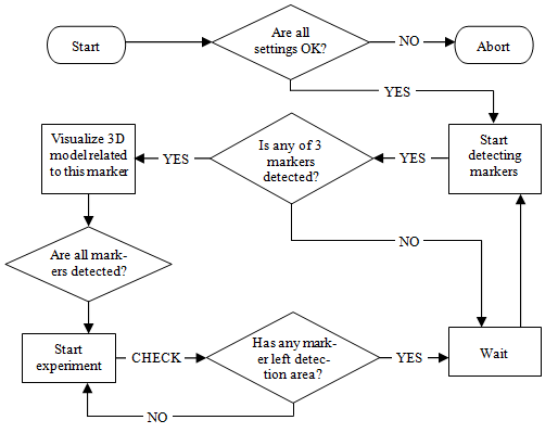



*Figure 4. The flow chart of the application algorithm*

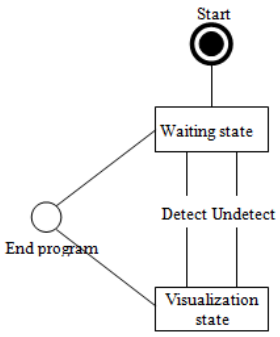



*Figure 5. The state diagram*

To run the program correctly, all three markers need to be placed in front of the camera. At this time, the experiment mode is turned on: the distance between markers is calculated and the projection is shown. Then the presence of all the three markers is checked every shot. If one of them

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disappears, the program turns into the waiting mode.

The Figure 5 depicts the state diagram. The application works only in two states, namely when it is detecting markers and when it is not. In the *Undetect* state the application only action is detecting markers. When the marker is caught, the program switches to the *Visualization* state immediately, in which the marker position is calculated, and the 3D model is placed right on this point.

## 5. RESULTS OF THE PEDAGOGICAL EXPERIMENTS AND DISCUSSION

The effect of the introduction of modern technologies into the process of teaching physics to the 1st year students of the International Information Technology University was studied. Four groups of 80 students participated in the experiment. The first two groups had a chance to use the developed application during their physics classes as an additional tool to study corresponding physics sections. The remaining two groups were taught the same topics in a traditional way.

First, the survey about the efficiency of the developed application was conducted among the students of the first two groups. The Figure 6 illustrates the results of the survey.

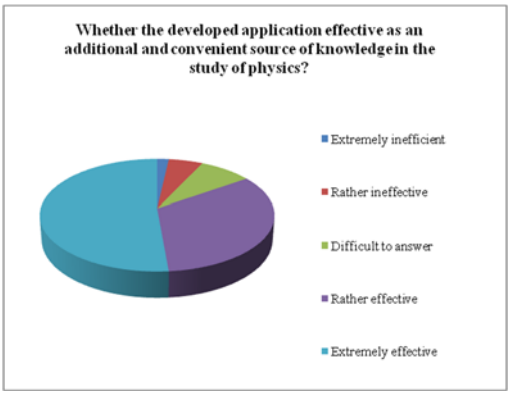


*Figure 6. The results of the survey about efficiency of the developed application*

The survey showed that about 85% of the students, participated in it, find the developed application quite effective and easy to use. We consider that this is mainly because of the "wow effect" of the application that helps to visualize and remember the results of the physical experiments.

Second, a test was given to all the four groups of students. The test questions were compiled only from the physics sections that are covered in the developed application and generally orientated on the understanding of the physical processes. For the objective assessment, the same lecturer taught in all four groups.

Analyzing the results of the test it can be concluded that the students from the first two groups (that used the developed application with AR) showed the overall better performance than the students from the remaining groups.

As a third part of the pedagogical experiment, to find out the reasons for different test results the students were interviewed about what exactly helped them to pass the test better. On the interview, most of them answered, that the AR visualization had helped them to understand better ongoing processes. Thus, they could spend twice more time to prepare to the test, instead of searching additional materials with 3D visualization. Another part of the students said that AR visualization also helped to ask the lecturer the right questions. And finally, all students exactly agreed about the benefit of AR in education.

Additionally, we invited the students who studied physics one or two years earlier on the demonstration lesson. After that the students were asked about advantages or disadvantages of using such applications with AR during physics classes. All of them endorsed the presented teaching approach and supposed that if similar applications were available for them before, their physics grades could be higher than they are.

Also, as a result of the analysis of the students' feedbacks, it was found out that the mobile version of the developed application would be more convenient to use. It is more interesting for students to observe the visualization of physical experiments on a smartphone screen than on a computer monitor. And in this case, in our opinion, the main role is played by the psychological factor, i.e. the ability of augmented reality to turn the learning process into a game.

In such a way, we believe that after using the developed program, not only the students' performance will improve, but also their interest in physics will increase.

In addition, it needs to be mentioned that the first two groups of students (who used AR application) showed in general higher results on the final exam than students from other groups. It can be explained by increased interest in physics after using the developed application. Thus, AR technology helps to increase the involvement of students in physics studying and improves understanding of complex physics concepts.

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This work is a continuation of the research of the authors related to the development of virtual physical laboratories based on various integrated development environments. The use of new technologies such as AR and VR creates new perspectives in the use of educational applications. However, the possibilities of their using should be carefully studied by educational authorities.

## 6. CONCLUSION

Natural sciences tend to describe and understand the surrounding world. However, there are limitations in the presentation of processes, the flow of which is not available in the laboratory conditions. To increase the understanding among students the idea of the project was to visualize some physical processes using the AR.

In the article the software application with the use of AR technology is presented. The developed application allows to visualize and to study the geometric and wave optics. The students can not only watch the animation but can be a direct participant in the experiment. The conducted surveys and interviews among the students of the university showed that it is an effective tool for deeper understanding of the topics. Also as a whole the interest to physics increased among the students after using the developed application.

Thus, the AR technology make it possible to carry out any form of physical experiment, open the broad perspectives in the development of original, and sometimes fundamentally new physics lab tasks. The authors continue to develop other virtual physical experiments that will be integrated into the current application.

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