Virtual Reality Technologies as a Tool for Development of Physics Learning Educational Complex

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Abstract. The paper describes the project on physics learning. It was implemented using the Unity game engine, Leap Motion package to provide controlling within the laboratory works, and C# programming language in order to define logic between objects of the app. Also, the survey on the efficiency of similar projects and applications is presented. It was conducted among students of the high school. The observations on using of virtual reality technology are also given. The main purpose of the article is to demonstrate and evaluate use of the application in subject's learning and its efficiency. The paper also raises question on educational tools relevance and modernity.

Keywords: Virtual reality · Virtual physical laboratory · Physics · Unity3d · Education

1 Introduction

Education is one of the most important need of the society. It is a basis of everyone's life that defines the future. That is why it is very important to make learning effective, useful and relevant. One of the features of relevant education is modern tools and approaches. Different companies and educational organizations work on development of specific apps and devices that will improve understanding of the material. The game approach allows presenting information to students in simplified form and at the same time does not ruin its conception. Moreover, it provides better representation of some complex concepts. Another advantage of modern technologies is that contemporary youth are familiar with them. It means that they do not need to be taught in order to work with apps. On the other hand, we can see the poor equipment in some that are not provided with all the necessary physical installations. Thus, the educational applications allow partially solving this problem. In order to gain additional information about other's experience in the field the analysis of existing projects with similar aims and implementation was conducted.

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2 Using of Virtual Reality Technology for Physics Learning

Over the past few years, there has been a sharp increase in the use of virtual reality technology in education, in particular for the study of physics. Sanders et al. present three different virtual environments that were developed using three different technologies [1]. A three-dimensional magnetic field emanating from a magnet in the form of a rod was used as a physical concept. Virtual environments have been developed that allow the interaction, control and study of electromagnetic phenomena. Another project consists of two demonstrations of virtual reality for electro-magnetism, which show electromagnetic fields generated by particles moving along a user-defined trajectory [2]. For this implementation, the Unity game creation engine was used. Testing took place on the headset HTC Vive VR with hand-held controllers. In [3], "measurements" can be carried out to determine various calibration coefficients necessary for correcting the electrometer readings for ion recombination, polarity, temperature/pressure. All of them are conducted within a virtual environment. Morales et al. show a prototype with augmented reality technology [4]. It was developed as a part of the study of mechanics that simulates uniform rectilinear movement and free fall of an object. The result was a prototype with two functions, the first of which allows simulating the movement of the vehicle at a constant speed, the second allows simulating the fall of objects taking into account gravity. In [5], the physics of air bubbles formed in a liquid is considered in detail. With the help of virtual reality, the sounds of drops falling in water were visualized. Sakamoto et al. created a prototype system using virtual reality technology, so that anyone could easily perform scientific experiments in physics and chemistry [6]. Also, the developed system is adapted for mobile devices. The ability of virtual reality technology to provide a sense of immersion and presence with tracking the whole body and receiving feedback allows conducting experiments in laboratories remotely, safely and realistically. Pirker et al. studied the experience of learning in a virtual laboratory within the framework of the scale of an ordinary room [7]. Virtual reality was created using a traditional screen and multi-user settings for virtual reality (mobile VR settings supporting multi-user setups). It is shown that the laboratory of virtual reality has such qualities as immersion, involvement, ease of use and training. Knierim et al. developed an application using virtual and augmented reality technologies to visualize the thermal conductivity of metals [8]. In [9], an interactive visualization of the physics of subatomic particles in virtual reality is presented. This system was developed by an interdisciplinary team as a training tool for the study and investigation of collisions of subatomic particles. The article describes the developed system, discusses solutions for the design of visualization and the process of joint development. Another project presents a multi-user virtual reality environment that allows users to visualize and analyze the structures and dynamics of complex molecular structures "on the fly" with atomic level accuracy, perform complex molecular tasks, and interact with other users in the same virtual environment [10].

3 Results

A software application for physics study with the technology of virtual reality was developed in the International Information Technology University (Almaty, Kazakhstan). As a platform of the application's implementation the Unity game engine was chosen. There were several reasons for this. Unity is a cross-platform engine that supports many additional packages and libraries. Another convenient feature of the engine is the support of the physical characteristics for game objects. Also it lets to extend specifications of the object's behavior and interactions between them using own scripts. For intuitive interaction with the app the Leap Motion controller was used. Its main feature is the ability to work without other additional devices, using only palm of the hands. Thus, it is possible to recreate the closest to real-life interaction between human and objects.

The developed application represents a program that allows studying physics both independently and at a school, together with a teacher. It fully reveals the studied physical laws and concepts thanks to the visual representation. An important aspect is that the software covers all the necessary components of the subject study, as it consists of problem tasks, laboratory works, animations and tests. These modules are the core of the program. Thanks to this structure, students gain new knowledge by doing a laboratory work or observing animation, apply them in practice, solving problem tasks and check their performance using test questions. The modular approach organizes the gradual flow of new information and its active use, thereby simplifying the perception and memorization. Figure 1 shows a component diagram. It reflects the internal structure of the system and demonstrates the relationship between the elements. Based on it, four main components can be identified: tasks, laboratory works, animations and a set of test questions. Their correct operation is ensured by auxiliary components, namely folders with common program objects, models, prefabs, and program codes. There are also separate elements necessary for a specific task, laboratory work, test question or animation exist. The operation of the Leap Motion module is provided by a separate package. Thanks to it, the laboratory works can be controlled with the help of hands.

The diagram presented in Fig. 2 shows the model of interaction between a user and system's components. The actors are the user and the application elements. Use cases are actions that are possible in the program. Thus, the main actor is the user that starts the whole system and initializes the rest of the processes. The user starts the Main launcher by opening the application. Through it, the user can run a laboratory work, a test, a problem task, a tutorial or an animation. Also, through the launcher the user can change the system settings, send feedback, learn about the developers of the application, or close the program. The use case Play allows the user to run the actors Problem, Laboratory work, Tutorial, Test, and Animation. The laboratory works and tasks consist of three precedents: starting a laboratory work/task, changing the values of variables and viewing the conditions of the task/order of laboratory work (Fig. 2).

From the main screen of the application, the user can go to the main elements of the application: laboratory works, tasks, tests, animations and a tutorial that helps to familiarize yourself with the operation of the application.

Figure 3 presents the scene of one of the five developed labs. In this work, the user needs to examine the relationship between voltage, current, and the location of the rheostat slider. The user needs to manage the experiment using the Leap Motion, which allows sliding the virtual rheostat slider manually.

Figure 4 shows a visualization of the problem of a boat and two fishermen of different weights. It is necessary to determine its movement, when the fishermen change their

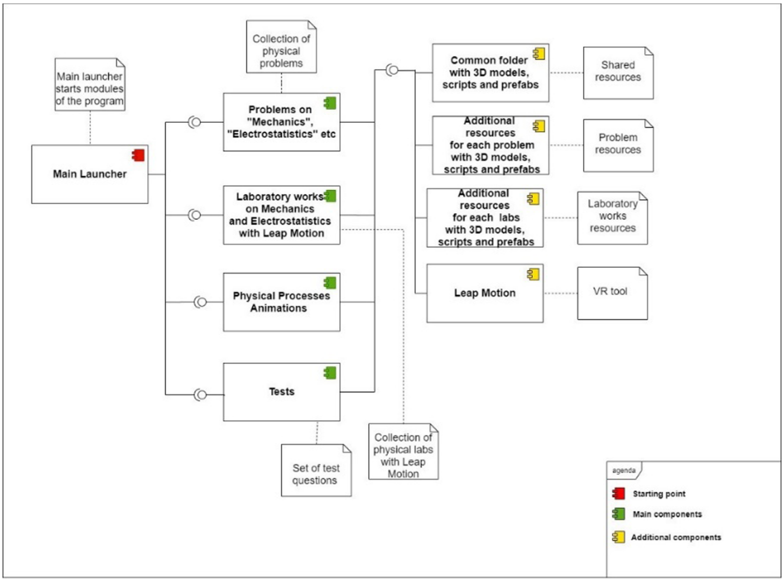


Fig. 1. Component diagram of the application

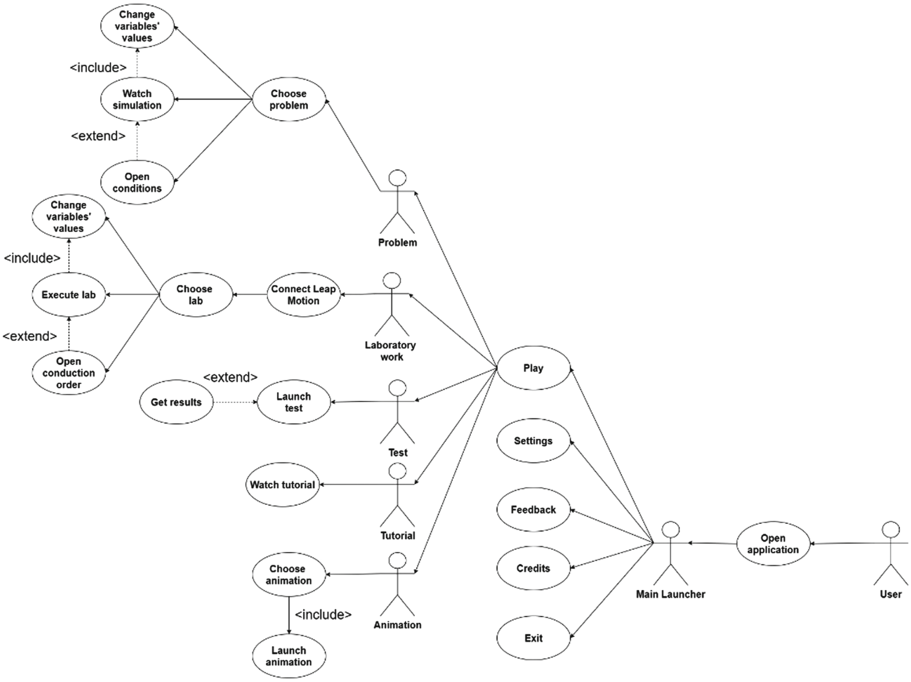


Fig. 2. Use case diagram

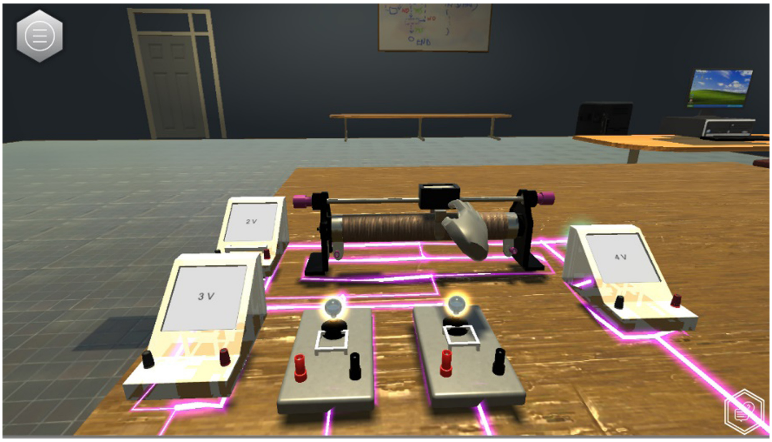


Fig. 3. Laboratory installation

places. The user can change the parameters of the task to study the relationship between the movement of the boat, the weights of people and the length of the boat. In total there are 16 problems on such topics like Mechanics and Electrostatistics. They relate to the themes of the laboratory works and help to deepen knowledge within the topics.

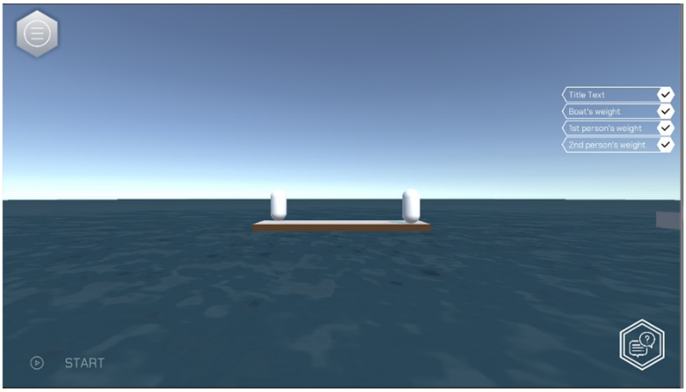
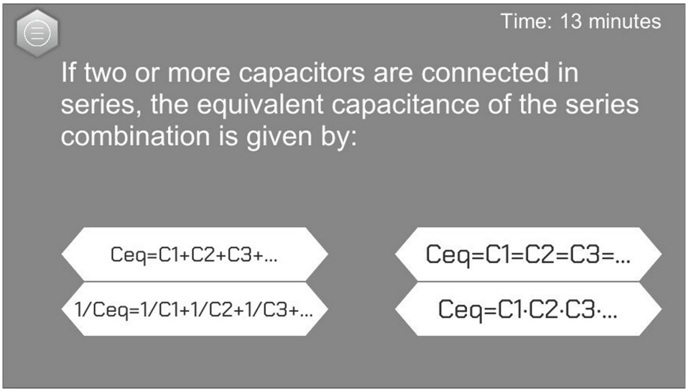


Fig. 4. Problem's scene

Figure 5 demonstrates the program in a test mode. The user can choose a specific topic and get a randomized set of questions. In the upper right corner, there is a time limitation displayed. The test allows checking the level of understanding the topic after the conducting the lab or solving the problem task. It helps to refresh the physical concepts and learned materials. The topics of the questions coincide with the topics of laboratory works and the problems. The total number of questions is 101, they are given to students randomly and have 4 different answers, only one of them is correct.

In Fig. 6 there is an animation scene screenshot. It is provided with the "Launch animation" button. It starts the animation that contains description of specific physical



Time: 13 minutes

If two or more capacitors are connected in series, the equivalent capacitance of the series combination is given by:

Ceq=C1+C2+C3+...

Ceq=C1=C2=C3=...

1/Ceq=1/C1+1/C2+1/C3+...

Ceq=C1·C2·C3·...

Fig. 5. Screenshot with a test question

process. The animations are dedicated to Dynamics, Kinematics, Statics, Electrostatics. The total amount of the animations is 30.

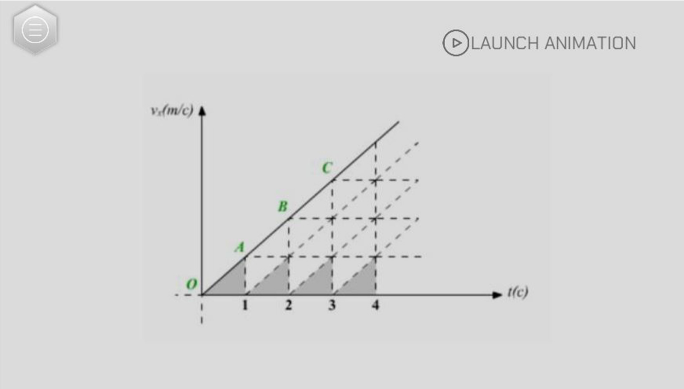


Fig. 6. Screenshot with an animation

Students can choose any of different modules of the application or perform all of them based on their preferences. Such approach improves the level of understanding and perception of information.

4 Evaluation

In order to approve the effectiveness of the application the following surveys were conducted. The participants were students of the 9th grade of the Republican Physics and Mathematical School. The total number of students was 24. The research was performed from September to December in 2019–2020 academic year. The first step of the study consisted of using the virtual laboratory in physics classes. Later in the end of December the students took part in the two types of surveys. The first one was general about evaluation of the usability of the virtual laboratory application. It was estimated based on the well-known method "Practical Heuristics for Usability Evaluation" [11]. This test consists of thirteen questions with the answers within the range from 1 (bad) to 7 (good). They are grouped into three sections: the first four questions relate to "Learning" (L1–L4), the next five questions relate to the quality of "Adapting to the user" (A1–A5), and the last four questions are about "Feedback and errors" (F1–F4). The hardware that was used for a demonstration of the application is a laptop HP Pavilion 15-ab017ur and controller Leap Motion. The operation system is Windows 10 x64, Intel Core i5-5200U, Intel HD Graphics 5500, graphic card NVIDIA GeForce 940 M. To provide correct work of the controller the Orion software was installed. The school equipment did not go under minimal technical requirements of the Oculus Rift HMD, that is why the desktop version was used.

The results of this survey are presented in the Table 1. The high values in each section show that the students are satisfied with the functionality, documentation and feedback provided within the virtual laboratory.

Table 1. The results of the usability evaluation questionnaire

Question	L1	L2	L3	L4	A1	A2	A3	A4	A5	F1	F2	F3	F4	Mean
Mean	6,4	6,3	6,3	5,8	3,9	5,8	5,9	6,2	6,7	5,2	5,8	6,2	6,2	5,9
Std. Dev.	5,5	0,6	0,6	0,7	0,7	0,1	0,8	0,6	0,5	1,4	0,9	0,6	0,6	0,7

On the other hand, from the Table 1 we can see the low values in the "Adapting to the user" section, which means that the students are less satisfied with this feature of the application. From the students' comments we can conclude that the application is missing such functionality like animations preview, the ability to go back to the previous step, or save the current state of the application.

The second survey was aimed at evaluating the user satisfaction. For this purpose, the standard questionnaire for User Interface Satisfaction was chosen [12]. The test is composed of thirty-two questions with answers in the range from 1 (bad) to 7 (good). The questions are grouped into six sections: overall reaction to the software (Impr1–Impr6), representation on the screen (Screen1–Screen4), terminology and system information (TSI1–TSI6), leaning (Learning1–Learning6), system capabilities (SC1–SC5) and usability and user interface (UUI1–UUI5). The original questionnaire was modified by reducing the number of questions to twenty-seven. The section of usability and user interface was removed, since these features were evaluated in the separate survey.

Table 2 presents the results of the answers evaluation. They show the students' positive attitude and the opinion about the laboratory. Separately, in the comments the students made several suggestions. The two most common suggestions were the following. The students would like to have a possibility to register in the system, so they could save the current progress with the practical tasks. Another suggestion was at the same time a disadvantage of the system. The students pointed out that not all visualizations of the practical tasks follow one style. All wishes and shortcomings marked by the students will be taken into account in the development of the next version of the program.

Table 2. The results of the user satisfaction evaluation questionnaire

Question	Mean	Standard deviation	Question	Mean	Standard deviation
Impr1	6,8	0,4	TSI5	4,4	0,5
Impr2	6,6	0,5	TSI6	4,4	0,5
Impr3	6,2	0,7	Learning1	6,6	0,5
Impr4	6,3	0,6	Learning2	6,4	0,5
Impr5	6,3	0,6	Learning3	5,9	0,7
Impr6	6,3	0,6	Learning4	6,7	0,5
Screen1	6,9	0,3	Learning5	6,6	0,5
Screen2	6,3	0,5	Learning6	6,6	0,5
Screen3	6,4	0,5	SC1	6,7	0,5
Screen4	6,4	0,5	SC2	5,5	0,7
TSI1	5,7	1	SC3	7	0
TSI2	6,5	0,5	SC4	5,8	0,7
TSI3	5,9	0,7	SC5	6,4	0,5
TSI4	6,4	0,5	Mean	5,9	0,5

Thus, the results of the conducted surveys indicate that the students are satisfied with the functionality and user interface of the virtual laboratory as an additional learning tool.

5 Conclusion

The paper showed the process of the research on the application of virtual reality technology in education, physics learning specifically. Also, the results of the survey among high school students about the efficiency of the developed software are presented. The process of interaction with the created program is shown and its components are described. The main conclusion of the article is that such type of education increases independent work of students, develop their analytical skills and the used technologies provide the better way of delivering the information.

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References

1. Sanders, B., Shen, Y., Vincenzi, D.: Understanding user interface preferences for xr environments when exploring physics and engineering principles. In: Ahram, T. (ed.) AHFE 2019. AISC, vol. 973, pp. 296–304. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-20476-1_30
2. Franklin, J., Ryder, A.: Electromagnetic field visualization in virtual reality. Am. J. Phy. **87**(2), 153–157 (2019). https://doi.org/10.1119/1.5080224
3. Beavis, A.W., Ward, J.W.: Innovation in education: computer simulation in physics training. In: 10th International Conference on 3D Radiation Dosimetry (IC3DDOSE) 1305(UNSP 012057). https://doi.org/10.1088/1742-6596/1305/1/012057
4. Morales, A.D., Sanchez, S.A., Pineda, C.M., Romero, H.J.: Use of augmented reality for the simulation of basic mechanical physics phenomena. Expotecnologia 2018 Research, Innovation and Development in Engineering 519(UNSP 012021) (2019). https://doi.org/10.1088/1757-899x/519/1/012021
5. Bolsee, Q., Bolsee, V.: A Fast water droplet sound simulation. In: 2018 International Conference on 3D Immersion. Brussels, Belgium (2018)
6. Sakamoto, M., et al.: A Study on applications for scientific experiments using the vr technology. In: 2018 International Conference on Information and Communication Technology Robotics (ICT-robot). Busan, South Korea (2018)
7. Pirker, J., Holly, M.S., Hipp, P., Koni, C., Jeitler, D., Gutl, C.: Improving Physics Education Through Different Immersive and Engaging Laboratory Setups. Int. Mobile Commun. Technol. Learn. **725**, 443–454 (2018)
8. Knierim, P., Kiss, F., Schmidt, A.: Look inside: understanding thermal flux through augmented reality. In: Adjunct Proceedings of the 2018 IEEE International Symposium on Mixed and Augmented Reality (2018)
9. Duer, Z., Piilonen, L., Glasson, G.: Belle2VR: A virtual-reality visualization of subatomic particle physics in the belle ii experiment. IEEE Comput. Graph. Appl. **38**(3), 33–43 (2018)
10. O'Connor, M., et al.: Sampling molecular conformations and dynamics in a multiuser virtual reality framework. Science Advances 4(6) (2018)
11. Perlman, G.: Practical Usability Evaluation. CH: Extended Abstracts on Human Factors in Computing Systems, ACM, 168–169 (1997)
12. Chin, J. P., Diehl, V. A., Norman, K. L.: Development of an instrument measuring user satisfaction of the human-computer interface. In: Proceedings of SIGCHI Conference on Human Factors in Computing Systems, pp. 213–218, ACM, New York (1988)