The development and use of mobile app AR Physics in physics teaching at the university

Arnold E. Kiv[1], Vladyslav V. Bilous[2], Dmytro M. Bodnenko[2], Dmytro V. Horbatovskyi[2], Oksana S. Lytvyn[2] and Volodymyr V. Proshkin[2]

[1]*Ben-Gurion University of the Negev, P.O.B. 653, Beer Sheva, 8410501, Israel*
[2]*Borys Grinchenko Kyiv University, 18/2 Bulvarno-Kudriavska Str., Kyiv, 04053, Ukraine*

Abstract
This paper outlines the importance of using Augmented Reality (AR) in physics education at the university as a valuable tool for visualization and increasing the attention and motivation of students to study, solving educational problems related to future professional activities, improving the interaction of teachers and students. Provided an analysis of the types of AR technology and software for developing AR apps. The sequences of actions for developing the mobile application AR Physics in the study of topics: "Direct electronic current", "Fundamentals of the theory of electronic circuits". The software tools for mobile application development (Android Studio, SDK, NDK, Google Sceneform, 3Ds MAX, Core Animation, Asset Media Recorder, Ashampoo Music Studio, Google Translate Plugin) are described. The bank of 3D models of elements of electrical circuits (sources of current, consumers, measuring devices, conductors) is created. Because of the students' and teachers' surveys, the advantages and disadvantages of using AR in the teaching process are discussed. Mann-Whitney U-test proved the effectiveness of the use of AR for laboratory works in physics by students majoring in "Mathematics", "Computer Science", and "Cybersecurity".

Keywords
complementary reality, mobile addition, physics, educational process, physics and mathematics education

1. Introduction

Today's realities suggest that most students studying university physics feel a certain tension and dissatisfaction. On the one hand, the weak level of school knowledge, as evidenced by the high school graduation examinations, is a factor. Thus, in 2020, only 9% of school graduates took the External Independent Examination in Physics. The average score on the External Independent Examination evaluation results is 138.4, which is much lower than many other school subjects [1].

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kiv.arnold20@gmail.com (A. E. Kiv); v.bilous@kubg.edu.ua (V. V. Bilous); d.bodnenko@kubg.edu.ua (D. M. Bodnenko); d.horbatovskyi@kubg.edu.ua (D. V. Horbatovskyi); o.lytvyn@kubg.edu.ua (O. S. Lytvyn); v.proshkin@kubg.edu.ua (V. V. Proshkin)
https://ieeexplore.ieee.org/author/38339185000 (A. E. Kiv); http://eportfolio.kubg.edu.ua/teacher/1308 (V. V. Bilous); http://eportfolio.kubg.edu.ua/teacher/244 (D. M. Bodnenko); https://fitu.kubg.edu.ua/pro-fakultet/komanda/763-1.html (D. V. Horbatovskyi); http://eportfolio.kubg.edu.ua/teacher/301 (O. S. Lytvyn); http://eportfolio.kubg.edu.ua/teacher/556 (V. V. Proshkin)
0000-0002-0991-2343 (A. E. Kiv); 0000-0001-6915-433X (V. V. Bilous); 0000-0001-9303-6587 (D. M. Bodnenko); 0000-0002-7828-4774 (D. V. Horbatovskyi); 0000-0002-5118-1003 (O. S. Lytvyn); 0000-0002-9785-06123 (V. V. Proshkin)

On the other hand, students' poor understanding of the discipline's meaning due to emotional non-acceptance of the teaching material and limited equipment in the laboratories of most Ukrainian universities [2]. This leads to the fact that many students do not understand the links between physical phenomena and processes and do not see the possibility of using physics to solve professional tasks and recognize the real world. One area of modernization of physics teaching in the university is the use of AR technology, which allows conducting physical experiments in the absence of the necessary equipment. AR provides an ability to move, wrap, zoom 3D models, view them under any object, combine and separate virtual objects, modeling of processes and phenomena, etc. Thus, complementary reality creates an atmosphere of excitement in problem-solving and in the environment of experimentation, helping to visualize complex processes and laws that are difficult or even impossible to achieve without special tools.

But at present, the use of AR in the process of physics teaching at the university is not systematic, and the majority of available mobile extensions or computer programs are limited to the school physics course. This makes the theoretical foundation of principles and approaches to the creation and use of AR at the high school level on the one hand; and, on the other hand, the development of apps with the material of a suitable level, and structure highly relevant.

The theoretical and practical aspects of teaching physics in the university are described by Bushuev et al. [3], Korobova et al. [4], Lozovenko et al. [5], Tsekhmister et al. [6], Velychko and Shulga [7], Zavrazhna et al. [8] and others. Particular attention to the improvement of methods of physical experimentation is paid by Boyes et al. [9], Han [10], Laouina et al. [11], Lu [12], Martyniuk et al. [13], Riggi et al. [14], Seliverstov et al. [15], Vallmitjana [16], Zhao et al. [17] and others.

Studies of the use of digital technologies in physics teaching deserve attention. Thus, Merzlykin [18] has developed a methodology for using digital technologies to develop research competencies of high school students in the process of professional education of physics.

Velychko [19] has substantiated the feasibility of using new state-of-the-art optics equipment and developed methods and techniques of performing demonstration and laboratory investigations on its basis combined with modern information technologies and computer devices for their implementation.

Velychko et al. [20] revealed the approaches and principles of virtual software support in the training of future physics teachers.

Recently, a number of studies have been implemented that reveal the potential of AR in the learning process. Thus, Blevins [21] examines the problem of enhancing students' digital literacy in the AR process. The author explores the use of one Augmented Reality (AR) software to support students composing AR and become familiar with concepts relevant to other composing occasions. He presents a scaffolded process involving analysis and composition, focusing instruction and discussion on the composing concept of the layer. Kurilovas [22] researched the quality evaluation and personalisation of virtual reality/augmented reality/mixed reality. Evaluation of quality of VR/AR/MR platforms/environments should be based on (a) applying both expert-centred (top-down) and user-centred (bottom-up) quality evaluation methods and (b) separating 'internal quality' criteria, and 'quality in use' criteria in the set of quality criteria (model).

Akçayır and Akçayır [23] identify the advantages and disadvantages of using AR in the educational process. Moreover, theoretical and methodological principles of using AR are given by Babkin et al. [24], Bacca et al. [25], Fidan and Tuncel [26], Kolomoiets and Kassim [27], Kramarenko et al. [28], Lavrentieva et al. [29, 30], Mintii and Soloviev [31], Nechypurenko et al. [32, 33], Palamar et al. [34], Petrovych et al. [35], Rashevska et al. [36], Rashevska and Soloviev [37], Semerikov et al. [38], Striuk et al. [39], Tarasenko et al. [40], Vakaliuk and Pochtoviuk [41], Zelinska et al. [42], Zinonos et al. [43] etc.

Recently, a low number of works have been implemented that show the use of AR as educational technology in the physics teaching process. Thus, the paper [44] states that introduction of the augmented reality technology in the training process at higher educational institutions increases learning efficiency, facilitates students' training and cognitive activities, improves the quality of knowledge acquisition, provokes interest in a subject, promotes development of research skills and a future specialist's competent personality. The methodology of use of the augmented reality for the development of a health-preserving competence of a physical education teacher under conditions of post-graduate education was improved in the study [45]. Specific theoretical and practical aspects of the use of AR in physics teaching can be found in the works of the Cai et al. [46], Fidan and Tuncel [47], Strzys et al. [48]. An analysis of these works allows us to conclude that AR increases students' physics and mathematics competence, stimulates their cognitive activity, supports organization of independent work, prompts experimental work, etc. The results are the basis for the implementation of our study.

This article *aims* to develop a mobile application AR from the university course of physics and experimentally test the effectiveness of its use in the process of professional students' training.

In the process of research, the following methods have been used:

- analysis of scientific and pedagogical literature on the theoretical foundations of using the supplemented reality in the process of teaching physics in the university;
- analysis of online resources, educational literature to enlarge the capabilities of the augmented reality, especially the disclosure of its varieties, and tools for developing AR apps;
- studying and consolidation of pedagogical experience in using AR in the educational process;
- pedagogical experiment to improve the efficiency of mobile AR app application in physics teaching as well as specifying of advantages and disadvantages of AR application by the teachers and students;
- mathematical statistics methods (Mann-Whitney U-criterion).

2. Results and discussion

Even though Augment Reality is a relatively new information technology, it has already gained popularity among educators and students in the university environment. The main factor contributing to its dissemination is that it is unnecessary to have costly special equipment (eyepieces, telescope, monitor, etc.) to work with AR. Use a smartphone or tablet with a cost-free app. The principle of AR is that text, photo, video, or other information is applied to real-world objects to supplement them.

An analysis of the scientific literature [49, 50] allows us to conclude that AR technology has these variations:

1. *Marker technology* (characterized by a connection to a certain object). Marker-assisted reality is based on the use of markers (targets) for content creation. Images and 3D objects can be used as markers. The unique features of this technology are the high coverage of mobile devices and the ease of use.
2. *Markerless technology* (often referred to as positioning technology). Markerless doped reality allows the use of any flat surfaces for content creation. This technology is limited by the capacity of mobile phones supporting this functionality. It works seamlessly with iPhone 6s and newer versions and newer Android devices.
3. *Projection technology* (projection of light onto physical surfaces). Special apps help to create an interaction between man and projection by determining the moments of human contact with the light being projected.

Each of these variants is used in the educational process depending on the availability of appropriate equipment and the development of teachers' and students' digital competence.

Today there are a significant number of libraries and frameworks for working with augmented reality technologies. Most of them are available with open source code [51]. Complement the information presented in the previous study [51] and highlight the most valuable tools for working with software and games in augmented reality, and note the main characteristics of such devices (table 1).

Table 1
Tools for developing AR apps

Library/framework	Graphics	Development software	Operating system
Vuforia	2D, 3D, OpenGL	Vuforia SDK, Android Studio, X Code, Unity, Unreal Engine, Tizen Studio	Android, Apple, Windows, Linux
Google Sceneform/ ARCore	2D, 3D, OpenGL	Android Studio, X Code, Unity, Unreal Engine, Tizen Studio, 3Ds Max, Blender	Android, Apple, Windows, Linux
ARToolKit	2D, OpenGL	Android Studio, X Code, Unity, Unreal Engine, Tizen Studio, 3Ds Max, Blender	Android, iOS, Windows, Linux, Mac OS X, SGI
Wikitude	2D, 3D, OpenGL	Android Studio, X Code, Unity	Android, iOS
LayAR	2D, 3D, OpenGL	Android Studio, X Code, Unity	Android, iOS

In September and October of 2019, we assessed 15 experts – teachers of mathematics, informatics, and physics at the Borys Grinchenko Kyiv University, the Sumy State Pedagogical University named after A.S. Makarenko, and the Uman State Pedagogical University named after Pavlo Tichyny. As a result of summarizing the respondents' thoughts, we identified the benefits of using AR in the educational process. We believe that these advantages will be a guideline for the development and implementation of the mobile AR app:

1. Evidence (the main point is that the AR system can be studied and investigated in detail, from different angles).
2. Attention (students are more receptive to information that is more visualised).
3. Detachment (students who use AR are more focused on the teaching material and do not get distracted by other external factors).
4. Controllability (AR is a technology that allows the teacher to control the scenario of learning the material according to the students' abilities, the pace of learning the material, the errors that occur in the learning process, etc.).
5. Safety (the AR technology can be used to carry out complex physical, chemical and other experiments in a safe manner).
6. Effectiveness (implementation of the educational process with the help of AR increases the motivation of students, is practically oriented and acts as a guarantor of educational quality).

Summarizing the respondents' answers, we hypothesize that AR increases students' attention and motivation to the learning material, makes learning more rewarding and effective, links the solution of learning tasks with real experience and future professional activity, enhances the interaction between teachers and students, etc.

Moreover, the results of previous experimental studies by the authors of the article [51, 52, 53] indicate the effectiveness of the educational process with the use of augmented reality tools. We strongly believe that special attention should be paid to AR when studying natural and mathematical disciplines in the university (mathematics, physics, chemistry, information technology, etc.). In the context of distance education, which outweighs traditional full-time education, and insufficient level of equipment and materials in the university experimental laboratories AR technology itself can significantly affect the quality of university training of students of natural and mathematical and technical specialties.

Physics disciplines are usually experimental disciplines and involve practical and laboratory work. The article authors' experience in teaching physics shows that the use of devices of augmented reality and simulator programs aims to ensure understanding of physical phenomena and enable demonstration of the essence of physical processes, which are the basis for the study of these disciplines.

At the current stage of the development of network technologies, especially at a time of active and total adoption of distance learning technologies (through LMS, MOOCs, educational services), rapid growth is taking place [54]:

- simulators (e.g. https://phet.colorado.edu, https://learning.ua/);
- virtual laboratories (e.g. https://stemua.science, http://modelscience.com/products.html);
- augmented reality learning environments (e.g. http://www.arloon.com/),
- adaptive learning systems (e.g. https://cerevrum.com/),
- gamified applications (e.g., "Passcode" [55]), etc.

These AR resources and tools create an environment in which students become active participants in the physics learning process.

Practice shows that the use of AR technologies and simulations improves students' conceptual understanding of physical processes. For example, the simulator can be an effective intuitive tool for students to create working models of electric cells with an explanation of the nature of electrical phenomena. Besides, AR contributes to the development of logical and critical thinking of students, which can understand the nature of physical phenomena and processes. The work with AR must be independent of the time and and geographical concept, which becomes particularly important in the conditions of distance learning.

In order to ensure the quality of physics teaching and increase students' interest, we solved the task of developing and using AR tools in the educational process.

1. To develop the mobile app, we used the following tools:
   - Android Studio (an integrated environment for the Android platform), SDK (a set of tools for developing utilities and documentation, which allows you to create apps for a particular technology or platform) and NDK (a set of tools allowing implementation of apps using languages such as C/C++/C# to adapt the app to various devices and to optimize the code);
   - Google Sceneform (ARCore, Sceneform Animation) is a library and framework for the visualisation of 3D models on controllable devices;
   - 3Ds MAX environment for developing 3D models (in our case, we use specific extensions to visualize models, mathematical description, and to animate elements of the model);
   - Core Animation (a library for the animation of 3D objects for augmented reality);
   - Asset Media Recorder (a library for working with sound in the Android Studio environment);
   - Ashampoo Music Studio (music, sound and voice recording software);
   - Google Translate Plugin (text translation plugin).

   The authors' experience in developing apps allowed to use markerless technology of augmented reality and intrinsically relocate 3D objects. 3D models of objects in the 3Ds MAX environment are shown in figure 1, 2.
2. The next step of the research was the import of the model and its rendering in the Android Studio environment, which allowed us to create a mathematical description of the model through the tools ARCore, Google Sceneform and Core Animation (figure 3).
3. Having analyzed some AR apps in official digital markets, we decided to develop an audio accompaniment of augmented reality models to explain the material. For this, we used Ashampoo Music Studio to record the voice narration and Asset Media Recorder to import and connect the audio to 3D models (figure 4). Currently available languages: Ukrainian, Russian, English, Slovak, Italian. Up to 30 languages are planned for future versions.
4. A standard MediaPlayer library is connected for the audio software description (figure 5).
5. A plugin was included so that users of different languages could use the addendum.
6. The next step was to write the code for processing the sub-action and visualization with the connection of the system libraries to work with the smartphone. After ad-hoc testing of the app, a 3D model bank with explanations was created. It should be noted that the AR Physics tool can work on different platforms (Windows, Android) and devices (mobile phone, smartphone tablet, laptop, desktop PC), see figure 6.

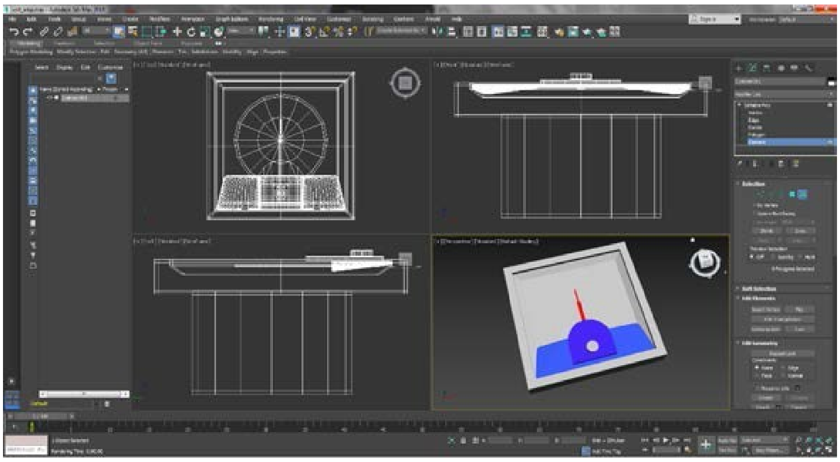

Figure 1: 3D Model of a voltmeter.

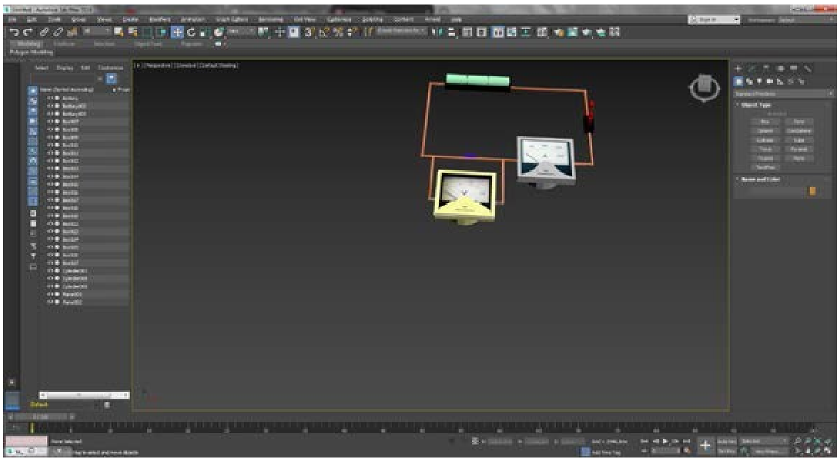

Figure 2: 3D Model of the implementation of the physical experiment.

The mobile AR Physics app focuses on teaching material using virtual laboratory experiments. It can be used to create electrical circuits and their upgrading, carried out virtual studies of the electric boiler at different values of indicators of the devices. Moreover, the AR Physics tool can serve as an intuitive and understandable game simulation with a set of the most popular elements of the electric boiler. The principle difference between this game and its existing analogs is that the characteristics of the electric components and the essence of physical phenomena and processes occurring in an open (or closed) electric stake are thoroughly explained.

AR Physics (at this stage of development) is suitable for the following topics:

- "Constant Electricity" of the module "Electricity and Magnetism" (used in the laboratory works on themes: "Ohm's Law", "Laws of series and parallel connection of conductors");
- "Fundamentals of the Theory of Electronic Circuits" of the module "Logic Circuits" (used in the framework of the laboratory work on the themes: "Fundamentals of Electricity",

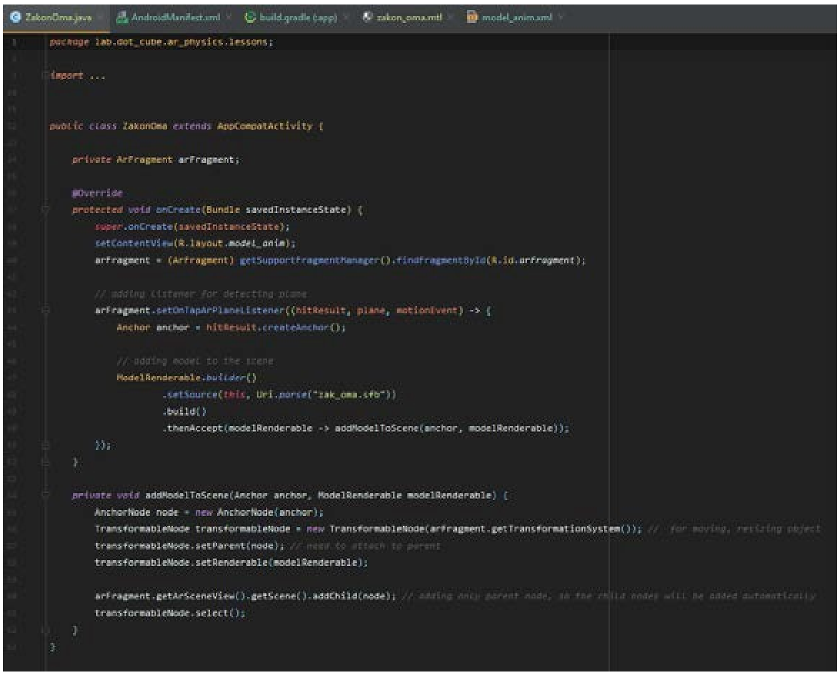

Figure 3: 3D model description and rendering code.

Figure 4: Software for professional recording, sound editing.

"Ohm's Law").

Implementation of the AR technology using the developed addendum was carried out at the Borys Grinchenko Kyiv University during the second semester 2019–2020 and the first semester 2020–2021 (January, March, September 2020 – full-time, other – distance learning). There were 93 students of the specialties "Computer Science", "Cybersecurity" and "Mathematics". In March 2020, the students were surveyed to find the advantages and disadvantages of using AR in

```java
package lab.dot_cube.ar_physics.sounds;    BelRoy, 14.01.2021 16:28 • basics

import ...

public class MainTheme extends Service {
    MediaPlayer player;

    @Override
    public IBinder onBind(Intent intent) { return null; }

    public void onCreate() {
        player = MediaPlayer.create(this, R.raw.maintheme);
        player.setLooping(true);
    }

    public int onStartCommand(Intent intent, int flags, int startId) {
        player.start();
        return Service.START_NOT_STICKY;
    }

    public void onDestroy() {
        player.stop();
        player.release();
        stopSelf();
        super.onDestroy();
    }

}
```

Figure 5: Code for the creation of an audio accompaniment service.

physics teaching (you could choose any variants out of 10 offered or not select any).

The following results were obtained, ranked in descending order of respondents' votes by the number of respondents (figure 7).

According to the survey results, students find all of the AR characteristics we have suggested to be significant. Still, the most important are: providing a sense of reality (76 votes), an exciting learning experience (73 votes), time-saving, and space-saving (72 votes).

Among the shortcomings, students cited mainly technical problems related to the characteristics of smartphones, tablets or lack of access to fast Internet.

In addition, we contacted expert teachers who identified these problems with the use of AR:

- Lack of digital competence, which prevents the full use of AR tools in the teaching process;
- The inadequacy of teaching methods using AR;
- The limited amount of didactic material based on the use of AR.

As an analysis of the use of our addendum shows, the didactic materials, enriched with the possibility of AR, have a low advantage:

- The teaching methodology needs only correction, not a radical overhaul;
- The educational tools to which participants are accustomed do not change, but their possibilities are greatly enhanced.

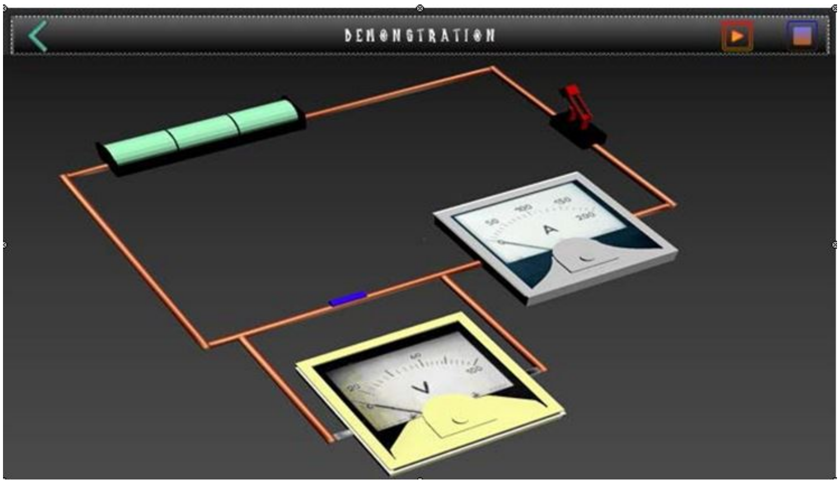

Figure 6: The animated model in the illuminator.

To determine the impact of AR Physics on the educational achievements of the students, we compared the results of laboratory works with the AR Physics tool (experimental group of 45 students) with the results of laboratory works, without AR (control group of 48 students). There were requested 4 laboratory works with maximum number of points – 40. The results of the students' laboratory works in physics are shown in figure 8.

The Mann-Whitney U-criterion is $U_{emp} = 109.5$. Since $U_{emp} < U_{cr1}$ (critical values $U_{cr1} = 706$ and $U_{cr2} = 845$) we accept the hypothesis of statistical validity of the difference in students' learning results of the experimental and control groups. Of course, it is too early to say that the very use of Augmented Reality affects the quality of students learning. In our opinion, Augmented Reality should be used in combination with other helpful tools, such as virtual laboratories, software simulators of physical experiments, etc. But the fact that Augmented Reality is an effective means of implementing the educational process in the current problems (lack of laboratory equipment, forced distance learning in a pandemic, low interest of students in physics) there is no doubt. An analysis of the use of mobile AR Physics app shows its usefulness for distance learning, especially for laboratory work. In face-to-face teaching, it is an effective means of adding reality to explaining theoretical material in lectures and practical exercises.

3. Conclusions

The article informs about the actuality of AR application in teaching physics in the university as the active tool for visualization of ideas about dynamics and interaction of physical phenomena processes, which influences students' comprehension of physics through emotional acceptance of educational material. A mobile AR Physics app has been developed, which enables virtual laboratory work. It can be used to create electrical circuits and modernization, conducting virtual studies of the electronic circuit at the different values of the devices. In addition, the AR Physics tool can serve as an intuitive game simulation with a set of the most common elements of the electrical circuit. The following tools were used to develop the mobile application: Android

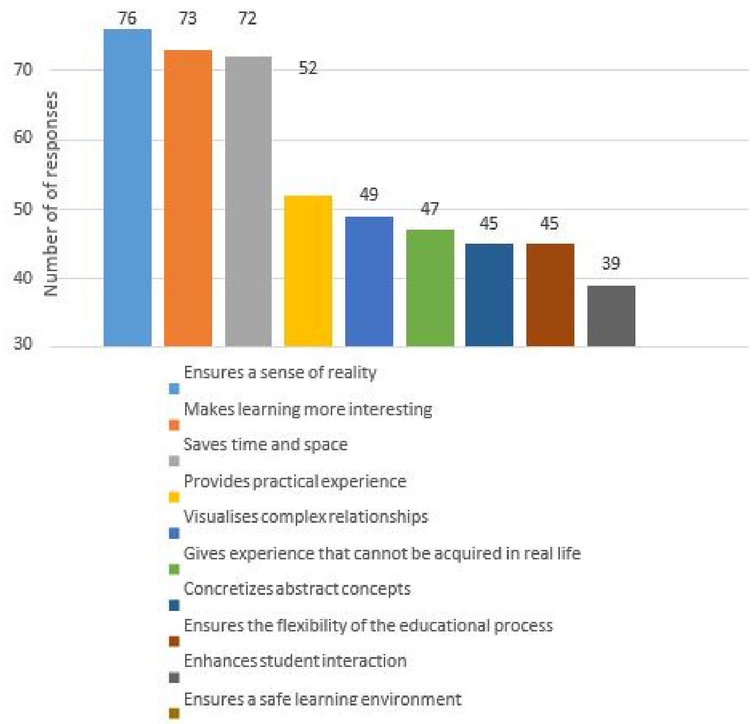

Figure 7: Benefits of AR in physics teaching.

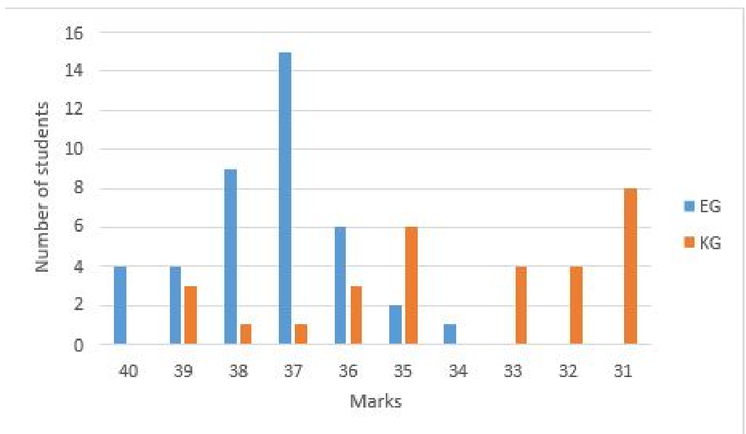

Figure 8: Results of students' laboratory work in physics

Studio, SDK, NDK, Google Sceneform, 3Ds MAX, Core Animation, Asset Media Recorder, Ashampoo Music Studio, Google Translate Plugin. The sequence of actions for the development of a mobile application is presented. The main difference between it and existing analogs is its rich voice of the characteristics of electrical elements and the essence of physical phenomena and processes. A bank of 3D models of elements of electrical circuits (power sources, consumers, measuring devices, conductors) was developed.

As a result of the use of the mobile AR Physics app in the study of topics: “Direct electronic current”, “Fundamentals of the theory of electronic circuits”, advantages of AR in the educational process (ensuring a sense of reality, increasing student engagement, saving time and space, etc.) and disadvantages of AR (insufficient development of digital competence, inadequate teaching methods, limited didactic material, etc.) have been identified. The main reasons for this are the lack of a real sense of reality, increased student engagement, savings in time and space, etc.) and AR disadvantages (insufficient development of digital competence, inadequate teaching methods, limited didactic material, lack of technical capabilities of gadgets, absence of broadband Internet, etc.). The analysis of students’ learning outcomes has confirmed the effectiveness of using AR Physics in the educational process. The Mann-Whitney U-criterion was used for this purpose. Prospects for further research lie in the expansion of the tools of AR Physics, its implementation in the educational process in the study of various sections of physics (e.g. “Nature of Light. Optics”).

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