Development of AR-applications as a promising area of research for students

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Abstract. The article substantiates the importance of using augmented reality in the educational process, in particular, in the study of natural and mathematical disciplines. The essence of AR (augmented reality), characteristics of AR hardware and software, directions and advantages of using AR in the educational process are outlined. It has proven that AR is a unique tool that allows educators to teach the new digital generation in a readable, comprehensible, memorable and memorable format, which is the basis for developing a strong interest in learning. Presented the results of the international study on the quality of education PISA (Programme for International Student Assessment) which stimulated the development of the problem of using AR in mathematics teaching. Within the limits of realization of research work of students of the Borys Grinchenko Kyiv University the AR-application on mathematics is developed. To create it used tools: Android Studio, SDK, ARCore, QR Generator, Math pattern. A number of markers of mathematical objects have been developed that correspond to the school mathematics course (topic: "Polyhedra and Functions, their properties and graphs"). The developed AR tools were introduced into the process of teaching students of the specialty "Mathematics". Prospects of research in development of a technique of training of separate mathematics themes with use of AR have been defined.

Keywords: augmented reality, mobile application, math, student research, computer science.

1 Introduction

As practice shows, the traditional forms and methods of realization of educational process, which was effective for another 10–20 years ago do not always work efficiently in today's digital realities. Today's youth, who are accustomed to routinely working with mobile technology and gadgets, which provide excellent visualization of the phenomena and processes of the environment [8; 24; 28; 29], is faced with a situation of extremely limited use of digital technologies in the educational process. Occurs a significant contradiction – the powerful technological, methodological and didactic tools through which students learn about the world outside of the educational process are not actually used in school. However, the results of international studies of

education quality PISA by 2018 [13] described a disappointing picture of the Ukrainian school education: the level of mathematical and scientific literacy among high school students is assessed lower than average.

Improving the quality of school readiness, we see in the skillful implementation of digital technologies in the educational process, the harmonious combination of the latest technology with the best practices of traditional high school. In addition, the powerful capabilities of digital technology, for example, in the context of visualization of the educational material using AR can increase the interest of pupils to learn, especially in the context of the study is not popular enough now subjects of natural science and mathematical area. Therefore, training of future teachers to the development and use of digital technologies in professional activity is considered an important task of modern higher education.

2 Literature review

Recently, a number of studies have been carried out outlining various aspects of the use of AR in educational and scientific processes. Thus, H. Kravtsov, P. Nechypurenko, V. Potkonjak and A. Striuk described the directions of work of virtual laboratories for education in science, technology, and engineering [9; 18; 20; 25]. S.-C. Chang and G.-J. Hwang revealed the possibilities of using AR in student research and substantiated the benefits of augmented reality-based educational process [4; 6]. D. Furió et al. carried out a comparative analysis of mobile learning (including AR technology) with traditional [5]. E. Kurilovas, O. Lavrentieva and V. Tkachuk considered the use of VR, AR and MR in the educational process [11; 12; 30]. In the study of M.-B. Ibáñez, S. Delgado-Kloos, theoretical and methodological foundations of the use of AR for the organization of STEM learning were revealed [7]. M. Shyshkina disclosed augmented reality as a tool for open science platforms by research collaboration in virtual teams [22]. N. Rashevska, A. Striuk, Yu. Yechkalo and S. Zelinska explored the methods of using AR in training engineering students [21; 26; 31; 32]. O. Merzlykin et al. outlined the problem of developing key competencies in the application of AR [14]. S. Semerikov and others presented a historical and pedagogical excursion of the use of AR in educational and scientific activities [27], etc. The problem of developing applications for AR has become the subject of research by a number of scientists, with particular attention to the researches of L. Midak et al. for the development of primary school applications [16; 17;].

Noteworthy are the scientific explorations on the use of various aspects of AR in the process of mathematics teaching: S. Shokaliuk and H. Sollervall – implementation of mobile mathematics teaching [15; 23], K.-E. Chang and L. Bilousova – the use of game techniques in teaching mathematics [3; 19], K. R. Bujak – research of psychological aspects of mathematics training [2], K. K. Bhagat and T. H. Kramarenko – application of GeoGebra for teaching geometry [1; 10] and others.

3 Research methodology

The purpose of the article is to discover the possibilities of using augmented reality technologies in education and to develop a mobile augmented reality application for teaching mathematics.

In the course of the research the following methods were used: analysis of the scientific and pedagogical literature on the separation of theoretical foundations of the use of augmented reality in the educational process; analysis of online resources, methodological literature on generalization of augmented reality opportunities and benefits; study and generalization of pedagogical experience on the use of augmented reality in the educational process; a survey on the effectiveness of augmented reality tools in the educational process.

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4 Results and discussion

Augmented Reality (AR) is a technology that uses fixed or mobile camera devices (smartphones, tablets, AR glasses, etc.) to enrich the real world with computer content. Unlike Virtual Reality (VR), which ensures complete immersion of a person in a virtual space, AR lets you superimpose on top of environmental virtual information (graphics, video, sound and so on). That is actually augmented reality can be viewed as a complement to the physical world with digital data in real-time.

In order to establish a link between the real world and computer content, you need to read the Image Target (marker) and link coordinate systems of the real (recorded) and to imaginary computer content.

Under the marker is usually understood as the object of a special image (e.g., QR code), which is located in the surrounding space. It’s analyzed by special software for further reproduction of virtual objects. The program is using the camera receives information about the set-another marker in space and projects it on a virtual object that simulates the effect of his presence in the surrounding space. It should be noted that the program shows the programmed result when the sensor for-a system reads the marker. This makes it possible to distinguish virtual objects from the real world. So, the app works on the principle of detection of markers. They are used as the basis for creating the computer system of coordinates through which to display augmented reality. For convenience, the markers can be plotted on a sheet of paper or presented on a computer screen.

Typically, researchers use various algorithms of image recognition in accordance with the markers, which can vary greatly. So, markers can be three-dimensional figures, and even the eyes or the face of a man. If you use high-quality models and additional graphics filters, you can achieve that the virtual object will become almost real and difficult to distinguish from the surrounding interior.

Today in the pedagogical literature allocate the various areas of research AR. The first direction is connected with studying of VR and AR technologies as a trend in the information technology industry, the basics of creating applications. The second area is the pedagogical design of learning tools based on the technology of virtual and augmented reality. Third is selection and experimental validation of organizational and pedagogical conditions and methods of effective use of AR in the educational process.

Hardware components for augmented reality is the CPU, display, sensors and input devices. Augmented reality types of devices used can be divided like this:

- HMD (head mounted display) – unit which is fixed on the head of the user and gives the opportunity to see the image of the virtual, augmented or mixed (hybrid reality MR as synthesis, VR and AR), creating a maximum effect of the presence;
- mobile device that has more computing power, various sensors, make this device suitable platform for augmented reality; the display of the mobile device implements profound methods of superimposing graphics on the real scene, in the general case is called a portable or handheld augmented reality display (handheld displays);
- personal computer, which in the presence of a web camera allows the user to see themselves when interacting with virtual objects;
- video projector, an optical element, a hologram, etc. means to overlay graphical information of the physical real objects without the need for a person to wear or hold the display; this means they form the so-called spatial augmented reality. Note that the choice of a particular device depends on the specific goals and objectives of using AR.

In addition to the considered marker AR technology (or image recognition), there are the following types of augmented reality:

- markerless AR uses technologies such as GPS – global positioning system, compass, speed sensor, gyroscope and accelerometer to provide information in accordance with the position of the user. Sometimes this technology is also called a base axis coordinate or GPS-axis. Thanks to the massive use of smartphones and tablets this technology is quite popular (for example, refer to directions in the process of finding the location of objects on the map);
- projection AR, which involves the design of artificial light on an object (physical surface) and allows it to interact with it (called holograms);
- AR-based overlay that allows you to completely or partially replace the original object with an enlarged one. This technology is considered to be the most promising area of AR development.

There are various augmented reality libraries available today that you can use to create your own application. Let's highlight the ARToolkit library, the first and most popular open source augmented library. This library has a number of sub-libraries. An ARTag sub-library, has sophisticated marker search algorithms that allow you to find markers more efficiently, even with variable lighting and minor bends or overlaps of the marker. In addition, the ARToolkit library has many sub-libraries written in a specific programming language, such as NyARToolkit for Java and JSARToolkit for

JavaScript. Therefore, the choice of application development tools, as well as display devices, depends on the ease of use of certain libraries when solving a particular problem.

Table 1. Summarizes the augmented reality libraries [27].

AR-Framework	Company	License	Platform Support
Vuforia	Qualcomm	Free and paid	Android, iOS, Unity
ARToolkit	DAQRI	Free	Android, iOS, Windows, Linux, macOS
Kudan	Kudan Limited	Paid	Android, iOS, Unity
Wikitude	Wikitude GmbH	Trial and paid	Android, iOS, Web
EasyAR	VisionStar Information Technology	Free	Android, iOS, Windows, Linux, macOS, Web

Augmented reality has a significant, but not yet up to the end opened potential for use in the educational process of institutions of secondary and higher education. However, the experience of the authors regarding the use of AR in educational process allows highlighting the benefits of such use:

1. *Visibility*. Any object or process that is created by using AR it is possible to study the detailed, under different angles.
2. *Concentration*. A person that uses AR focuses on the material study and is not distracted by other external stimuli.
3. *Manageability*. AR allows the educator to fully control and change the learning scenario according to the students' abilities, the problem solving process, and the like.
4. *Safety*. With AR technology it is possible to conduct experiments in a safe mode.
5. *Effectiveness*. Sufficient motivation of pupils and students to study a discipline using AR is the guarantee of quality education.

To date, scientists have developed a many of programs for the use of augmented reality technology in mathematics, physics, chemistry, biology, astronomy, foreign languages, etc. Consider some of the AR applications for implementation of the educational process in mathematics. So, the "Academy of intellectual development SMARTUM Ukraine" developed a mobile application with augmented reality for the course "Mental arithmetic". In addition, it is worth highlighting the application of 3D Graphics GeoGebra that allows you to create geometric constructions in 3D, save and share your results. The program allows you to create 3D objects, to build section and find the point of intersection. Among the programs that also let you work with 3D models in augmented reality for basic geometric shapes is to provide the following: Geometry – Augmented Reality, AR Geometry Geometría – Realidad, Aumentada, CleverBooks Geometry, ARGEO so forth. At the same time, it should be noted that it is still underdeveloped remains the development of AR programs for learning algebra.

We have a deep belief that AR allows better actors learning to absorb information, store it in large volumes. Contribute to this are highlighted above the benefits of AR, which promote increase of interest of students to academic discipline, development of creativity, and the like. Thus, AR is actually acts as a kind of unique tool set that allows teachers to present learning material for the new "Digital Natives" in convenient for perception, understanding, learning and memorizing the format that is the basis of formation of steady interest in learning.

It is clear that the development of the content, forms and methods of realization of educational process using AR is an important task of modern researchers-methodologists. We believe that special emphasis should be placed on the use of AR in the study of natural and mathematical disciplines, in particular, mathematics. The importance of the outlined task has been driven by the disappointing results of the 2018 International PISA Education Survey [13]. This study, which was launched by the Organization for Economic Cooperation and Development (OECD) for over 20 years, is one of the most respected sources of information on secondary education in the world. To date, more than 80 countries are participating in the study. Government officials trust the PISA results and use them to adopt sound education development strategies and tactics. Detailed information on the results of educational achievements of Ukrainian 15-year-old teens in mathematics, which were rated lower than average, outlined a number of problems:

- Students are mostly only able to answer mathematics questions about a known context where information is provided in full and the question is clearly formulated.
- Students are only able to perform simple procedures, such as arithmetic operations, according to direct instructions in obvious situations.

The obtained results of an international study of the quality of education PISA [13] allowed us to draw attention to the problem of development and use of AR in learning mathematics. In fact, we see AR technology as a means of improvement of mathematical training of students.

Given that one of the most important components of professional training of students is the research work, we were set the task of developing AR-applications of mathematics in the research activities of CS-students at Borys Grinchenko Kyiv University.

The key to the implementation of such assignments were made by the following methodological principles:

- Augmented reality in the study of mathematics, first of all, helps to visualize mathematical objects (geometric shapes, bodies of function graphics, etc.). Let's notice also that the augmented reality in the course of studying of mathematics gives such possibilities, as moving, rotation, scaling of 3D-models, their consideration under any angles, connections and disconnections of virtual objects and studying of the received results and so forth;
- The research work of students is a mandatory, integral part of professional training at the university. Development of students' research work system is the most

important function of the educational system and important statutory activity of the university as an educational institution.

Despite the above advantages of augmented reality in the educational process, denote the number of weighty issues. First, remain insufficiently developed techniques of using AR. Second, the existing limitations in methodological and didactic literature on the implementation of learning through AR technology. Third, the significant lack of AR – applications of mathematics as learning tools. The problem of the limited teaching facilities, we partially tried to solve by attracting students to design their own augmented reality object using specialized software. Note that this activity has a pronounced interdisciplinary character, because it promotes effective integration of such industries as information technology and mathematics.

To develop the application used the following tools:

- Android Studio (the IDE for Android platform) and the SDK (a set of development tools, utilities and documentation that allows you to create application programs on a particular technology or platform-specific);
- ARCore (set to develop software from Google that allows you to build apps AR);
- QR Generator (a tool for creating QR codes);
- Pattern Math (library of the mathematical models).

Let's present the code of the program for rendering of the image in AR space (fig. 1).

The next step in organizing the research work of computer science students was to develop a bank of models that fit the school math course. We chose two topics: polyhedra for grade 11, as well as functions, their properties and graphs for grade 10. What caused the choice of these topics? Polygons are known to be the central subject of stereometry training, which has a variety of material for the development of spatial representation, imagination combined with logic, and the like. Considering that one of the main tasks of mathematics teaching is the formation of abstract thinking students, it is necessary to pay attention to such important aspects of mathematics teaching as making connections between a function that is given in analytical and graphical form, plotting functions by means of transformations, etc.

In fig. 2, you can see examples of our developed QR code images to display augmented reality models.

The developed application and markers for it were tested by students of the specialty "Mathematics" of the Borys Grinchenko Kyiv University during December 2019 - February 2020 within the study of the discipline "Methods of teaching mathematics". Users were offered a printed set of algebra and geometry problems containing AR markers. Capturing the camera turned on when you started the app on your mobile device. The user points the camera at a task so that the marker is within the camera's viewing area, a three-dimensional object, which is a visualization of the mathematical task, is displayed on the screen. Examples of images obtained with markers (fig. 2) are shown in fig. 3, 4.

As the analysis of the use of the application developed by us in the process of studying the discipline "Methods of teaching mathematics" shows, didactic materials enriched with AR have a number of advantages:

- the teaching methodology only needs correction, its cardinal revision is not required;
- paper manuals used by the participants in the educational process are not canceled, but their capabilities are significantly expanded;
- the features of traditional paper educational materials are increased in the direction of presenting information through text, three-dimensional animation and sound, etc.

```
public class MyARNode extends AnchorNode {

    private AugmentedImage image;
    private static CompletableFuture<ModelRenderable> modelRenderableCompletableFuture;

    public MyARNode(Context context, int modelid)
    {
        if (modelRenderableCompletableFuture == null)
        {
            modelRenderableCompletableFuture = ModelRenderable.builder()
                    .setRegistryId("my_model")
                    .setSource(context, modelid)
                    .build();
        }
    }
@SuppressLint("NewApi")
public void setImage(final AugmentedImage image){
        this.image = image;
        if (!modelRenderableCompletableFuture.isDone()){
            CompletableFuture.allOf(modelRenderableCompletableFuture)
                    .thenAccept((Void aVoid)-> {
                        setImage(image);
                    }).exceptionally(throwable -> {
                        return null;
            });
        }
        setAnchor(image.createAnchor(image.getCenterPose()));

    Node node = new Node();
    Pose pose = Pose.makeTranslation(0.0f, 0.0f, 0.25f);

    node.setParent(this);
    node.setLocalPosition(new Vector3(pose.tx(),pose.ty(),pose.tz()));
    node.setLocalRotation(new Quaternion(pose.qx(),pose.qy(),pose.qz(),pose.qw()));
    node.setRenderable(modelRenderableCompletableFuture.getNow(null));

    }

    public AugmentedImage getImage() {
        return image;
    }
}
```

Fig. 1. Image rendering code in AR.

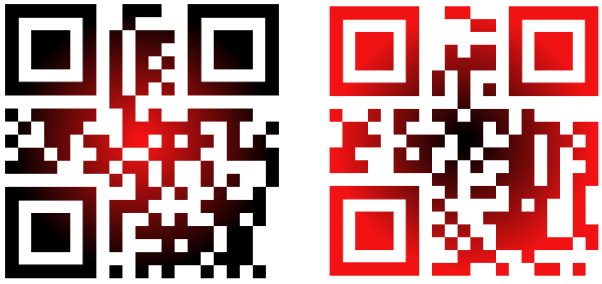

Fig. 2. Specially created labels for reading information.

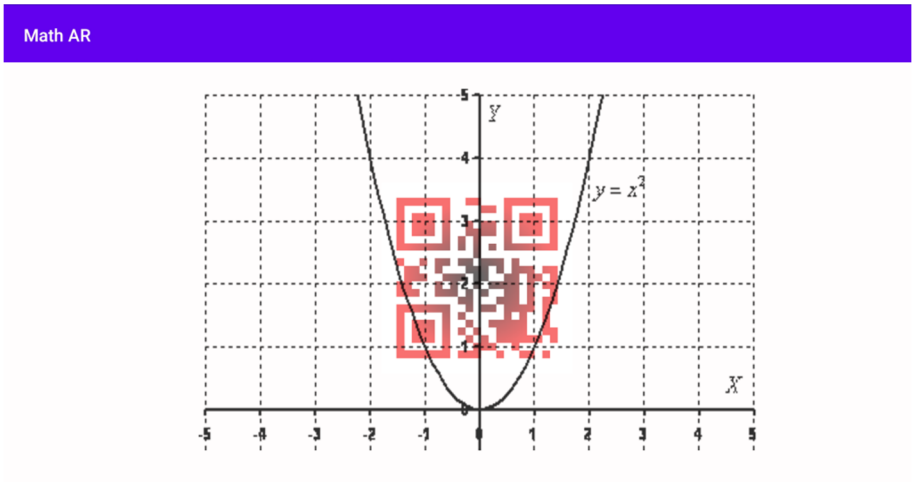

Fig. 3. Parabola in the application, polygonal view.

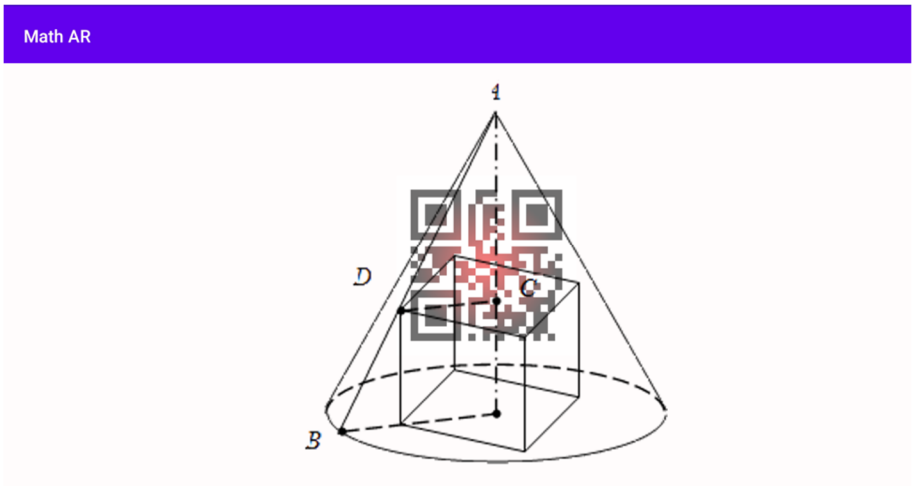

Fig. 4. The parallelepiped is inscribed in a cone in the application, polygonal view**.**

In April 2020, the application developed by us was proposed for testing to 114 individuals, namely: 52 students of 10th grade, 38 students of 11th grade, and 24 students of higher education institutions. All respondents are students of different schools and courses in programming in Kyiv. The survey found that 94 people were comfortable using the app. However, only 48 students are sure that they would like to have augmented reality subjects. This may be due to the fact that the vast majority of respondents do not yet have experience in using AR in the educational process. This clearly indicates that the problem of organizing the educational process with AR requires further scientific and methodological research.

5 Conclusions

As a result of separation of essence, technical and software, directions of use of AR, the advantages of using AR technology in the educational process (clarity, focus, controllability, safety, efficiency) are established. It is proven that AR is a unique tool that allows educators to teach the new digital generation in a readable, comprehensible, memorable and memorable format, which is the basis for developing a strong interest in learning.

The results of an international study of the quality of PISA education have become the basis for the development of the problem of using AR in the process of teaching mathematics. Within the limits of realization of research work of students of the Borys Grinchenko Kyiv University of the AR-application on mathematics was developed as an important component of their professional preparation. To create it, you have used the following tools: Android Studio, SDK, ARCore, QR Generator, Math pattern. A number of math markers have been developed to fit the school's math course (Topics: Polyhedra and Functions, Their Properties, and Graphs). Surveys of people who tested the application (students of the specialty "Mathematics" of Borys Grinchenko Kyiv University and Internet users) received positive feedback.

The prospect of further research is seen in the development of a methodology for teaching specific topics in mathematics using AR.

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