

Exploring the Potential of Augmented Reality for Teaching School Computer Science

Vasyl Oleksiuk¹ [0000-0003-2206-8447] and Olesia Oleksiuk² [0000-0002-1454-0046]

¹ Ternopil Volodymyr Hnatiuk National Pedagogical University
2 M. Kryvonosa St., Ternopil, Ukraine
oleksyuk@fizmat.tnpu.edu.ua

² Ternopil Regional Municipal Institute of Postgraduate Education
1 V. Hromnytskogo St., Ternopil, Ukraine
o.oleksyuk@ippo.edu.te.ua

Abstract. The article analyzes the phenomenon of augmented reality (AR) in education. AR is a new technology that complements the real world with the help of computer data. Such content is tied to specific locations or activities. Over the last few years, AR applications have become available on mobile devices. AR becomes available in the media (news, entertainment, sports). It is starting to enter other areas of life (such as e-commerce, travel, marketing). But education has the biggest impact on AR.

Based on the analysis of scientific publications, the authors explored the possibilities of using augmented reality in education. They identified means of augmented reality for teaching computer science at school. Such programs and services allow students to observe the operation of computer systems when changing their parameters. Students can also modify computer hardware for augmented reality objects and visualize algorithms and data processes. The article describes the content of author training for practicing teachers. At this event, some applications for training in AR technology were considered. The possibilities of working with augmented reality objects in computer science training are singled out. It is shown that the use of augmented reality provides an opportunity to increase the realism of research; provides emotional and cognitive experience. This all contributes to engaging students in systematic learning; creates new opportunities for collaborative learning, develops new representations of real objects.

Keywords: augmented reality, mobile learning, school computer science, augmented reality applications.

1 Introduction

Today, the topical areas of research for scholars in education are the didactic potential of digital technologies and methods of their application. Modern digital tools create opportunities to complement real space with contextual, dynamic, visual content.

Accordingly, such technologies are increasingly being implemented and explored in education.

Augmented reality (AR) is a technology that enriches human sensations with digital data and thus mixes the real and virtual environment. It uses virtual information as an additional useful tool. As a result, a new, more informative and stimulating environment is created [10].

The principle of the AR program is to use the sensors of the device to read the environment and supplement it with digital, interactive content.

AR applications can be used on different devices such as desktops, laptops, mobile devices. But most AR programs work on smartphones, tablets. Glasses, headphones, and other controllers can be further connected to mobile devices. Built-in cameras, GPS sensors, gyroscopes and other sensors are used to recognize objects, images and scenes. After successful recognition, relevant digital content becomes available and is displayed on screen. The purpose of their application is to combine the real environment with digital content. This enables the user to receive more information about the environment than is available to him in the real world. The advantage of AR is not only to increase the available information in the environment, but also to create an attractive representation of the world. For this reason, AR is used in many industries such as marketing, design, medicine, entertainment, tourism, education, etc [12].

2 Related research review

The ability to improve the visualization of objects and processes in the learning environment through interactive digital content has generated interest in the using of AR applications for educational purposes. New possibilities of AR technologies for teaching and learning has been analyzed by S. Smerikov, M. Kyslova, A. Striuk, M Striuk, N. Rashevskaya, Y. Yechkalo, K. Slovak [15; 31; 33]. Scientists (A. Iatsyshyn, V. Kovach, Ye. Romanenko, I. Deineha, A. Iatsyshyn, O. Popov, Yu. Kutsan, V. Artemchuk) described examples of AR applications in such industries as the entertainment and gaming industries, tourism, sales and presentations, education [12]. Classification of directions of using of augmented reality in education and practice of using AR applications are given in the publications [35; 21]. The analysis of the papers shows that AR is implemented to different disciplines of elementary and secondary school (N. Honcharova [9], N. Balyk, G. Schmyger [2], D. Matsokin, I. Pakhomova [18], Yu. Matvienko [19], T. Coimbraa, T. Cardoso, A. Mateu [6]) and in the higher education institutions (K. Leshko, L. Rykova, [16], E. Modlo, S. Semerikov, Y. Echkalo [32]). These and many other researchers have found that AR technologies increase the level of success and motivation of pupils and students [13; 17; 11].

Scientists say that learning in the AR can have a positive impact on the development of spatial imagination, the formation of abstract concepts, the transfer of knowledge, the acquisition of digital skills and experience. V. Tkachuk, Y. Echkalo, O. Markova, in their study of AR, identified AR as an important prerequisite for implementing effective strategies to achieve the goals of inclusive education [33]. Now,

AR is not only useful for studying individual subjects or individual students. It can also be applied to the development of new approaches to learning, in particular the concept of STEM [2; 28; 25].

AR technologies can be an effective means of organizing interaction and collaboration to present learning outcomes. Other studies, such as [12; 18; 6; 10] concluded that AR is particularly suited for teaching subjects that need to form difficult for understanding in the real world concepts [9; 25]. Yu. Matvienko described his experience in creating a computer museum. He used augmented reality technology to virtualize objects. The author developed an interdisciplinary study excursion in the museum [19].

The common practice of using AR in education is to create supplementary books. Some didactic aspects of mixed reality books have been studied in the study by N. Honcharova [9]. When AR is used, books are transformed into dynamic sources of information. Augmented reality technology has made it possible to “revive” its pages [21]. Now this technology is used in cognitive books such as encyclopedias, atlases, books about space, structure of the Earth, dinosaurs, for reproduction of historical events. Gradually, from coloring books and fairy-tales, augmented reality technology is being extended to the production of educational products. That is, they are gradually moving from game technology to learning. For example, students use specialized software for joint study of mathematics, physics, chemistry, geometry [16; 32; 24; 19; 6; 12]. These studies have shown the benefits of using AR books as a tool to increase children's motivation. Books in the AR have also proven to be effective means of concepts formation.

3 The problem statement

AR technology is developing quite rapidly. As a consequence, research in education does not have time to provide theoretical understanding or develop a systematic methodology for creating appropriate learning tools. We believe that the use of AR technology is a modern trend, and therefore research in this field is relevant and timely.

The **purpose of this study** is to explore the possibilities of using augmented reality technology at school, in particular when teaching computer science.

Objectives of the study are:

1. To analyze the experience of using AR technologies in education;
2. To find out the possibilities of using augmented reality technology in teaching computer science
3. To experimentally test the attitude and readiness of teachers to use AR in teaching of computer science.

Object of study is the process of teaching computer science in secondary school.

Subject of research is augmented reality technology as a mean of teaching computer science in secondary school.

4 The Presentation of Main Results

In the Ukrainian education system, postgraduate institutes are responsible for implementing innovations in primary and secondary schools. These institutions remain an important component in the process of computer science teacher training. This article will describe the experience of trainings organization at the Ternopil Regional Municipal Institute of Postgraduate Education (TRMIPE). The purpose of these trainings is to develop teachers` skills for augmented reality application. The article will explore the services and their functionality for the computer science lessons. Augmented reality allows the student to visualize complex spatial connections and abstract concepts. Therefore, with their help, the teacher can develop abilities that are difficult to form in a traditional learning environment [30; 23].

Technologies for augmenting reality with digital objects (perhaps not just digital ones) can be conditionally positioned between two polar variants of possible realities: the reality we live in and virtual reality (VR) (see figure 1).

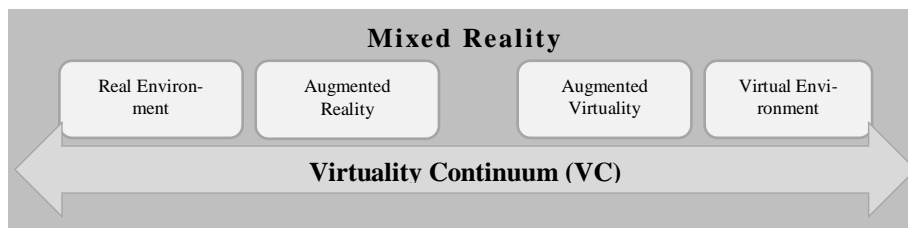


Fig. 1. Reality-virtuality continuum by Milgram and Kishino

Reality is a philosophical term that means what actually exists in physical space, and physical space itself. Virtual reality is the absolute absence of real objects. It is a technically created world that is transmitted to man through his senses: sight, hearing, touch and others.

Quite often, a combination of these realities is called Mixed Reality (MR). Virtual reality can be filled with people, weather, events, and more. If images of these objects are broadcast from the real world, then the result will be augmented virtual reality (AV) technology. At the current level of development, AV technology is virtually unused, but in the future it can be much more impressive than AR and VR.

Ronald Azuma [1] identified augmented reality features such as:

- combining the real and the virtual world;
- interactivity;
- three-dimensional representation of objects.

The augmented reality system is the mediator between man and reality. Therefore, it must generate a signal for one of the human's perception organs. Therefore, according to the type of presentation of information in the AR system, they can be classified such as visuals, audio, and audiovisuals.

By type of sensors for the acquisition of data from the physical space there are AR systems:

- Geo-location. They focus on signals from GPS or GLONASS positioning systems.
- Optical. Such systems process the image obtained from the camera. The camera can move with or without the system.

Augmented reality systems can be classified by user interaction. In some systems, the user has a passive role. He only watches the system react to changes in the environment. Other systems also require active user intervention. There he or she can control the operation of the system and modify its virtual objects. According to this feature, the systems are divided into offline and interactive.

Let's look and analyze the program tools that are most appropriate to use when teaching computer science at school. Based on the analysis of articles and sites, we can say that there are very few such applications and services. Therefore, teachers and scholars are looking for ways to use augmented and virtual reality to improve and support school-based learning. But to make the right choice, they need to know the requirements for existing applications and services and the limitations of using them. As the experience suggests, most Ukrainian schools do not have high-end AR or VR devices.

The benefits of AR are the ability to increase motivation, emotional perception of the students' learning content. The highest level of application of these technologies is the involvement of students in the creation of their own virtual worlds. At the same time, teachers should also be interested in implementing such innovations. They should have as little doubt as possible about the capabilities of AR technologies and their own capabilities.

Among augmented reality applications, there are those that can be used in the study of various subjects, not just computer science.

The Quiver application allows the teacher to create coloring books with augmented reality. With the app, students can interact with objects they create. Painted images are transformed on the gadget screen into augmented reality. There is an opportunity to play with animated characters. The teacher can use the Quiver app in the lesson as a tool for developing creative skills or for pupils' reflection.

WallaMe is a platform that can be implemented to integrate augmented reality into the learning process. WallaMe Ltd launched the application in 2015. Using this app is an easy way for both teachers and students. WallaMe is a free iOS and Android application. It allows users to hide and share messages in the real world using augmented reality. These messages appear as a result of changing the geolocation of the smartphone. In addition, the WallaMe app provides students and teachers with additional tools such as

- a library of stickers;
- advanced drawing tools;
- tools for working with text;
- simple and minimalistic graphics and elements of the interface;
- connection to a smartphone camera;

- comment option;
- accessible to all or private messages.

WallaMe allows a teacher to take a picture on a smartphone and leave a picture or message there. The object created in this way is linked to the image and geographical coordinates. Another app user sees a message icon on the map. He or she will only be able to find out it if he points his camera at this wall.

The application can be used in the study of computer science to create knowledge maps or tests in augmented reality. For example, a teacher creates a geotag on a specific computer hardware device. The learner should identify and add text with the characteristics of this device. In the study of programming, students can perform in augmented reality the task of completing a code snippet, determining the values of variables, finding errors. In the case of a positive experience, the teacher can use the application to create integrated tasks, such as web quests [26].

One of the most popular mobile apps is Google expedition. It is an immersive education application that allows teachers and students to explore the world through over 100 augmented-reality tours. In addition, the app offers more than 1,000 virtual reality tours [4]. They can be used effectively by teachers of various subjects.

Unfortunately, as of now, only 2 expeditions are available for computer science in AR mode:

- Computers. The tour allows students to learn and explore how different components of a computer function.
- Introduction to Computer Graphics. It covers topics such as: History of Computer Graphic, Creating a 3D World, Modeling, Texturing and Shading, Ray Tracing and Light, Rendering.

Google Expedition provides collaborative learning opportunities. The teacher has the opportunity to download the completed tours and invite students to see them in augmented reality. Unfortunately, creating your own AR Tours with Tour Creator is not currently available. For now teachers can use an external tool such as cospaces.io. The service allows them to create or import three-dimensional models. These objects can be offered to students for using on mobile devices.

CoSpaces Edu service provides great programming experience. It enables students to learn by doing, using the various tools available with the VR and AR technologies. All features in CoSpaces Edu can be adapted to fit different class subjects and learning objectives. The platform uses a visual programming language ideal for beginners or gets access to scripting languages for more advanced coding. With its fun Lego-like colored blocks, CoBlocks is the ideal solution for junior pupils. More advanced coders can have fun coding scripts to add interactions and events or even create games [7].

The platform enables the collaboration of the teacher with several students. They can work on individual or collaborative projects. Most of these projects these projects can be saved in AR. Augmented Reality lets students project their own creations onto any plane surface in the real world by looking through the screen of their device.

The advantage of the system is the use of single sign-on technology. It integrates well with cloud services, including G Suite for education.

Michael Drezek of the New York State's Lake Shore Central School District uses the CoSpaces service to perform tasks for students such as creating an animal habitat, creating a game about holiday traditions in virtual and augmented reality to share with the schools around the world. Michael says that students in own space can experience what they design and program in virtual and augmented reality [8].

In our opinion, the highest level of implementation of AR in the teaching of computer science is the development of students own elements and scenes in augmented reality. According to research [3; 34; 5] one of the most popular and productive means of achieving this goal is the engine Unity and the library Vuforia. One of the many advantages of Unity is that it is a free game engine that has the possibility to deploy to many different platforms as iOS and Android. This, combined with the Vuforia AR platform, makes it possible to assign a virtual camera in the 3D scene that is linked to an image tracker. This combination can then be deployed to a smart phone or tablet. Finally, it is possible to utilize the camera on the device in order to mix the 3D scene with the camera image [14].

We compared these tools according to the main criteria (type of tool, equipment, interaction with the student, place in training, cost). Table 1 contains a comparative analysis.

Table 1. Augmented reality program tools

Name	Software	Equipment	Interaction	Place	Cost
Quiver	Application	Mobile device	One user	Reflection	Free/Commercial
WallaMe	Application	Mobile device	Many users	Quests, Learning Projects	Free
Google Expedition	Application	Mobile device	Many users	Demonstration, STEM-projects	Free
CoSpaces Edu	Site, Application	Mobile device, PC	Many users	Programming, development	Free/Commercial
Vuforia AR	Application	PC	One user	Development	Commercial
Unity	Application	PC	Many users	3D-modeling	Free and Commercial
Poly	Library	PC	Many users	3D-modeling	Free
SketchUp	Application, Site	PC	One user	3D-modeling	Free with a state grant/Commercial

In addition to AR services created by IT firms, there are also authoring AR applications to support computer science training. Let's look at some of them.

AR-CPULearn is based application for learning CPU. It was created by scientists of Universiti Kebangsaan (Malaysia). AR-CPULearn was implemented as an exercise activity for computer organization and operating system students in higher education. This applications offer for execution some exercises with overlaid multimedia information. For example, answer a few questions based on a training video; name the main components of the motherboard, explain how the processor and motherboard work [33].

The Mixed Reality Laboratory (Bond University and CQUniversity, Australia) is involved in the development of mixed reality applications for solutions to complex pedagogical problems. In our opinion The "Network and ICT modeling" project is the most exciting startup of this lab. The purpose of this project is to use the augmented reality visualization method to help students understand the theoretical model of open systems interconnection (OSI) and its implementation as a stack of TCP/IP protocols [22].

The application simulates in augmented reality the construction of simple computer networks. This simulation uses a five layer TCP/IP model to visualize how packets are interpreted and distributed. The simulation utilizes augmented reality markers which are detected and tracked in 3D space by smartphones cameras. When students are focusing a camera on the marker then they can see a multiple network devices such as modems, routers, switches, wireless AP etc. These devices can be connected to the network. Visually, this will be shown as lines on the smartphone screen.

The application visualizes packets from devices that generate traffic. This visualization corresponds to the TCP/IP model. The demo shows not only traffic but also individual packages and their headers. Visualization in augmented reality is dynamically transformed as the network topology changes. The application also demonstrates signal conditioning between wireless devices. The student can select any device as the source and as the recipient when transmitting traffic. As a consequence, he or she will see the visualization and model of this process in augmented reality.

5 Experimental study

We continued our research on augmented reality training. The training was conducted at TRMIPE from September to November 2019. Participants of the trainings were 2 groups of computer science teachers (20 people in each group). They could choose augmented reality topics. We used different techniques to teach different topics (see Table 1).

Table 2. Augmented reality training topics

Topic number	The name of the topic	Training technique
1.	The concept of virtual and augmented reality	Conversation
2.	Types of augmented reality	Mini-lecture
3.	Examples of augmented reality	Demonstration

4.	Checking mobile gadgets for support of AR technologies	Work in groups
5.	Prospects for the use of AR technologies in education	Training exercise, brainstorming
6.	Create your own augmented reality effects	Individual work
7.	Develop a list of required AR models for the computer science course	Collaboration

We have conducted a survey to verify attitude and readiness of computer science teachers to use AR in teaching. The participants of the training filled out a questionnaire. They evaluated AR applications by the factors of frequency and usefulness of their use in training. The questionnaire was based on the usability measurement software developed by A. Kostin [27]. The questionnaire contained 12 questions. The answer options were formed according to the 5-point Likert scale. They determined the ratio of the respondents from completely negative (0 points) to completely positive (4 points). This distribution prevented the respondents from making unreasonable choices about the mean of the answer. We avoided questions in the negative form when forming the questionnaire. We also used the Likert scale to determine respondents' age (from 0 points – age over 60 years to 4 points – age 20-30 years). The entire table of respondents' scores can be downloaded from the link <https://drive.google.com/file/d/1zIS8c0RForHw8KA49qBQGhynQvAcpzTy>

To check the internal consistency of the questionnaire, we calculated the Alpha Cronbach coefficient. Its value ($\alpha_C=0,73$) can be considered acceptable. We considered the latent indicator of each question to be the average of all respondents' scores. Table 2 shows the list of questions and their respective mean values.

Table 3. Questionnaire items

Question code	The content of the question	Average of respondents' scores
UGT	How often do you use gadgets in teaching?	2,38
SUG	How often do your students use their own gadgets in learning?	1,9
MAR	How often do you use AR apps in computer science teaching?	1,8
CAR	How often do your colleagues use AR in computer science teaching?	1,9
EAR	How easy is it for you to learn AR technologies?	1,98
ARI	Using AR in computer science teaching can be interesting	2,43
RAR	I feel ready to use AR	1,83
ARE	AR is entertaining	2,05
ARC	AR used in computer science training can be credible	2,33
PAR	My proficiency level of AR	1,9
ARA	The use of AR is advisable in the study of computer science	2,58

We have selected the following significant average values of respondents' scores:

Since the asymptotic significance is less than 0.05, the distribution is not normal. In this case, the Spearman rank factor should be used. It is a statistical measure of the strength of a monotonic relationship between paired data. Correlation is the size of the effect. The coefficient determines whether the quantitative factor influences the quantitative response. Its absolute value is usually interpreted according to the following ranges:

- 0 – 0,19 – relationship is very weak;
- 0,2 – 0,39 – relationship is weak;
- 0,40 – 0,59 relationship is moderate;
- 0,60 – 0,79 relationship is strong;
- 0,80 – 1,0 relationship is very strong.

Its positive value shows the existence of a direct relationship between factor and response. A negative coefficient indicates the reverse relationship.

We used the Statistica program and calculated the rank correlation coefficients. All correlations are significant at 0,05 level.

Table 5. Spearman Rank Order Correlations

	Age	UGT	SUG	MAR	CAR	EAR	ARI	RAR	ARE	ARC	PAR	ARA
Age	1,00	<i>0,49</i>	<i>0,46</i>	0,80	0,27	0,59	<i>0,43</i>	<i>0,42</i>	-0,07	<i>0,41</i>	0,79	0,80
UGT	<i>0,49</i>	1,00	0,05	0,46	0,19	0,17	0,19	0,34	-0,07	0,25	<i>0,42</i>	0,36
SUG	<i>0,46</i>	0,05	1,00	0,39	0,02	<i>0,45</i>	0,36	-0,06	-0,27	0,18	0,30	<i>0,48</i>
MAR	0,80	<i>0,46</i>	0,39	1,00	0,39	<i>0,45</i>	0,26	0,20	-0,10	0,39	0,63	0,68
CAR	0,27	0,19	0,02	0,39	1,00	0,13	-0,23	0,06	-0,21	0,17	0,03	0,31
EAR	0,59	0,17	<i>0,45</i>	<i>0,45</i>	0,13	1,00	0,20	0,11	-0,26	<i>0,46</i>	<i>0,41</i>	<i>0,44</i>
ARI	<i>0,43</i>	0,19	0,36	0,26	-0,23	0,20	1,00	0,29	-0,04	0,17	0,34	0,31
RAR	<i>0,42</i>	0,34	-0,06	0,20	0,06	0,11	0,29	1,00	0,10	0,02	0,31	0,16
ARE	-0,07	-0,07	-0,27	-0,10	-0,21	-0,26	-0,04	0,10	1,00	-0,18	0,07	-0,18
ARC	<i>0,41</i>	0,25	0,18	0,39	0,17	<i>0,46</i>	0,17	0,02	-0,18	1,00	0,20	0,30
PAR	0,79	<i>0,42</i>	0,30	0,63	0,03	<i>0,41</i>	0,34	0,31	0,07	0,20	1,00	0,65
ARA	0,80	0,36	<i>0,48</i>	0,68	0,31	<i>0,44</i>	0,31	0,16	-0,18	0,30	0,65	1,00

We considered indicators with a moderate and strong correlation. In Table 4, they are highlighted in italics and bold respectively.

The first line of the table indicates a strong relationship between teachers' age and their experience with AR use. That is, younger teachers are easier to learn AR applications, they are more confident in their ICT competencies. Therefore, they are more likely to use AR in computer science training.

The study found a strong link between the frequency of use of AR technology in teaching computer science and the beliefs of teachers about the feasibility of its use. A

positive strong relationship was also found between teachers' proficiency level and the frequency of AR use.

The use of augmented reality by colleagues has a positive moderate impact on the same activities of the interviewed teachers. The Bring Your Own Device (BYOD) approach also helps to incorporate AR into learning. Teachers who are learning to work with AR applications are more positive about the credible data that this technology displays.

In addition, the survey found several indicators that were poorly explained. First of all, there is no significant positive correlation of ARE (Entertainment of AR) with other survey questions. This may mean that teachers do not pay enough attention to the gaming approach in teaching. A similar situation was found with the RAR indicator. That is, despite some level of AR using, teachers still do not consider themselves ready for it.

We also found no significant correlation between the use of AR and the fact that these technologies are interesting and motivating. Also surprising is the fact that communication with colleagues has no effect on the readiness of a computer science teacher. In our opinion, these paradoxes are a result of the lack of appropriate methodology. In general, we can say that negative research results require rethinking and further exploration.

6 Conclusions

Therefore, innovative ICTs should be used in computer science lessons, as they are necessary and crucial for living in the modern world. Augmented reality is one of the most up-to-date teaching content visualization technologies. Currently, the use of AR in education has been a success. In our opinion, the introduction of this technology will increase the motivation to learn, increase the level of mastering the material. This is also possible due to the variety, interactivity of visual presentation of educational objects, migration of part of students' research work into the virtual environment.

Our analysis of publications on the problem of research has shown that the experience of using augmented reality applications is mostly fragmentarily described in scientific articles and blogs of enthusiasts. Appropriate implementation of AR means in the practice of educational institutions will be done step by step.

It is clear that successful implementation of this technology requires special attention to the system of teacher training and retraining, curriculum development and next-generation textbooks. However, such fragmented use of augmented reality is already facilitating the process of its implementation. Our experience has shown that the developed training courses are in demand in advanced training courses. They are of interest to teachers. The results of this study show that IT teachers have access to computers and mobile devices and have a high level of interest in augmented reality technology.

The study found difficulties in implementing AR such as:

- increasing the time of teacher's preparation for augmented reality classes;

- AR tools are usually application-specific, so learning about different topics requires installing and sometimes integrating multiple applications;
- sometimes AR is perceived by students and teachers as an entertainment game, not as a learning environment;
- development of high-quality AR applications clearly requires the work of professional programmers.

This study has several limitations. The questionnaire was based on self-assessment. Therefore, the level of ICT competence and teacher readiness was not sufficiently objectively determined. Also, the degree of use of AR applications has not been measured in practice. In addition, the number of teachers was limited. As a consequence, it is likely that teachers with advanced digital competence participated in the experiment. There is a need for future research on the technical aspects of augmented reality technologies, in particular in developing a repository of training applications to support computer science education.

References

1. Azuma, R. T. : A survey of augmented reality. In *Presence: Teleoperators and Virtual Environments*, 6(4), 355-385 (1997).
2. Balyk, N., Vasylenko, Y., Shmyger, G., Oleksiuk, V., Skaskiv, A.: Design of approaches to the development of teacher's digital competencies in the process of their lifelong learning. *CEUR Workshop Proceedings*, 2393, pp. 204–219 (2019).
3. Boonbrahm P., Kaewrat C.: Assembly of the Virtual Model with Real Hands Using Augmented Reality Technology. *HCI*, 16, 329-338 (2014).
4. Bring your lessons to life with Expeditions, https://edu.google.com/products/vr-ar/expeditions/?modal_active=none, last accessed 2020/03/18.
5. Cakir, R., Korkmaz, O.: The effectiveness of augmented reality environments on individuals with special education needs. *Education and Information Technologies*. 24,1631-1659 (2019)
6. Coimbraa, T., Cardoso, T., Mateu, A.: Augmented Reality: An Enhancer for Higher Education Students in Math's Learning?. *Procedia Computer Science* 67, 332-339 (2015).
7. CoSpaces Edu, <https://cospaces.io/edu>, last accessed 2020/03/10.
8. Drezek, M.: How I use CoSpaces to help students create their dreams, <https://www.hypergridbusiness.com/2017/01/i-used-cospaces-to-help-students-create-their-dreams>, last accessed 2020/03/14.
9. Honcharova, N.: Technology of augmented reality in textbooks of new generation. *Problems of a Modern Textbook* 22, 46-56 (2019).
10. Hrunтова, T.V., Yechkalo, Yu.V., Striuk, A.M., Pikilnyak, A.V.: Augmented Reality Tools in Physics Training at Higher Technical Educational Institutions. In: Kiv, A.E., Soloviev, V.N. (eds.) *Proceedings of the 1st International Workshop on Augmented Reality in Education (AREdu 2018)*, Kryvyi Rih, Ukraine, 2018. *CEUR Workshop Proceedings*, vol. 2257, pp. 33-40. <http://ceur-ws.org/Vol-2257/paper04.pdf> (2018).
11. Iatsyshyn A.V., Sokoliuk O.M The use of augmented reality in educational practices. *Digital Transformation of Open Educational Environments: A Collective Monograph*. In: Bykov, V.Iu., Pinchuk, O.P. Kyiv (2019).

12. Iatsyshyn, A. V., Kovach, V.O., Romanenko, Ye.O., Deinega, I.I., Iatsyshyn, A.V., Popov, O.O, Kutsan ,Yu.G., Artemchuk, V.O., Burov, O.Yu., Lytvynova, S.H. : Application of augmented reality technologies for preparation of specialists of new technological era. In: Arnold, E. Kiv, Shyshkina, M, P., Proceedings of the 2nd International Workshop on Augmented Reality in Education (AREdu 2019), Kryvyi Rih, Ukraine, March 22, 2019, CEUR Workshop Proceedings, Vol. 2547, pp. 181-200. (2019).
13. Kesim M, Ozarslan, Y. : Augmented reality in education: current technologies and the potential for education. *Procedia - Social and Behavioral Sciences* 47, 297-302 (2012)
14. Kjellmo, I.: Educational: 3D Design for Mobile Augmented Reality. In: Shumaker R., Lackey S. (eds) *Virtual, Augmented and Mixed Reality. Designing and Developing Virtual and Augmented Environments. VAMR 2014. Lecture Notes in Computer Science*, vol 8525. Springer, Cham (2014)
15. Kyslova, M.A. Semerikov, S.O. Slovak, K.I.: Development of mobile learning environment as a problem of the theory and methods of use of information and communication technologies in education. *Information Technologies and Learning Tools* 42(4), 1–19 (2014).
16. Leshko, K.V., Rykova, L.L.: Augmented reality as a tool in creative development of future education professionals. *New Computer Technology, Cloud technologies in education* 17, 76-81 (2019).
17. Martin-Gutierrez, J., Meneses F., M.: Augmented Reality Environments in Learning, Communicational and Professional Contexts in Higher Education. *Digital Education Review* 12, 61-73 (2014).
18. Matsokin, D.V., Pakhomova, I.M. : Use of augmented reality technologies in physics teaching. *Problems of modern education. Collection of scientific and methodological works*, Kharkiv. V. N. Karazin Kharkiv National University 2, 151-159 (2019).
19. Matviienko, Yu. S.: Introduction of augmented reality technology into the educational process. *Engineering and Educational Technologies* 11(3), 157-159 (2015).
20. Milgram, P., Kishino, F.: A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems*, vol. E77-D 12(12), 1321-1329. (1994).
21. My creative encyclopedia, https://www.ranok.com.ua/series/moya-tvorcha-entsiklopediya-578.html?utm_source=blog&utm_medium=link&utm_campaign=moya-tvorcha-entsiklopediya, last accessed 2020/03/18
22. Network and ICT Modeling, <http://www.mixedrealityresearch.com/#networkModeling>, last accessed 2020/03/14.
23. Oleksiuk, V., Oleksiuk, O., Berezitskyi M.: Planning and Implementation of the Project "Cloud Services to Each School". *CEUR Workshop Proceedings* 1844, 372-379 (2017).
24. Orlova, E.Yu., Karpova, I.V.: Using Augmented and Virtual Reality Technologies in Teaching at a Technical University. *Teaching Methods of Info communications in Higher School* 7(2), 40-43 (2018)
25. Pinchuk, O. P., Tkachenko, V.A., Burov, O. Yu.: AR and VR as Gamification of Cognitive Tasks. *CEUR Workshop Proceedings*, 2387, pp. 437-442. (2019)
26. Review: Augmented reality app WallaMe creates secret notes – Gearbrain, <https://www.gearbrain.com/wallame-augmentedreality-app-review-2485341122.html>, last accessed 2020/03/18
27. Serdiuk, S. M.: Ergonomic design issues for human-machine systems: Tutorial. ZNTU, Zaporizhzhia (2014). (http://eir.zntu.edu.ua/bitstream/123456789/1543/1/Serdiuk_Problems_of_Human_Machine_System.pdf)
28. Shapovalov, V.B., Atamas, A.I., Bilyk, Z.I., Shapovalov, Y.B., Uchitel A.D.: Structuring Augmented Reality Information on the stemua.science. In: Kiv, A.E., Soloviev, V.N. (eds.)

- Proceedings of the 1st International Workshop on Augmented Reality in Education (AREdu 2018), Kryvyi Rih, Ukraine, 2018. CEUR Workshop Proceedings, vol. 2257, pp. 75-86. <http://ceur-ws.org/Vol-2257/paper09.pdf> (2018).
29. Silva, I.: Application of Mobile Augmented Reality in a Computer Science Course. H. Badioze Zaman et al. (eds) IVIC 2013, LNCS 8237, pp. 516–525. Springer (2013).
 30. Spirin, O. Oleksiuk, V. Oleksiuk O., Sydorenko S.: The Group Methodology of Using Cloud Technologies in the Training of Future Computer Science Teachers. CEUR Workshop Proceedings, vol. 2104, pp. 33-40. (2018).
 31. Striuk, M.I., Semerikov, S.O., Striuk, A.M.: Mobility: a systems approach. *Information Technologies and Learning Tools* 49(5), 37–70 (2015).
 32. Syrovatskyi, O.V., Semerikov, S.O., Modlo, Y.O., Yechkalo, Yu.V., Zelinska, S.O.: Augmented reality software design for educational purposes. CEUR Workshop Proceedings Vol. 2292, pp 193-225. (2018)
 33. Tkachuk, V. V. Yechkalo, Yu.V., Markova, O. M.: Augmented reality in education of students with special educational needs. CEUR Workshop Proceedings. Vol. 2168, pp. 66-71. (2018).
 34. Youm, D., Seo, S., Kim, J.: Design and development methodologies of Kkongalmon, a location-based augmented reality game using mobile geographic information. *J Image Video Proc.* 2019, 1, 329-338 (2019).
 35. Yuen, S., Yaoyuneyong, G., Johnson, E.: Augmented reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange*, 4(1), 119-140 (2011).