Assessing Augmented Reality Possibilities in the Study of School Computer Science

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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. The authors studied the relationship between some factors that influence the introduction of augmented reality in school computer science, such as: the age of teachers, student interest, the use of gadgets in education, play and entertainment style of learning. Several augmented reality STEM projects have been selected. On the basis of expert evaluation, the attitude of teachers to these projects was determined and the most rated of them were evaluated.

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.

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. Smart 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

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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 (Iatsyshyn et al., 2019; Hruntova et al., 2018; Rashevska and Soloviev, 2018; Striuk et al., 2018; Zelinska et al., 2018).

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 in (Shepiliev et al., 2021). Iatsyshyn et al. (Iatsyshyn et al., 2019, 2020) described examples of AR applications in such industries as the entertainment and gaming industries, tourism, sales and presentations, education.

Classification of directions of using of augmented reality in education and practice of using AR applications are given in the publications (Ranok, 2020; Yuen et al., 2011). The analysis of the papers shows that AR is implemented to different disciplines of elementary and secondary school (Coimbra et al., 2015; Matsokin and Pakhomova, 2020; Matviienko, 2015; Midak et al., 2021) and in the higher education institutions (Barkatov et al., 2020; Klochko et al., 2020; Lavrentieva et al., 2019, 2020). These and many other researchers have found that AR technologies increase the level of success and motivation of pupils and students (Gutierrez and Fernandez, 2014; Kesim and Ozarslan, 2012).

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. Dyulicheva et al. (Dyulicheva et al., 2020), Kolomoiets and Kassim (Kolomoiets and Kassim, 2018), Osadchyi et al. (Osadchyi et al., 2020), Tkachuk et al. (Tkachuk et al., 2017) identified AR as an important prerequisite for implementing effective strategies to achieve the goals of inclusive education. 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 (Shapovalov et al., 2018; Valko et al., 2019).

AR technologies can be an effective tool of organizing interaction and collaboration to present learning outcomes. Other studies, such as (Coimbra et al., 2015; Matsokin and Pakhomova, 2020) concluded that AR is particularly suited for teaching subjects that need to form difficult for understanding in the real world concepts (Kravtsov and Pulinets, 2020; Valko et al., 2019). Matviienko (Matviienko, 2015) 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.

The common practice of using AR in education is to create supplementary books. Some didactic aspects of mixed reality books have been studied by Kravtsov and Pulinets (Kravtsov and Pulinets, 2020), Panchenko et al. (Panchenko et al., 2020). When AR is used, books are transformed into dynamic sources of information. Augmented reality technology has made it possible to “revive” its pages (Ranok, 2020). 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 (Coimbra et al., 2015; Iatsyshyn et al., 2019; Kramarenko et al., 2019; Matviienko, 2015; Zinonos et al., 2018). 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.

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.
4. To define some STEM projects with augmented reality technologies. Assess opportunities for their implementation in secondary schools

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.

2 PROBLEM STATEMENT

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 training's 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 (Oleksiuk et al., 2017; Ponomareva, 2021; Spirin et al., 2018; Vlasenko et al., 2019).

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) (figure 1).

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.

Azuma (Azuma, 1997) identified augmented reality features such as:

- combining the real and the virtual world;
- interactivity;
- combining the real and the virtual world.

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

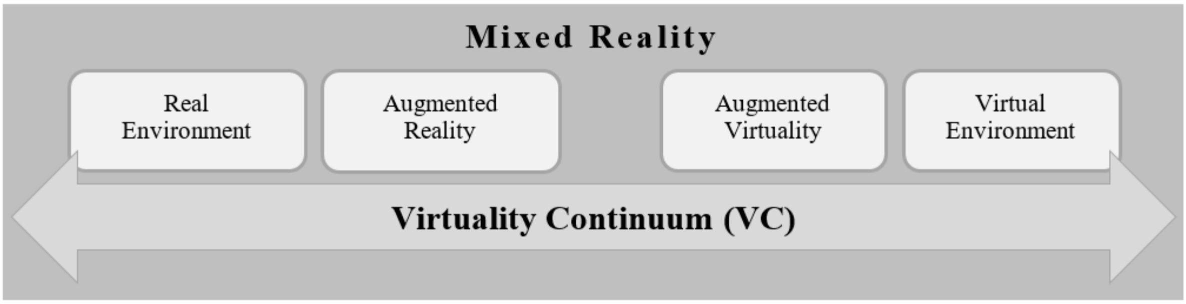

Figure 1: Reality-virtuality continuum (Milgram and Kishino, 1994).

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 (Wang, 2017).

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 (edu.google.com, 2020). 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 (Cospaces, 2020).

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 Google Workspace for Education.

Drezek (Drezek, 2020) uses the CoSpaces service to perform tasks for students such as creating an animal habitat, creating a game about holiday traditions in virtual and augment 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.

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 (Boonbrahm and Kaewrat, 2014; Cakir and Korkmaz, 2019; Youm et al., 2019) one of the most popular and productive means of achieving this goal is the Unity engine and the Vuforia library. 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 (Kjellmo, 2013).

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.

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 (Boonbrahm and Kaewrat, 2014).

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 (www.mixedrealityresearch.com, 2019).

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.

3 RESULTS AND DISCUSSION

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 (table 2).

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 (Serdiuk, 2014). 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 down-

Table 1: Augmented reality program tools.

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

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-lection
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

loaded 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 ($\alpha_{Cr} = 0.73$) can be considered acceptable. We considered the latent indicator of each question to be the average of all respondents' scores. Table 3 shows the list of questions and their respective mean values.

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

- less than 1.5 points – the indicator is not almost manifest;
- 1.5-2.0 – the indicator is weak;
- 2.0-2.5 – the indicator is sufficient;
- more than 2.5 – the indicator is strong.

The obtained average values of the indicators are shown in the following diagram (figure 2). Significant values of indicators are highlighted with colors.

As can be seen from the diagram, a weak manifestation is found in indicators related to the readiness and use of AR in the real learning process. However, the study found strong and sufficient manifestations of the indexes regarding the usefulness, motivation for use and pedagogical potential of AR applications. At the trainings we observed the interest of teachers, especially when they saw in AR their own digital world.

Another objective of our study was to determine the dependencies between these indicators. To do this, we used a correlation method. To determine the specific correlation coefficient, we checked the normality of the distribution of each indicator. We have performed the Shapiro-Wilk test of normality. Here are the results of the R-function shapiro.test for all indicators:

- `p-value(UGT) = 0.01297000;`
- `p-value(SUG) = 0.00004502;`
- `p-value(MAR) = 0.00186300;`
- `p-value(CAR) = 0.00386600;`
- `p-value(EAR) = 0.00124000;`
- `p-value(ARI) = 0.00024080;`
- `p-value(RAR) = 0.00066520;`
- `p-value(ARE) = 0.00531300;`
- `p-value(ARC) = 0.00011270;`
- `p-value(PAR) = 0.00019137;`
- `p-value(ARA) = 0.00235700.`

Since the asymptotic significance is less than 0.05, the distribution is not normal. In this case, the Spear-

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?	1.90
MAR	How often do you use AR apps in computer science teaching?	1.80
CAR	How often do your colleagues use AR in computer science teaching?	1.90
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	1.90
ARA	The use of AR is advisable in the study of computer science	2.58

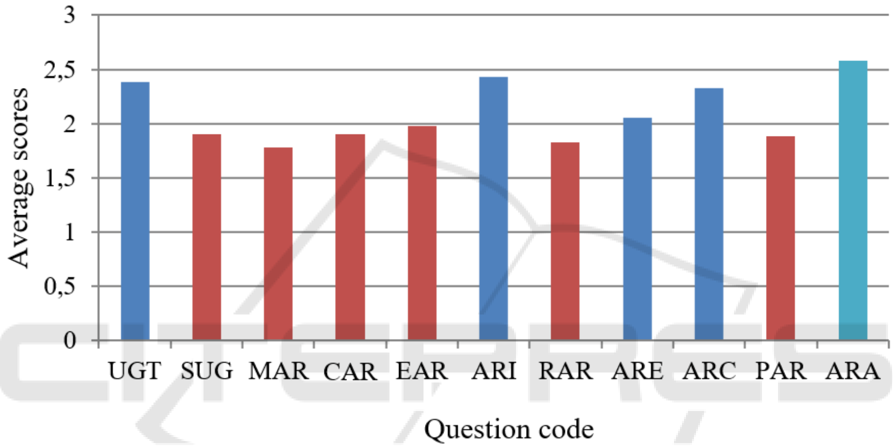

Figure 2: Distribution of indexes.

man 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:

- 0.00 – 0.19 – relationship is very weak;
- 0.20 – 0.39 – relationship is weak;
- 0.40 – 0.59 relationship is moderate;
- 0.60 – 0.79 relationship is strong;
- 0.80 – 1.00 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 R-library “corrplot” to calculate and display the rank correlation coefficients. All correlations are significant at 0.05 level. We considered indicators with a moderate and strong correlation. In the figure 3, they are highlighted in red.

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

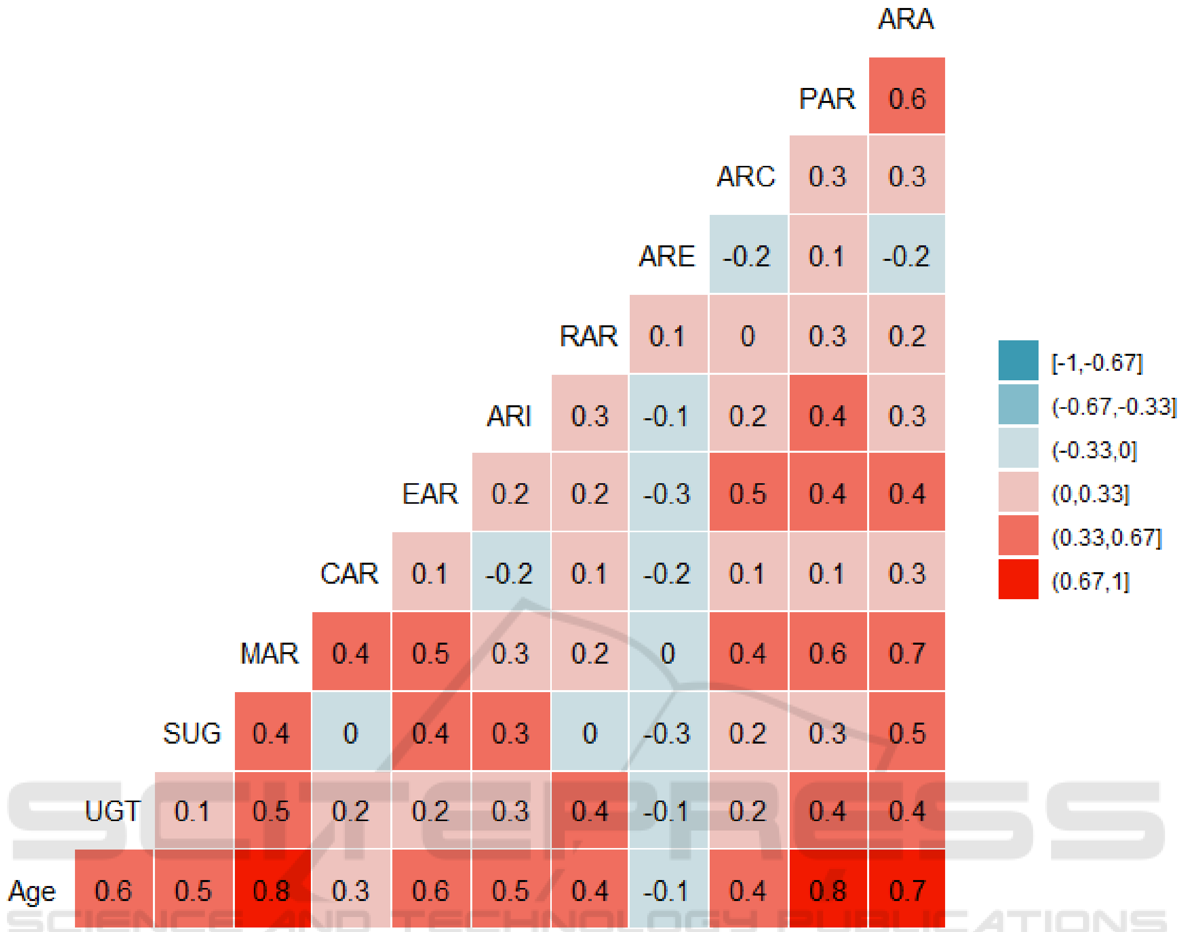

Figure 3: Matrix of plots with a indicators data set.

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.

Figure 4 contains a matrix of plots for indicators with significant correlation. These plots show the distributions of values for the indicators "PAR", "MAR", "ARA", "CAR", the corresponding diagrams and the correlation coefficients between them.

4 EVALUATION OF SOME STEM PROJECTS WITH AUGMENTED REALITY

Today, STEM projects are becoming very popular in schools. Their implementation allows you to integrate knowledge from different subjects. Solving real problems determines the practical direction of tasks. At the same time, students generate new ideas and develop their own competencies, such as mathematical, technological, social. Mobile applications with augmented reality allow to increase the interest of modern schoolchildren in the study of natural sciences. First of all, this is possible thanks to advanced multimedia technologies. These tools make it possible to "revive" and clearly represent complex concepts.

We invited teachers to consider and evaluate several STEM projects at the training. In these projects, augmented reality mobile applications were proposed. These applications are free and available

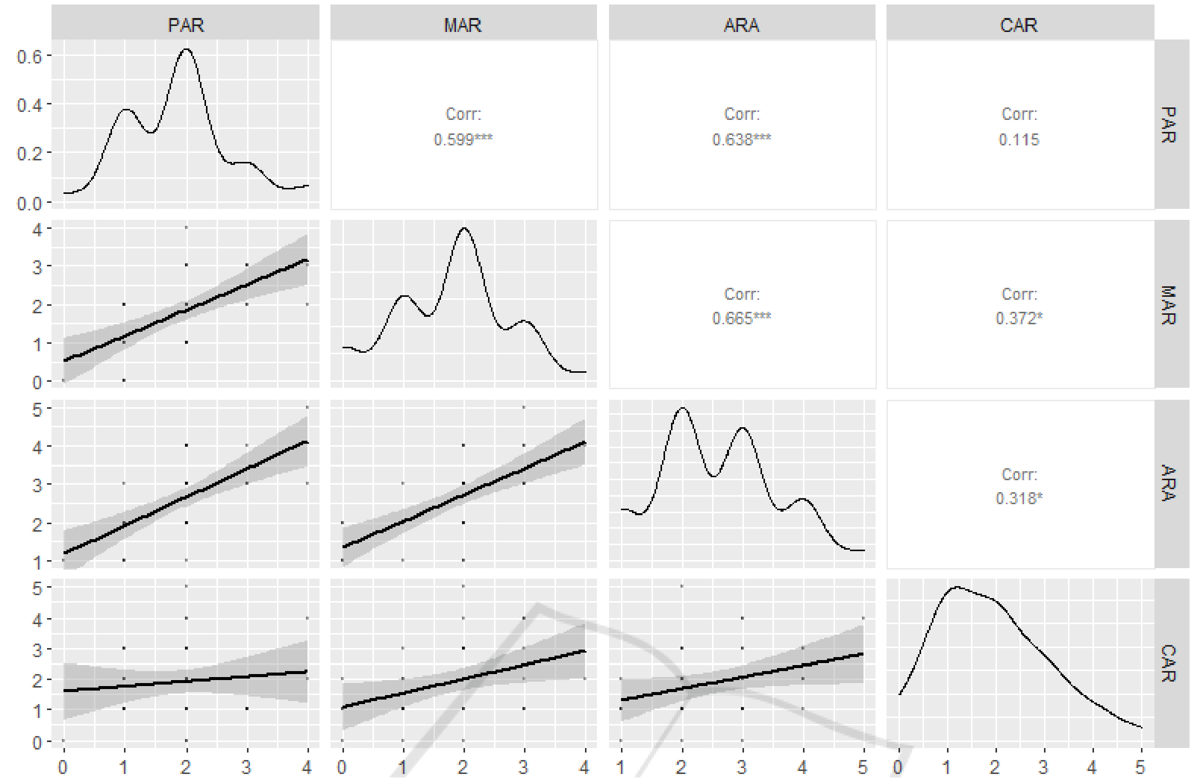

Figure 4: Matrix of plots with significant correlation values.

for download in Google Play and App Store.

Project 1. Skyscrapers. In this project, we used the Skyscrapers AR mobile application to study 3D models of five famous high-rise buildings in the world. Today, engineers use robust materials and innovative schemes to design buildings of this height. So, it would be good for students to implement this STEM project. In computer science lessons, they study augmented reality technology, its capabilities and terminology. In math lessons, children learn to build diagrams. In language lessons, they discuss the project in dialogues and prepare essays on construction technologies. In geography lessons, students can explore the soil for building skyscrapers. In technology lessons, children create models of skyscrapers and design a device to test their own buildings.

Students during the project should find answers to questions such as:

- How to choose a building material?
- How to check whether the manufactured materials meet the advertised specifications?
- How long will the finished product last?
- Are the materials safe to design and use?

Finally, it is advisable to discuss with students what career prospects they see after participating in this STEM project.

Project 2. Da Vinci Machines. In this project, we used a mobile application with augmented reality to study the models of the famous inventor Leonardo da Vinci. This project is related to history, mathematics, technology, art. Students will learn about the biography of Leonardo da Vinci in history lessons. In computer science lessons, they learn to search, collect, process, present data from various sources. The AR application is designed so that children have the opportunity to work with two layouts of pictures-labels: horizontal (the picture is located on the desk) or vertical (on the stand, interactive whiteboard, screen, etc.). The teacher can offer students to study such models as: Helicopter da Vinci, “Self-supporting” bridge da Vinci, Tank da Vinci, Catapult da Vinci.

In technology lessons, it is advisable to organize the practical manufacture and testing of these models. For example, a self-supporting bridge can be made of simple materials, such as ice cream sticks.

With their own catapults, students can explore the mechanical motion of a body thrown at an angle to the horizon, to check the law of conservation of mechanical energy. It is important for the project that children study 3D models in AR applications and compare them with hand-made devices. Shooting distance competitions should also evoke positive emotions in children.

Project 3. Bridges. Today, bridges are built in different shapes, sizes and materials. What makes a bridge the strongest? Project participants learn about this by building simple paper bridges. The children can then measure the maximum allowable weight for each such sample. Students also use the "Bridges AR" application to explore some models.

In this project, important issues for research are such as:

- identification of the main types of bridge structures;
- explanation of the importance of bridges in human life;
- study of the main characteristics of bridges and parts for their
- construction (for example, the distribution of compressive and tensile forces)
- building a model of your own bridge from simple materials;
- experimentally check the maximum load that can withstand the constructed structure.

As a development of this project, it is advisable for the teacher to offer students additional practical tasks. Here are some of them:

- Try to build bridges from other household materials, such as aluminium foil, wax paper or cardboard. Which material is the strongest?
- Experiment with different shapes. What happens if I roll up a sheet of paper in the shape of a tube or a triangle?
- Try making a longer bridge by gluing two sheets of paper together. How long can you skate a bridge before it collapses under its own weight?
- Is bridge design important?
- How safe are different bridges?
- Are there bridges on your way to school or near your house? What type are they?

Such a project can be proposed for a science fair. Children will probably also find interesting stories about professions related to objects of the project.

Project 4. Notable Women. It's no secret that there have always been women in science. They conducted research in various sciences. Some of them made important discoveries.

Studying such stories is important for girls to see themselves as future scientists. With the "Notable Women" mobile application, students will be able to read about an outstanding female scientist, her ideas and research. It is also advisable to create appropriate presentation materials such as info-graphics, videos, booklets, posters, etc.

As a result of presenting these materials, students should see the influence of many women throughout history and think about the thesis that "power is the ability to influence". The completion of the project can be held as a discussion on the question "What is the relationship between power and influence"?

Project 5. The universe. The content of the project is to study the structure of the universe and study astronomy using the Big Bang AR application. This software is the result of a collaboration between CERN and Google Arts & Culture. It will allow students to see the shape of the universe in the palm of their hand, to witness the formation of the first stars, our solar system and the planet Earth. Children will be able to immerse themselves in the mystery of the early universe and watch events unfold around them, for example in their own classroom.

It is advisable for the teacher to ask students to make a model of the solar system and calculate the size of the planets. To see how much space there is between different objects in the solar system, students will have to practice with fractions.

The task of technology may involve the manufacture of models of planets. Children should think about whether it is possible to place "planets" so that their model is proportional to real orbits.

Students can work in groups to solve problems such as:

- search for scale factor;
- calculating the size of the planets;
- creation and processing of graphic 3D models.

Such tasks develop mathematical skills in scaling, and allow a better understanding of space scales. With the help of the Big Bang AR application, the project participants should summarize the concepts and visualize the basic concepts.

Unlike traditional classroom teaching, STEM projects bring students closer to practice, bridging the gap between theoretical problem solving and practical implementation of acquired knowledge. Often in the project the need to use knowledge from different disciplines contributes to the awareness of new material. Career discussions can help students make important connections between the lesson in the classroom and the specifics of STEM professions in the real world.

We conducted some research to understand the attitude of practicing teachers to the STEM projects outlined above. Expert evaluation was chosen as the main method of the experiment. Experience shows that it is effective for assessing the qualitative characteristics of educational methods in various scientific studies (Kuzminska et al., 2019). Decision-making by experts is based on a reliable presentation of the current situation, a correct understanding of the essence of the methodology and the completeness of the characteristics of its components.

We selected 64 computer science teachers as experts. They attended TMPIRE teacher training courses in 2020. To estimate the desired sample size, we used the results of (May and Looney, 2020). To ensure the quality and uniformity of expert assessments, we selected teachers according to criteria such as:

- Work experience more than 10 years;
- 80–90% success rate of learning in TMPIRE;
- The highest national professional category;
- Experience in using augmented reality technologies.

We asked these teachers to evaluate the projects described above according to the following criteria.

Cr1. Relevance of the project as the importance of the project for students. Here we understood the integrated indicator of the project. It determines the possibility of student development through a combination of cognitive, research interdisciplinary activities of students.

Cr2. Realism of the project tasks and availability of execution. The criterion evaluates the possibility of project implementation by students of a certain age group, the compliance of its tasks with the level of preparation of students.

Cr3. Possibility of project development. The integrated indicator involves assessing the prospects of the project through the expansion of research objects, participation in affiliate programs, profit The content of the project is an information component.

Cr4. The criterion should assess the possibility of developing ICT competencies, in particular their skills for the use of augmented reality applications.

The experts ranked each of the projects according to these criteria. The evaluation was performed on an ordinal scale from 1 to 5. One point was awarded to the least significant indicator and five points to the highest significant one. We summarized the results of the survey in the table. To transform evaluation into ranking, we asked experts to evaluate all projects according to the first criteria, then according to the second, third, and fourth. The table is available by the link https://drive.google.com/file/d/1xkuiKZUF33nMYNwnCaQaOSkuErLJXqxb.

The most obvious value of the criterion is its overall rating (average rating), which is determined by all experts. This statement is also true for projects. However, it is necessary to check whether this rating is not accidental. This means that we need to check the consistency of expert assessments. Since the distributions of estimates by all criteria and by all projects are not normal (p-value $< 2.2 \times 10^{-16}$), we should use non-parametric criteria to process these statistics. As is known, the Kendall rank correlation coefficient is used to determine the relationship between only two variables. To assess the agreement of more than two evaluators, it is advisable to use Kendall's coefficient of concordance (W).

Statistical processing of ranking results was carried out using the R language. In particular, we used its libraries such as: nortest, irr, Kendall, DescTools, ggplot2.

To calculate the coefficient W, we used the function:

```
KendallW(tcr1, correct = FALSE,
    test = TRUE, na.rm = FALSE)
```

where

- tcr1 is a transposed dataframe of evaluations of all projects according to the 1st criterion;
- correct is a parameter that determines the need to use the emission correction when calculating W;
- test is a logical indicating whether the test statistic and p-value should be reported;
- na.rm is a parameter to skip empty score values.

The results of the calculation of W for criteria 1-4 are presented in table 4.

Table 4: Generalized data for calculating the concordance coefficient W for criteria.

	Kendall chi-squared	**P-value**	**W**
Cr1	152.79	$< 2.2 \times 10^{-16}$	0.60
Cr2	138.70	$< 2.2 \times 10^{-16}$	0.54
Cr3	157.82	$< 2.2 \times 10^{-16}$	0.62
Cr4	130.93	$< 2.2 \times 10^{-16}$	0.51

To interpret the obtained results, we used the following ranges of values of the coefficient W (May and Looney, 2020):

- 0.01– 0.20 – poor agreement;
- 0.21– 0.40 – fair agreement;
- 0.41 – 0.60 – moderate agreement;
- 0.61 – 0.80 – good agreement;

- 0.81 – 1.00 – very good agreement.

From these data we can reject the zero and accept the alternative hypothesis of the existence of agreement between experts. Unfortunately, we have to state that the assessments of experts on the criteria of realism and development of ICT competencies are less consistent. This indicates a difference in the estimates of this criterion for almost all projects.

We additionally performed the calculation of the coefficient W for projects (table 5). We took into account that the same project received the same points from the experts. Therefore, the "correct" parameter was used in the KendallW function. It corrects the calculation of W if there are related ranks.

As can be seen from the table, the Bridges project was ranked by experts on fair agreement. Instead, DaVinci and Woman received good values of W coefficiente.

Therefore, the sums or averages of expert estimates for almost all projects can be objective indicators of the experiment. Summary table6 contains systematized data of average values of evaluations for criteria and projects.

Figure 5 contains a graphical representation of the results obtained. It demonstrates the distribution of total ratings by all criteria.

The DaVinci project received the highest average value of expert estimates. Teachers consider it relevant, realistic and effective for the development of ICT competencies. According to the survey, the SkyScrapers project turned out to be relevant and promising. The Bridges project also received a high rating for the development of ICT competencies. Despite the overall low score, experts consider the "Notable Women" project to be promising. This may be due to the fact that most of the teachers surveyed were women.

In general, STEM augmented reality projects are an effective tool for organizing students' search activities. The objectives of such projects demonstrate the integration between mathematics, computer science, engineering, history, art. The STEM concept is a source of interdisciplinary innovation in school education. As our experiment showed, the organization of STEM projects with augmented reality aroused the interest of computer science teachers. They found the projects relevant and useful for the development of ICT competencies. We can predict that the use of augmented reality technologies will also interest students and will have a positive impact on their choice of future profession.

We recommend scientists, lecturers, teachers to create more STEM projects. This should help to involve students in interdisciplinary learning to gain real practical experience, the development of lifelong learning skills.

5 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

Table 5: Generalized data for calculating the concordance coefficient W for projects 1-5.

	Kendall chi-squared	P-value	W
DaVinci	153.1	$< 2.2 \times 10^{-16}$	0.80
Universe	80.94	$< 2.2 \times 10^{-16}$	0.42
Bridges	70.72	$< 2.2 \times 10^{-16}$	0.37
SkyScrapers	111.74	$< 2.2 \times 10^{-16}$	0.58
Notable Women	132.19	$< 2.2 \times 10^{-16}$	0.69

Table 6: Final table of expert evaluation.

	DaVinci	Universe	Bridges	SkyScrapers	Women
Cr1	3.27	3.59	2.22	4.53	1.39
Cr2	4.58	3.70	2.92	1.91	1.89
Cr3	1.61	1.86	3.17	3.94	4.42
Cr4	4.27	2.27	4.11	2.63	1.73
ProjectSum	13.73	11.42	12.42	13.01	9.43

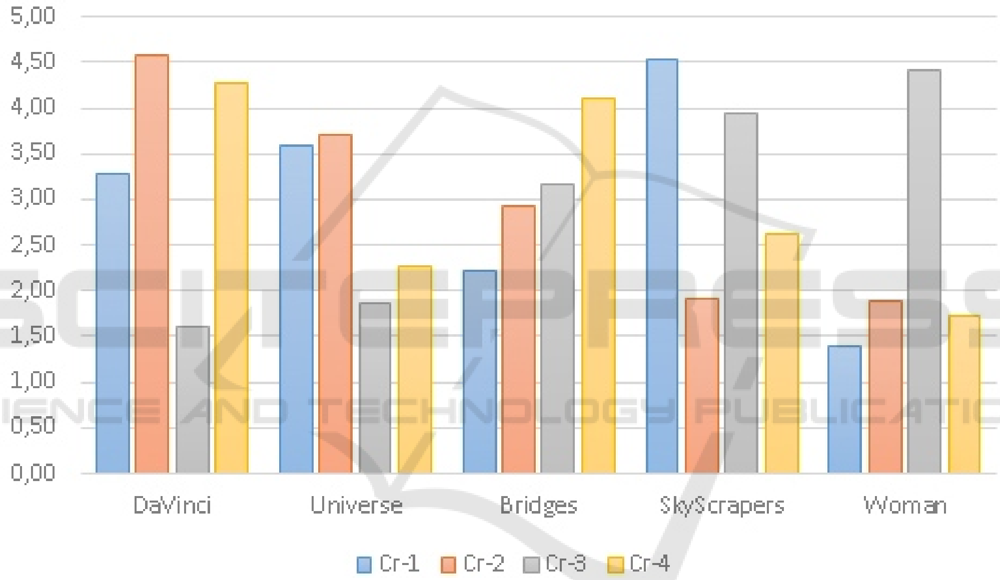

Figure 5: Diagram of distribution of expert assessments according to criteria 1-4.

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. Expert assessments can be only one of the methods for determining the complexity of the STEM project, and therefore have a recommendatory nature.

There is a need for future research on technical and methodological issues of using augmented reality technologies in school STEM projects. For example, the development of repositories of educational AR-applications to support computer science is currently in demand.

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