VIRTUAL AND AUGMENTED REALITY TECHNOLOGY IN EDUCATIONAL PROCESS: ISSUES AND PERSPECTIVES

A. Nurutdinova[1], E. Dmitrieva[2], D. Shakirova[1], Z. Fazlyeva[1], E. Panfilova[3]

[1]Kazan Federal University (RUSSIAN FEDERATION)
[2]Kazan State Power Engineering University (RUSSIAN FEDERATION)
[3] IACLD CPE ANCO (RUSSIAN FEDERATION)

Abstract

Development of modern society, computer technology, globalization, and informatisation affect all spheres of social structure, including education. The meaning, purpose, and mission of modern education is not just the basic knowledge acquisition and necessary skills and abilities, it is the development of a cultural code, an independent approach to the assimilation of new knowledge, cultural values, new forms and types of activities. Virtual and augmented reality are among the key information technologies of the digital economy. Experts predict the growth of the VR / AR technology market and consider it one of the most promising. The strategy for the development of the information society involves the training of specialists in the field of information technology. At present, to solve this problem, innovative methods are used that allow you to more effectively assimilate new knowledge with a high degree of enthusiasm in the educational process. These include, among other things, virtual and augmented reality technologies, that is, they can be both a learning tool and an object of research. Technology and augmented virtual reality are used in medicine, training programs and simulators are being developed, medical devices are used to simulate and conduct operations. In view of the above, this has to do with the impact that technology and augmented virtual reality can have on education.

Keywords: Virtual reality, augmented reality, educational process, information technology, digital economy, new technologies, innovation, diffusion, technological.

1 INTRODUCTION

The socialisation, education and professional activity in a post-industrial society are accompanied by an unprecedentedly fast-changing information infrastructure in business life. Modern social phenomena are the continuous learning of new knowledge and human existence in different spheres of communication process which requires permanent mastering of new communication formats at all levels. The educational sphere is one of the most promising and popular areas of development and application of virtual and augmented reality technologies. In modern practice of secondary and higher schools, there are already many examples of AR and VR reality technologies - from virtual tours in school history classes to training professional competences at different levels and majors by means of virtual simulation. The latest state documents and the reality of information society dictate an increasing speed of implementation the latest information and communication technologies.

Recently, there has been a lot of discussion about augmented reality and virtual reality. The rapid development of augmented and virtual reality technologies has been significantly influenced by the mobile device market, which has changed beyond recognition over the past 10 years: touchscreen smartphones and tablets with full-fledged operating systems, equipped with a powerful video camera, positioning sensors and gyroscopes have replaced push-button devices [1], [2], [3]. The increasing computing power of devices and ubiquitous digital transformation have elevated augmented and virtual reality technologies to a fundamentally new level, where they can go beyond the entertainment industry and cover a wide range of new areas of human activity.

Today, virtual and augmented reality technologies have become a source of technological opportunities and contribute not only to the creation of conceptually new markets, but also to the expansion of existing ones [4], [5]. Apart from the entertainment sector, augmented and virtual reality technologies are now widely used for design, training and retraining in software products for engineers, architects, designers, realtors and retailers. Augmented and virtual reality technologies are used in medicine; training programmes and simulators are developed on their basis; medical devices simulate and perform operations. In view of the above, the question of the impact that augmented and virtual reality technologies can have on education is relevant. In this regard, this study aims to identify the relevance degree and

demand, as well as to determine the situational level of virtual technology implementation in the educational activities of Russian universities.

The present study focuses primarily on augmented reality (AV) and virtual reality (VR). The fundamental difference is that virtual reality constructs a fully digital world, completely limiting the user's access to the real world, while augmented reality merely adds elements of the digital world to the real world by modifying the space around the user. In virtual reality, the environment is created by comprehensively influencing its perception through the use of virtual reality helmets or other technical means that dynamically update the user's visible space. In the human brain, neurons respond to virtual elements in the same way as they do to elements in the real world. Therefore, a person perceives the virtual environment and reacts to events occurring within the virtual world in the same way as those occurring in reality [6].

2 LITERATURE REVIEW

In Russian higher education, mixed reality technologies are used no less widely. Within the framework of the All-Russian Scientific and Methodological Conference “Virtual and Augmented Reality - 2020: Status and Prospects” a number of practical examples of AR and VR technologies use in the educational process were presented, as well as prospects and conditions for their further successful implementation were discussed. In particular, Y.N. Ovechkis points out that active implementation of such aids in the educational process requires a systematic approach and a number of comprehensive studies, and necessarily from two sides: “first, from the users’ side, i.e. from the educational system - teachers, methodologists, curriculum developers; second, from the technical executors - hardware and software developers” [7, pp. 264-269]. A. Yu. Rolich, K. Deryabina. A. and A. Kovalev. V. argue that “the use of CAVE-systems in universities to train specialists in various fields can not only improve the quality of higher professional education, but also allow universities to strengthen their research potential” [7, pp. 283-288].

A. A. Shcherbakov, analyzing the use of augmented reality technology at different stages of the life cycle in education, comes to the conclusion that “augmented reality technology is just a vivid example when a technology developed at the R&D stage has a full right to be implemented and becomes a final product” [7, p. 363-365]. The author cites the examples of the Unity game engine and Vuforia platform being in demand for the development of educational technologies.

B.V. Yurieva examines the possibilities of virtual reality systems in education, science and engineering. The researcher gives examples and formulates advantages of new technologies: “Virtual reality systems make it possible to study navigation, animal and human behavior, giving powerful experimental support and increasing the ecological validity of experiments. Virtual reality speeds up development and improves training of engineers. Due to the flexibility and controllability of virtual environments, recording capabilities and the immersive effect, such systems are widely used in various fields of science, education and engineering” [7, pp. 366-371].

E. B. Vorobyov describes the principles of augmented reality application as a way to interact with applicants. Provided certain rules are followed, "an interactive model can be presented to an applicant, which can not only expand his/her understanding of the training areas under consideration and the industry as a whole, but also further orient him/her towards postgraduate activities" [7, p. 81-85].

Thus, the education in Russia is undergoing the transformation: the latest educational and communication technologies, including virtual and remote access to educational systems and resources, are being actively introduced into the learning process. A number of trends that have emerged in the modern economy have an impact both on the economy as a whole and on the Russian market for educational services in the higher education system, which is one of the most promising and dynamic sectors of the modern national economy. The researchers note: “Innovative progress and opportunities for higher education institutions force them to respond quickly to economic and social changes, given the current situation in the market of knowledge, technologies and educational services” [8], [9], [10].

3 METHODOLOGY

Semi-structured interviews were conducted to study the experience of AR / VR technologies application and their influence on the educational processes. Questions about the use of new technologies were formulated taking into account the research [1], [2], [3]. Questions about barriers in the use of technology are formulated with research [4], [5] in mind.

Forty people participated in the interviews, the respondents were both genders - 20 men and 20 women, predominantly under the age of 40 (85.8%). Respondents were selected among informants who: 1) have experience of using virtual or augmented reality technologies at their work; 2) are aware of examples of such use in other institutions in their industry; 3) work in a company that is planning to implement augmented or virtual reality solutions in the near future; 4) are directly involved in the development, implementation or content for augmented or virtual reality; 5) have a scientific and research interest in the field (have an understanding of the current level of technology development).

Respondents were asked to complete a distance interview using the online application “Google Forms”. The choice of the interview format was due to the impossibility of face-to-face meetings and interviews with respondents due to various circumstances. The questions were grouped into three blocks: general block - questions in order to learn more about the respondent; introductory block - questions to find out the respondent's technology awareness; a special block - questions directly related to the subject of the survey.

The last two blocks contained questions to be answered by selecting one of several options or by giving a detailed answer. In case the forms were poorly completed, there was a discussion of the answers at the third stage in order to supplement and clarify them. Communication with respondents was conducted via voice or text chat in messengers (FB, VK, Telegram, Discord).

Particular attention was paid to the discussion of the following questions:

1 Do you see the potential for using augmented and virtual reality technologies at your work (positive effect of their use)?

2 What risks can be faced (have you encountered) when using these technologies?

3 What factors, in your opinion, hinder implementation of augmented and virtual reality technologies? What problems have you faced?

4 What does the market for augmented and virtual reality technologies expect in the next 5 years?

To gain a deeper understanding of the results, a SWOT analysis was carried out in order to 1) to systematize the data obtained during the previous stages of the research; 2) to identify the weaknesses and strengths of augmented and virtual reality technologies; 3) to identify opportunities for their use and threats that educational institutions may face.

4 RESULTS

In general, the majority of respondents have an optimistic attitude towards technology (71% were positive). Emotionally, the experience is described as “useful”, “necessary”, “changing the future”, “exciting”, “effective”, “productive”, “interesting”, “has potential”, “no prospects for further use in the near future”, “generally entertaining but little implementation”, “does not justify the costs”. Five respondents are directly involved in the development of educational software (content) using augmented and virtual reality. Another 32 respondents used augmented and virtual reality in their work: more than once - only 15 people, 4 people use it on a permanent basis. Six respondents expressed an opinion on the possibility of introducing the technology now, while another 18 considered that in Russia, the technology may not become widespread until 2024-2025 at the earliest. Nine respondents have not dealt with augmented and virtual reality in their work, but five of them see the potential of technology in their field (education, medicine and sociology). Nine believe that their industry is ready to adopt these technologies today (education, sales, logistics, automation, aviation, sociology and psychology). Thirteen respondents indicated high potential for application in the near future. Three people have doubts about the development of the Russian B2B segment in the near future, explaining this by the unfavorable institutional environment and the lack of necessary infrastructure.

The most optimistic forecasts were given by respondents working in large commercial companies. Representatives of medium and small enterprises and those working in the public sector and budgetary institutions were reticent. This is easy to explain, because in the early stages, adopting technology requires a lot of courage and investment. However, when technology adoption becomes mainstream, it is small and medium-sized businesses that will benefit the most, as the benefits, for example through significant reductions in transaction costs, will outweigh the costs of implementation.

In addition to entertainment and games, respondents named education, medicine, construction and real estate, commerce and marketing as the most promising areas for the introduction and application of technology (Figure 1). The superiority of virtual reality over augmented reality is observed only in the areas of entertainment, games and tourism that are of greater interest to consumers.

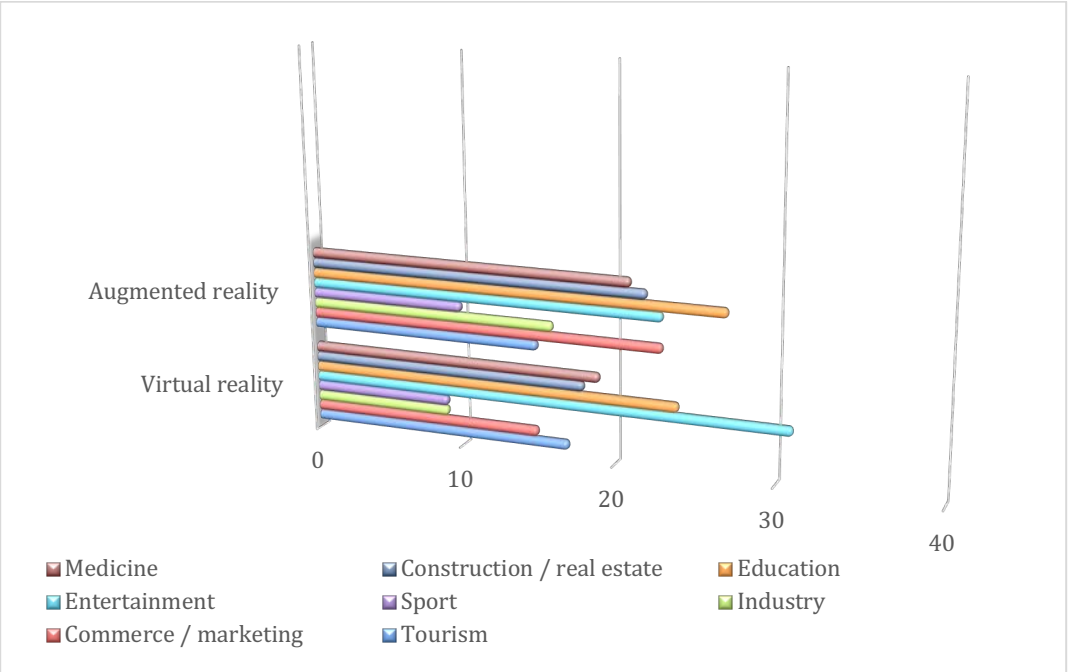

Figure 1. Prospective applications of virtual and augmented reality technology (according to respondents).

A sociological survey was conducted in order to determine the prospects of implementing VR and AR programs in the educational process, as well as to identify the attitude of the teaching staff of Kazan Federal University to new educational technologies and "teacher-student" communication systems. Eight respondents from the teaching staff of the federal university took part in the qualitative sociological research in the format of expert interview.

The results of the sociological survey allowed us to draw the following conclusions. First, teachers have a positive attitude towards the trends of using modern information and communication technologies in higher education and are already active with digital education tools. At the same time, most respondents stressed as some learning formats should be taught "live", visually. Not all teachers are users of social networks, and they are against the involvement the social networks in the educational process, noting that there is too much distracting. Thus, teachers are positive about the use of mobile gadgets and mobile applications in the educational process, noting the convenience and extensive functionality of smartphones and applications. At the same time, teachers emphasise that mobile applications can be used in the educational process only as a supplementary learning digital tool. Secondly, they pointed out that cloud storage technology is very effective for HEIs, and that this technology should be introduced and developed in HEIs. Cloud storage allows a convenient and fast information exchange, which in the educational process is an important communication tool. At the same time, educators pay special attention to cyber-security issues, the threat of data leakage, as well as improvements in technical platforms. Thirdly, the opinions and assessments expressed by HEIs teachers regarding the specialised AR are overwhelmingly positive. Teachers are ready to use this AR in their professional activities, provided it is adapted to the disciplines they teach. In addition, the respondents were in favour of the general positive outlook for the use of AR in the educational process, emphasising the particular relevance of such technologies in practice-oriented specialities, such as biology, medicine, physics and chemistry.

4.1 Virtual and augmented reality technology projects

In this regard, further implementation of virtual forms into the education process is very relevant, as it allows HEI to communicate in the same language with the target audiences - students, applicants, students, other groups of young people seeking further education. The implementation of VR and AR technologies in educational services has many advantages:

- full involvement in the process and focus on the subject due to the full 360o immersion in the area of interest and due to the playful and interactive nature of the communication;
- non-restricted visualisation, i.e. subject demonstration in every degree of detail;

- safety of virtual training models in teaching life- and health-threatening professions.

An analytical review of the VR and AR market estimated revenues from the software sale for schools and universities at $300 million by 2020 and $700 million by 2025 [9]. Experts estimate that the education system will spend about five years for the purchase and implementation of 8 million the VR and AR devices. At the first stage, the VR and AR systems will be popular primarily in schools; later, HEI will also become widely interested in these technologies.

A virtual augmented reality laboratory “My Profession”: there are 30 interactive projects (22 of them are projects at the intersection of VR and AR technologies). Thanks to virtual reality glasses, the user sees 3-D scenes that can be interacted with using a joystick. The museum has prepared educational and entertainment projects using projected AR. For example, by playing a game, a child can learn about major industries, such as building a building step-by-step or learning about alloys by mixing their components in a melting pot. The opening of the laboratory has attracted a new auditorium. The project demonstrated that in education, the use of gamification methods combined with the visualisation of material using virtual elements allows to engage students more deeply into the educational process, to retain their attention and increase their motivation for learning, respectively, the acquired knowledge and skills are better assimilated. Visitors were invited to see the interactive science park, the atomic energy information centre, the winter garden, the planetarium, educational circles and programmes, etc., which will consequently increase the institution's revenue not only through the museum itself, but also through the increase of new consumers in other projects Interactive Museum.

The processes of implementation of AR and VR technologies in the sphere of educational services of HEI are at an early stage, but there are already examples of successful implementation of the state programme “Digital Economy of the Russian Federation”. According to this programme, approved by the Russian government in July 2017, the VR and AR technologies platform is to be implemented in the creation of interactive complexes for automated learning systems for universities: it will be implemented for interactive computer classes [7]. The platform will be used to create the first 1,000 educational programmes by 2021. According to experts' comments, the personnel training quality will improve, including the number of errors in operations will decrease by 40% by 2020 [9]. The relevant platform will provide specialists with the following opportunities:

- acquiring knowledge and skills of operating complex equipment, performing laboratory and hazardous works;
- acquiring knowledge of how to reduce the probability of occurrence of off-nominal situations;
- gain experience in error correction and restoration of normal working conditions in case of abnormal situations.

The prospects of introducing virtual formats of communication are also incorporated in the priority federal project “Universities as Centres of Innovation Creation Space”, which is aimed at creating university innovation centres, technological and social development of the regions. Such centres act as a basis for the space of innovation creation and a source for positive changes in the state and regional environment. According to the project passport, it is planned to create at least 100 university centres in the Russian Federation by 2025 [7], [9]. The Science and Education Council under the President of the Russian Federation approved the systematic project of the Strategic Initiative Agency “Cyber Russia”, which is a federal educational programme aimed at training specialists and creating start-ups in the field of computer software development using virtual, augmented and mixed reality technologies and block chain technology [10]. It is planned that by 2020, the number of programme participants may reach at least 10 thousand people, and the number of start-ups launched for commercial implementation, at least 25 [9].

The processes of implementation of VR and AR technologies in universities are quite active and have a wide range of implementation. Application of such innovative technologies as AR and VR-reality not only adds innovative character to educational programmes, but also significantly strengthens the position of HEIs in the educational market. The use of VR and AR technologies represents HEIs in the image of target audiences as modern, advanced and high-tech educational institutions. A positive effect has been obtained from the introduction of VR and AR technologies into educational processes, from its use as a tool for attracting new audiences and increasing profits. The experience of implementing technologies in general suggests their potential for further use in education. The development of national projects in education, science and the digital economy should be guided by the following objectives:

- creating infrastructure for advanced R&D;

- ensuring digital security;
- ensuring highly qualified personnel training for the digital economy;
- creation of end-to-end digital technologies primarily based on local developments;
- introduction of digital technologies and platform solutions in priority sectors of the economy and the social sphere;
- founding of a comprehensive system for financing projects (venture financing, other development institutions) for the development and implementation of digital technologies and platform solutions.

We believe that learning using VR and AR technologies is convenient and effective for students at Russian universities. Students of Tomsk Polytechnic University can take practical classes at the virtual polygon - an exact copy of the university's base in the Republic of Khakassia. Tomsk State University is introducing training with the help of virtual reality glasses, the programmes for which can replace traditional teaching aids [11].

In recent years, a number of Russian universities have announced and are implementing undergraduate programmes related to VR. Moscow Polytechnic University – the programme “Augmented and Virtual Reality Technologies in Printed Products” introduces students to augmented and virtual reality application development systems, gives working skills with hardware and software complexes of VR and AR technologies. Students learn how to create interactive applications for mobile devices and print products with augmented reality elements [12].

St. Petersburg Polytechnic University implements the programme “Virtual Prototyping Technologies in Mechanical Engineering”. The School of Design of the National Research University Higher School of Economics has developed and implements the Game Design and Virtual Reality programme. The programme trains specialists capable of creating games using virtual reality technology.

Far Eastern Federal University and the Cyber Russia project launched a master's degree educational programme in VR technologies development in 2017. Game development & VR students will learn to develop and implement promising types of software based on virtual and augmented reality technologies. By 2020, it is planned to graduate more than 100 qualified and in-demand specialists in the IT market, as well as get expert tutors capable of teaching children and helping them to navigate in the IT sphere. Instead of lectures, students will practice and every six months they will present and defend their projects during hackathons [13].

Southern Federal University has opened a virtual reality laboratory. This project was created at the initiative of postgraduate students and young scientists of the International Research Centre “Intellectual Materials” with the support of the START Programme Innovation Fund. The centre now has international research and scientific laboratories working on nanodiagnostics, nanopyritonics, photonics and quantum computers [14].

Kazan Federal University implements the master's programmes in “Virtual and Augmented Reality Technologies” and “Virtual and Augmented Reality Technologies, Visualisation and Game Development”. Today there are more than 20 laboratories at Kazan Federal University, among them: Mobile Lab, Digital Media Lab, Intelligent Robotics Lab, Smart Education Lab, Data Lab, Cloud Lab, Web Lab, Mentor Lab, 42 Lab, FlatStack Lab, BARS Group Lab.

The Russian Science Foundation has launched a project to create virtual tours of Russia's leading scientific laboratories, including laboratories of universities. The project is called “Science in 360°” format and is a series of spherical panoramic images of universities’ R&D institutes in Russia. With these virtual tours, users can move around the premises, view the equipment, and receive detailed information via text, audio and video staccato [15].

It is also worth noting the activities of the National Technological Initiative, in particular the action plan “Neuronet”. According to this document, already by 2025, it is planned to implement a number of activities towards the integration of VR and AR technologies in education, medicine, entertainment and sports; by 2035, it is expected to implement systems of human integration with the virtual environment. The government plans to provide comprehensive support to developers in the field of VR and AR technologies.

4.2 SWOT analysis of augmented and virtual reality technologies

Through interviews and case study analysis, data was obtained to identify the weaknesses and strengths of AR and VR technologies, opportunities for its application and threats that universities may face. In order to systematise information from sources and interviews, a SWOT-matrix was constructed (Table 1). AR and VR technologies have a number of advantages. Their possibilities are practically limitless in education, medicine, science, sports, industrial use, as well as in games and entertainment and other spheres. If the potential of technology is used intelligently, companies can achieve the desired benefits by increasing employee productivity, improving work processes, attracting new consumers and customers, and deepening the professional competencies of their employees.

Table 1. SWOT analysis of augmented and virtual reality technologies.

Strengths: – Diversity of applications; – Native management; – Innovativeness; – Powerful 3D tool; – Real-time interaction	Weaknesses: – Technological limitations (imperfect software); – Lack of quality content; – High costs; – Lack of qualified personnel; – Negative impact on health
Opportunities: – High market potential, available niches; – Readiness to adopt the technology; – Growing investor interest; – Related markets development	Threats: – Competitive technologies (internet of things, artificial intelligence, robotics); – Insufficient knowledge about experience; – Unpredictable external environment; – “Young” market

5 CONCLUSIONS

This study suggests a high degree of relevance and demand for the use of the VR and AR technologies in higher education, as well as an active process of virtual learning technologies implementation in Russian HEIs. The result of the research is the statement of successful introduction of mixed reality technologies in the sphere of higher professional education, as well as revealing of positive attitude of Kazan Federal University teachers to the use of the latest technologies of VR and AR technologies in the educational process. Due to the unprecedented speed of information and communication technologies implementation, Russian higher educational institutions are introducing the latest learning formats, which not only improve the education quality, but also increase the competitiveness level of Russian universities in the global educational market. The process of introducing new learning formats is not only in demand, but also mutually conditioned. On the one hand, students are interested in any technological innovations in learning, and as part of their research work, they independently develop proposals and projects to improve the effectiveness of “teacher-student” communication systems. On the other hand, teachers are well aware of the latest virtual technologies, use online systems in their work and are ready for further implementation of information and communication technologies in the educational process of higher education institutions. It can be argued that AR and VR-reality technologies, being actively upgraded every day, have a huge potential for development and further prospects in the sphere of higher professional education.

ACKNOWLEDGEMENTS

This paper has been supported by the Kazan Federal University Strategic Academic Leadership Program.

ABBREVIATIONS

HEI – Higher Education Institutions

AR – augmented reality

VR – virtual reality

R&D – research and development

REFERENCES

[1] A.V. Trachuk, N.V. Linder, “Adaptation of Russian firms to changes in the external environment: the role of e-business tools,” *Management Sciences*, vol. 1. pp. 61-73, 2016.

[2] A.V. Trachuk, N.V. Linder, “Innovation and Productivity of Russian Industrial Companies,” *Innovation*, vol. 4 (222). pp. 53-65, 2018.

[3] A.V. Trachuk, N.V. Linder, “Innovation and Productivity: an Empirical Study of Growth Barriers by Longitudinal Analysis,” *Management Sciences*, vol. 7, pp. 78-93, 2019.

[4] A.V. Trachuk, N.V. Linder, “Prospects for mobile payment services in Russia: a theoretical approach to understanding of distribution factors,” *Bulletin of Faculty of Management*, vol. 1-1. pp. 322-328, 2020.

[5] A.V. Trachuk, N.V. Linder, “Distribution of e-business tools in Russia: results of empirical research,” *Russian Management Journal*, vol. 15(1), pp. 27-50, 2020.

[6] S.M. LaValle, “Virtual Reality”. University of Illinois. [S.l.:] Cambridge University Press. 418 p. URL: http://vr.cs.uiuc.edu / vrbook.pdf, 2017.

[7] Virtual and augmented reality-2020: state and prospects: Collection of scientific and methodological materials, abstracts and articles of the conference. Under the General editorship of doctor of technical Sciences, Professor D. I. Popov. Moscow, 2020, 386 p. (in Russ.)

[8] L.S. Nabokova, F.R. Zagidullina. “Outlooks of applying augmented and virtual reality technologies in higher education”, *Professional education in the modern world*, vol. 9, no. 2, pp. 2710–2719, 2019.

[9] Official website of the Ministry of Education and Science of the Russian Federation: priority project «Universities as centres of innvation space». Available at: https://минобрнауки.рф/проекты/вузы-центры-инноваций (accessed March 10, 2018). (in Russ.)

[10] Project «Cyber Russia». Available at: http://cyber-russia.ru (accessed March 10, 2018). (in Russ.)

[11] Official website of TSU / Panel discussion «Educational environment and global education in the digital age». Available at: http://www.tsu.ru/meetings_rector/panelnaya-diskussiya-obrazovatelnaya-sreda-i-global-noe-obrazovanie-v-tsifrovuyu-epokhu (accessed March 10, 2018). (in Russ.)

[12] Official website of the Moscow Polytechnic University / Educational program (profile) «technologies of augmented and virtual reality in printed materials». Available at: http://mospolytech.ru/op/files/op_c81e728d-9d4c2f636f067f89cc14862c_1513434981.pdf (accessed March 10, 2018). (in Russ.)

[13] Official website of the University / news. Available at: https://www.dvfu.ru/admission/news/at_the_university_run_a_masters_programme_in_augmented_and_virtual_reality/ (accessed March 10, 2018). (in Russ.)

[14] Official site of southern Federal University. Available at: http://sfedu.ru/www2/web/press-center/view/news/54 557 (accessed March 10, 2018). (in Russ.)

[15] Russian science Foundation / Science in 360° format. Available at: https://www.sprgm.ru/360 (accessed March 10, 2018). (in Russ.)

[16] Garzón, Juan, Kinshuk, Baldiris, S., Gutiérrez, J., & Pavón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educational Research Review*, *31*, 100334. https://doi.org/10.1016/j.edurev.2020.100334

[17] Iqbal, Muhammad Zahid; Mangina, Eleni; Campbell, Abraham G. (2021): Current Challenges and Future Research Directions in Augmented Reality for Education. TechRxiv. Preprint. https://doi.org/10.36227/techrxiv.16369224.v1

[18] Palamar, Svitlana P. та Bielienka, Ganna V. та Ponomarenko, Tatyana O. та Kozak, Liudmyla V. та Nezhyva, Liudmyla L. та Voznyak, A (2021) *Formation of readiness of future teachers to use augmented reality in the educational process of preschool and primary education* AREdu 2021 Augmented Reality in Education 2021 Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021) (2898). с. 334-350. ISSN 1613-0063.

[19] Abad-Segura, E., González-Zamar, M.-D., Luque-de la Rosa, A., & Morales, M. (2020). Sustainability of Educational Technologies: An Approach to Augmented Reality Research. *Sustainability*, *12*(10), 4091. https://doi.org/10.3390/su12104091

[20] Brown, M., McCormack, M., Reeves, J., Brooks, C., Alexander, B., Grajek, S., Bali, M., & Bulger, S. (2020). *2020 EDUCAUSE Horizon Report: Teaching and Learning Edition* (p. 58). EDUCAUSE. https://library.educause.edu/-/media/files/library/2020/3/2020_horizon_report_pdf.pdf?la=en&hash=08A92C17998E8113BCB15DCA7BA1F467F303BA80

[21] Calabuig-Moreno, F., González-Serrano, M. H., Fombona, J., & García-Tascón, M. (2020). The Emergence of Technology in Physical Education: A General Bibliometric Analysis with a Focus on Virtual and Augmented Reality. *Sustainability*, *12*(7), 2728. https://doi.org/10.3390/su12072728

[22] J. Herron. “Augmented Reality in Medical Education and Training,” *Journal of Electronic Resources in Medical Libraries,* vol. 13, issue 2, pp. 51–55. DOI: 10.1080/15424065.2016.1175987, 2016.

[23] D. Kelly, T.N. Hoang, M. Reinoso, Z. Joukhadar, T. Clements, F. Vetere. “Augmented reality learning environment for physiotherapy education,” *Physical Therapy Reviews*, vol. 23, issue 1, pp. 21–28. DOI: 10.1080 /10 833 196.2018.1, pp. 447 256, 2018.

[24] H. Bower, C. Howe, N. McCredie, A. Robinson, D. Grover. “Augmented Reality in education – cases, places and potentials,” *Educational Media International*, vol. 51, issue 1, pp. 1–15. DOI: 10.1080/ 09 523 987.2014.889 400, 2014.

[25] J. Iqbal, M.S. Sidhu, S. Wang. (Reviewing Editor) “A review on making things see: Augmented reality for futuristic virtual educator,” *Cogent Education*, vol. 4, issue 1. DOI: 10.1080/2331186X.2017.1287392, 2017.

[26] A.I.M. Elfeky, M.Y.H. Elbyaly. “Developing skills of fashion design by augmented reality technology in higher education,” Interactive Learning Environments, DOI: 10.1080/10494820.2018.1558259, 2018.

[27] Avila-Garzon, Cecilia, Jorge Bacca-Acosta, Joan Duarte, and Juan Betancourt. "Augmented Reality in Education: An Overview of Twenty-Five Years of Research." (2021).

[28] Mystakidis, Stylianos, Athanasios Christopoulos, and Nikolaos Pellas. "A systematic mapping review of augmented reality applications to support STEM learning in higher education." *Education and Information Technologies* (2021): 1-45.

[29] Radu, I., Joy, T., Bott, I., Bowman, Y. and Schneider, B., 2021. Using Augmented Reality in Education: Opportunities and Pitfalls.

[30] Purnama, Sigit, Nazilatus Syukriyah, Maulidya Ulfah, Ahmad Arifuddin, and Hafidh Aziz. "Augmented Reality in Education in Era 4.0." (2021).

[31] Sala, Nicoletta. "Virtual reality, augmented reality, and mixed reality in education: A brief overview." *Current and prospective applications of virtual reality in higher education* (2021): 48-73.

[32] Buchner, Josef, and Michael Kerres. "Students as Designers of Augmented Reality: Impact on Learning and Motivation in Computer Science." *Multimodal Technologies and Interaction*5, no. 8 (2021): 41.

[33] Abdinejad, Maryam, Borzu Talaie, Hossain S. Qorbani, and Shadi Dalili. "Student perceptions using augmented reality and 3d visualization technologies in chemistry education." *Journal of Science Education and Technology* 30, no. 1 (2021): 87-96.