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Extended reality technologies in higher education

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Abstract: In the last few years, the topic of extended (i.e. virtual or augmented) reality in education has become so popular among researchers that it creates problems when preparing reviews of papers on the topic: a search of Scopus and Web of Science databases alone yields to several thousand results, which obviously indicates the relevance and very high demand for this tool. However, the majority of publications are dedicated to pilot studies exploring the integration of extended reality technologies in educational settings. They either do not address or only peripherally touch upon conventional educational practices, with the exception of IT-related courses. Additionally, there is a dearth of studies utilizing established methodologies for the quantitative evaluation of research outcomes. This paper aims to fill these gaps. It describes the use of a specially developed augmented reality application in practical classes for four years (2021–2024) in the training of aviation university students majoring in air traffic control. The NASA-TLX test, which has become the de facto aerospace industry standard for evaluating the usage of new technologies and is widely adopted in other industries, was employed to objectively quantify this work. The long-term application and the validated assessment tool suggest that the findings and recommendations based on them can serve as a sound basis for planning further research and practical implementation of these technologies in higher education.

Key words: aviation, higher education, extended reality.

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Технологии расширенной реальности в высшем образовании

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Аннотация: В последние несколько лет тематика расширенной (то есть виртуальной или дополненной) реальности в образовании приобрела такую популярность среди исследователей, что создает проблемы при подготовке обзоров работ по направлению: поиск только по базам Scopus и Web of Science дает несколько тысяч результатов, и это очевидно свидетельствует об актуальности и очень высокой востребованности данного инструментария. Однако большинство публикаций посвящено пилотным экспериментам по применению технологий расширенной реальности в образовании, они не затрагивают регулярную учебную практику (исключение – курсы для студентов IT-специальностей) и не используют проверенные методы для количественной оценки результатов исследований. Настоящая статья призвана заполнить указанные пробелы. Описывается использование в течение четырех лет (2021–2024) специально разработанного приложения дополненной реальности на практических занятиях при обучении студентов авиационного университета со специализацией на управлении воздушным движением. Это первый подобный опыт в вузах России. Для объективной количественной оценки этой работы применялся тест NASA-TLX, ставший де-факто стандартом авиакосмической индустрии при оценивании использования новых технологий и получивший широкое распространение в иных отраслях. Многолетнее применение и проверенный инструмент оценки позволяют предполагать, что полученные результаты и основанные на них рекомендации могут служить надежной основой для планирования дальнейших исследований и практического внедрения настоящих технологий в высшем образовании.

Ключевые слова: расширенная реальность, высшее образование.

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Introduction

In the last few years, the topic of extended reality (extended reality, XR), i.e. virtual reality (VR) and augmented reality (AR) technologies in education has become so popular among researchers that it creates serious problems when preparing reviews of papers on the topic: a search of Scopus and Web of Science databases alone yields thousands of results, which obviously indicates the acute relevance and very high demand for this toolkit. However, the majority of publications are devoted to pilot experiments on the application of augmented reality technologies in education, they do not affect at all or very weakly, familiarize regular educational practice (exception – VR/AR courses for students of IT-specialties) and do not use proven methods for quantitative assessment of research results.

In addition, the sophistication of the technologies and, thus, the unestablished terminology may often lead to conceptual contamination which, in turn, brings about ambiguities in research descriptions. Indeed, while there is a more or less broad consensus on the definition of VR, in the context of AR one encounters the terms “mixed reality”, “altered reality”, “enriched reality”, “combined reality”, “augmented reality”, etc., each with its own, often highly subjective definition. We will adhere to the following taxonomy, which has recently begun to prevail: XR is an umbrella term that includes the taxa VR, AR plus various combinations of the former and the latter. VR is a technology that implies complete audio and visual isolation of the user from the real world; the user becomes an element of a completely artificial, computer-generated environment. AR means equal coexistence of the real world objects and virtual, computer-generated objects in the same space.

The present article is intended to fill these gaps. It describes the regular use of a specially developed AR-application during four years (2021–2024) in practical training of aviation students majoring in air traffic control. *There were no requirements for students to have any sort of special knowledge or skills in IT.* This is the first experience of this kind and scale in the universities of Russia. The NASA-TLX test, which has become a de facto standard in the aerospace industry for evaluating the use of new technologies and has been widely used in other industries, was used for objective quantitative evaluation of this work, which ensures the comparability of the results with other studies.

The need to change the current model of university students’ use of XR applications is demonstrated. The current widespread practice implies either mastering the toolkit for creating XR-products when training IT-specialists, or general familiarization with such products for other students. In the foreseeable future, when AR smart goggles will replace smartphones (as all IT-industry leaders are talking about), the use of AR and VR will become a ubiquitous background, so it is reasonable to switch to special applications that simulate the prospective use of XR in work after higher education.

The main results of this paper are:

- a state-of-the-art methodology for utilizing XR technologies in higher technical education outside of IT;
- reliable quantitative assessments of the results of such use;
- recommendations based on these assessments for the use of XR in higher education.

Literature review

The difficulties in preparing a review of papers on XR in education are due to the explosive growth of their number in recent years, and the strictest filtering criteria do not improve the situation much. Therefore, we will turn to review articles on this topic (the number of which is also large and already counts in dozens), limiting ourselves to publications that a) concern university education and b) are published in journals indexed by the most representative scientmetric databases. The purpose of the review is to verify the assertion that regular application of XR products outside the IT-education sector has not yet come to the attention of researchers.

[1] – the experience of 10 years of teaching a course on VR/AR technologies for postgraduate students is presented, and a comparison to simi-

lar courses in four other universities is given. The specifics of the course imply the students' knowledge of programming skills and working with 3D-graphics packages, which greatly narrows the possibilities of dissemination of this experience.

[2] – review of the reviews (65 sources since 2020) on XR in the STEM (science, technology, engineering, and mathematics) cluster. Benefits: it was performed according to the well-known PRISMA recommendations; after filtering, 17 articles from 6 representative databases of scientific publications IEEE Xplore, ACM Digital Library, Compendex, ERIC, Education Source, and Web of Science were selected for biased analysis. Criticisms: the terminological oddities with definitions of AR and VR, hence ambiguous recommendations; exclusion of non-English articles. Overall conclusion: XR has the potential to transform STEM education by providing students with interactive and engaging learning experiences at different educational levels.

[3] – 105 sources, since 1999. 52 articles from 6 databases Web of Science, Scopus, IEEE Xplore, ERIC, ScienceDirect, and ACM Digital Library on the topic of using XR in teacher education were thoroughly analyzed. The results of a SWOT analysis of XR-based teacher-training education are presented, among which are: benefits – bridges the gap between theory and practice; criticisms – unclear process of knowledge perception; opportunities – maximizes the effect of presence and engagement; threats – high cost.

[4] – 150 sources since 2015. A review of publications on the impact of using XR and related learning analytics on different categories of learners and teachers in different educational systems, including higher education. Selection of articles from Google Scholar, Scopus and IEEE Xplore databases with filtering according to PRISMA guidelines. The results of the study show that increasing motivation and attention, improving students' understanding and performance are the most significant factors affecting all types of learners. Regarding teachers, it is found that XR technologies noticeably help in teaching and professional training and reduce the workload. It is found out that higher education and augmented reality were the dominant educational system and type of technology in the analyzed works. Most of the researchers prefer to use inquiry forms and online surveys for data collection.

[5] – 191 sources since 2015. Selection of articles from Scopus and Web of Science databases filtered according to PRISMA recommendations on the use of XR-technologies in metauniverses for educational purposes. The potential of AR-technologies for educational platforms in the aviation and space industries is especially noted.

[6] – 73 sources since 2020. Selection of articles from Scopus and Web of Science databases filtered according to PRISMA-S recommendations on the use of XR-technologies for educational purposes in higher education (mainly STEM cluster) in metauniverses. In addition to fairly standard conclusions regarding the improvement of the effectiveness of university education through XR-technologies, the opportunities that XR opens up for distance tuition are pointed out.

[7] – 77 sources since 2017, the result of filtering a primary array of 1536 articles obtained from the Scopus database. The results show that the adoption of XR technologies in education has grown exponentially in recent years, with portable devices having made a significant contribution to this development. A lack of appropriate criteria for evaluating research on augmented and virtual reality in education has been revealed.

[8] – 52 sources from 2017 to 2021. Selected publications on XR topics in higher education from a number of databases including IEEE Xplore, ProQuest, and Scopus. After filtering according to PRISMA guidelines, 12 studies have been detailed, mostly using Microsoft Hololens AR smartphones. The studies show that augmented reality has the potential to improve learning in universities, especially in medical and STEM clusters.

[9] – 36 sources since 1997. PRISMA recommendations were used to select publications on XR + AI in higher education. It is concluded that augmented reality in higher education has a promising potential to improve teaching and learning, but its successful implementation re-

quires careful consideration of the aspects of the theory of education, availability and overcoming technological barriers.

[10] – 92 sources (PRISMA selection) from 12 educational technology journals from 2009 to 2020 on the topic of AR in education were analyzed. Emphasis is placed on comparative studies and it is shown that 80% have problematic methodological issues. Taking as axiomatic the thesis about the general effectiveness of AR in education, the authors discuss the questions of where and how to effectively use educational AR tools.

[11] – 73 papers on AR in education (mainly university) were selected from Science Direct, Scopus, Google Scholar, Web of Science, MDPI, PubMED, IEEExplore, and ACM Digital Library databases using the PRISMA protocol. It is shown that almost two-thirds (61.90%) of the articles utilized specially designed questionnaires as evaluation tools. SUS was the most widely used of the known tools (n = 7, 11.11%), followed by IMMS (n = 4, 6.35%) and QUIZ (n = 3, 4.76%). Tues, AM, So ASSES, QLIS, PEURA-E, NASA-TLX, OARM, IMI, HARUS and CLS were used in one study each (an example of NASA-TLX use is [12]). Thus, most researchers evaluated the effectiveness of educational AR applications subjectively using specially designed unreliable instruments, this fact makes the results incommensurable. In addition, the limited number of participants and the short duration of pilot testing prevent generalization of the results obtained.

Let us consider two typical works on pilot experiments for XR in higher education. The authors of the article [13] describe a study of the influence of university students' use of AR tools on their assessment of their own ability to master academic material. AR has been proved to increase this assessment. At the same time, neither the learning environment nor the specifics of the tasks to be solved affect the desire to use AR. The article [14] investigates the way the role-playing games in XR influence students' independent work in higher education institutions. A qualitative evaluation approach was used. The results obtained suggest that incorporating XR into higher education practices has a positive impact on self-study by promoting active student engagement and meaningful learning experiences. In addition, students perceive these immersive learning methods as a means of bridging the gap between virtual and real learning environments, which ultimately leads to improved learning performance.

In conclusion, let us introduce a few recent papers that match the search term "XR + university" and date back to 2025. An article [15] on higher aviation education presents the results of the experiment on upgrading the curriculum to reflect the latest XR practices in aircraft maintenance. The article [16] focuses on the use of XR technologies in university (mostly) libraries. It is noted that XR tools dramatically facilitate such procedures as checking the availability of books on the shelves, inventory and search for lost items, contribute to the expansion of search capabilities of readers, but the lack of experience of library staff and financial resources causes the current "laboratory" condition of the issue. A review [17] provides insight into the use of XR in university foreign language learning. As a result of the authors' analysis of experimental activities in this sector, they identified six types of activities that are situational for the use of XR technologies and formulated recommendations, the most significant of which is the transition from outdated VR tools to AR.

The absence of papers on the regular use of XR in the practice of higher education outside the IT sphere in the reviewed array of publications is quite understandable due to the novelty of this toolkit. The more interesting is the real experience of such use, described below, which was carried out taking into account the information of publications on the implementation of pilot experiments.

Method

From 2021 to 2024, the practical classes on the subject "Innovative Technologies in Air Traffic Control (ATC)" at the Moscow State Technical University of Civil Aviation were carried out by students using a special AR application OKO Labs for mobile devices (iOS and An-

Fig. 1. A practical lesson in augmented reality mode

droid) developed by "Aviareal" LLC. The purpose of the sessions was to familiarize students with modern methods of air surveillance, which are adequate to the situation of mass appearance of unmanned aerial vehicles in the airspace. At the end of each class, the students evaluated their academic work by means of the NASA-TLX test presented by an automated computerized version. The one and a half hour sessions were conducted weekly during the spring semester from February to May, with 6 different exercises, each involving between 56 and 65 students.

The AR-application of OKO Labs (which students install on their smartphones or tablet computers) displays virtual air traffic simulating the movement of aircraft in the combined sectors West-1 and West-2 of the Moscow ATC zone against the background of a picture of a mobile device camera observing special markers for positioning virtual objects. Some of virtual aircraft are in a situation of a near miss (the most frequent abnormal situation in aeronautical practice) both when moving at the same flight level with converging, opposite and same direction overtaking courses, and when changing one flight level for the other. The aircraft proximity a distance of less than 10 km or less horizontally and less than 300 meters vertically is considered dangerous. OKO Labs positions virtual objects using special graphic markers with SLAM support (autonomous positioning technology), if the model of the mobile device allows it.

Air traffic monitoring is performed in AR mode within the wireless local network with simultaneous display of the virtual air situation on the screens of mobile devices of all system users. The user's task is to timely detect and signal threats of dangerous aircraft approach. The work is performed by all students simultaneously in a single AR space (fig. 1) and in a competitive mode: students try to determine the occurrence of the threat of dangerous aircraft proximity as early as possible, whenever any student registers a threat (fig. 2), information about it appears on the screens of other students' devices. Timely signals about threats of dangerous approach are rewarded with prize points (depending on the time from signaling to the moment of approach and on the order in which the threat is recorded), unnoticed threats and false alarms are penalized.

The session is controlled by the instructor on the computer with the server part of the application. At the beginning of the lesson, the instruc-

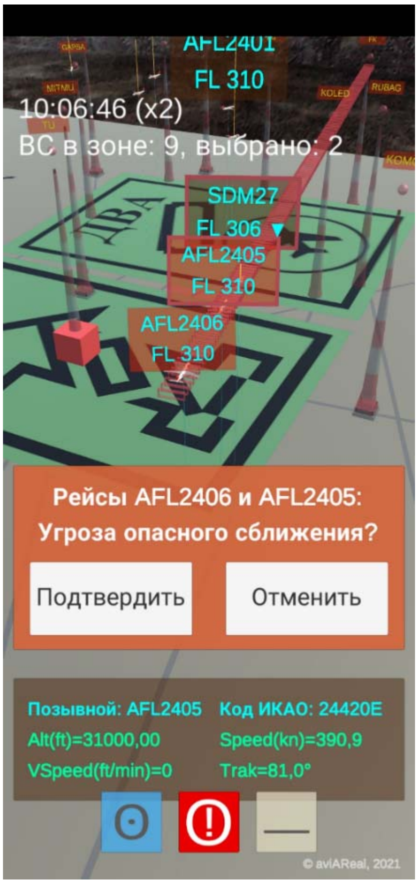

Fig. 2. Registration of the potential near miss (Top to bottom, left to right: aircraft in the area; 2 selected, flights AFL 2406 and AFL 2405: Is there a near miss; Confirm; Cancel; Callsign AFL 2405, ICAO code 24420E)

tor downloads the next exercise from the server via wireless network to the client parts of the application. The exercises differ in the types of near misses of aircraft. Upon completion of the exercise, the instructor displays information about the points scored by the students on the projector screen in the classroom. The scores were counted after the student had sent his/her NASA-TLX test results [18].

The main advantage of air traffic monitoring in AR space is the ability to view what is happening from any point in space and at any scale by moving the mobile device, which significantly increases the probability of early detection of near miss. Using the application, the student can:

- observe aircraft from any angle and their information banners (flight number and altitude in FLs), navigation waypoint markings;
- select an aircraft to receive a form with additional information and display its flight plan (air corridor (airway) from red frames in Figure 2) – click on the aircraft banner;
- select several aircraft and reset the selection (click any point on the screen outside the banners);
- use the service menu buttons at the bottom of the screen (fig. 2): blue on the left – call the control panel, red in the middle – message about dangerous approach, gray on the right – mode of underlying surface transparency for the virtual scene.

The students had to undergo each exercise 2 times at an interval of 1 week: the first time in the familiarization and training mode, the second time – with fixation of the scored points. The stimulating factor was a simplified procedure of passing the credit test for those whose result was higher than the threshold of 90% of the difference between the maximum and minimum values of the scored points of the students of the group.

The results

The results of statistical processing of data (student scores and NASA-TLX factor scores) for 2022 and 2023 are presented. The 2021 data are omitted because in the first year, the methodology for conducting classes using the AR application was being refined. The 2024 data are omitted because there was a change in the conditions for using the AR application in that year. Nevertheless, the recommendations below are based on the practice of all four years of XR-enabled lessons.

Before processing, the data were filtered to reject anomalous values by the criterion of the ratio of the centered random variable to the standard deviation, and then tested for independence by the Abbe-Helmert criterion and normality by the Kolmogorov-Smirnov criterion. Statistical significance of the processing results was checked by means of one-factor analysis of variance for the significance level of 0.05.

Figure 3 shows the change in mean values of the NASA-TLX factors over the 12 weeks of the spring semester. The NASA-TLX test is a multivariate rating procedure, a weighted average based on 6 rating factors:

1) mental workload;
2) physical workload;
3) pace-related workload;
4) productivity;
5) effort expended;
6) dissatisfaction.

Factors 1–3 are related to the stresses on the subject, factors 4–6 are related to the interaction between the subject and the task at hand.

NASA-TLX includes the stages of evaluating weights and factors. In the first step, test takers assign weights to factors according to their ideas on their contribution to the final load. This information is used to identify differences in expert approaches and differences in the importance of criteria for the tasks. In the second stage, subjects evaluate the factors themselves using a scale divided into 20 sections, each section having a weight of 5, with a minimum score value of 0 and a maximum score value of 100. The scales are provided with oppositional descriptors. Students practiced evaluating the factors while trying out the test tasks.

The indicator of factor 4 (“Performance”) is close to the indicator “Score”, but if the former is a subjective self-assessment, the latter is an objective “external” assessment. This circum-

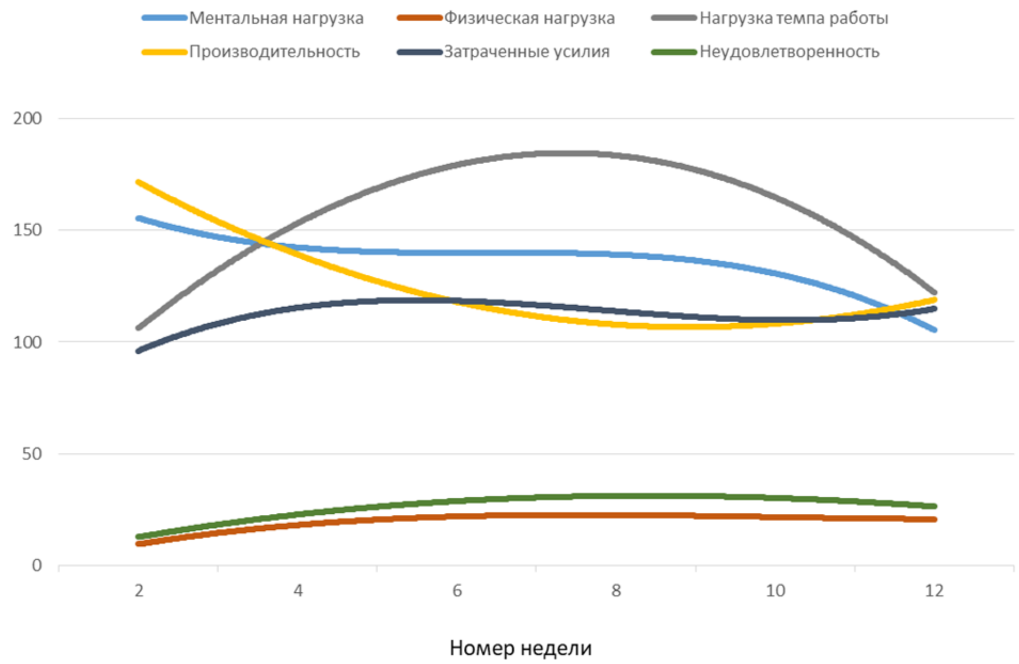

Fig. 3. The dynamics of changing of the NASA-TLX factors during the academic semester. Polynomial smoothing of degree 3
(Top to bottom, left to right: mental workload; physical workload; pace-related workload; productivity; effort expended; dissatisfaction; number of the week)

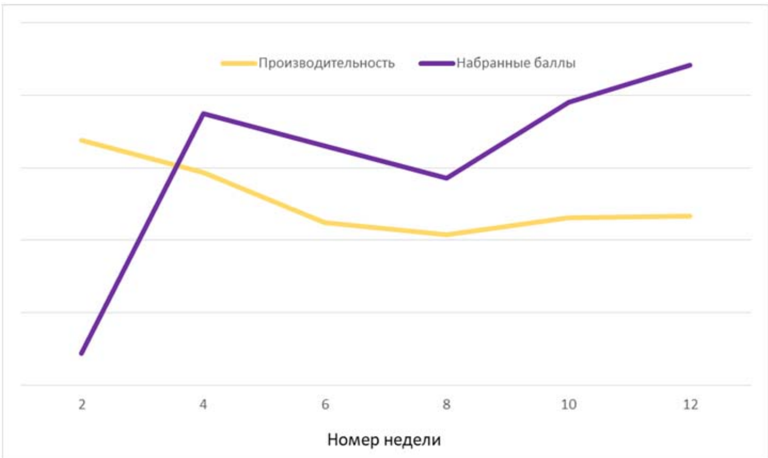

Fig. 4. The change in the average values of the NASA-TLX Performance factor and the Score during the academic semester
(Top to bottom, left to right: performance factor; score; number of the week)

stance allows the use of scored points to verify NASA-TLX data, as demonstrated in Figure 4.

Discussion and conclusion

The graphs in Figure 4 confirm the effectiveness of NASA-TLX factors as assessments of the results of XR-technologies application in the learning process, as they show high correlation starting from the fourth week. The starting divergence in the second week for the "Score" is obviously explained by the insufficient readiness of the users at the beginning of the period to use the new toolkit despite the fact that by this time the users have already used it twice in practice – at the first familiarization and the first training sessions.

The period of starting instability is also indicated by the behavior of all other factors in Figure 3, except for "Dissatisfaction" and "Physical activity" – these have predictably low and almost unchanging values. The factor "Effort expended" also changes little during 12 weeks, its fluctuations can be associated with the specifics of the exercises performed.

A strong rise by week 8 and then a decrease in the values of the "Pace-Related Workload" factor is most likely due to the peak of competitiveness in the lessons followed by adaptation to the game environment of interaction between users. The "Mental Load" factor expectedly decreased after an initial relatively high value as the user mastered the skills of solving the proposed tasks using the AR application. Finally, the behavior of the "Productivity" factor may be explained by the disappearance of the initial euphoria from using a new unusual tool.

A huge array of publications on the "topic of XR in education" makes it unnecessary to discuss the usefulness of these technologies in educational practice, so as a conclusion we will give a number of recommendations based on the experience of using XR-technologies in the university educational process, taking into account the analysis of graphs in Figure 3.

1) Currently, all (sic!) key players in the IT market consider XR as the next (after the spread of smartphones) "big wave" of revolutionary changes in mass digital technology, expecting the arrival of this wave within a few years. Therefore, it is fair enough to expect that the application of AR (or to a lesser extent, VR) will touch upon almost any professional activity, and this fact determines the dominant model of XR implementation in higher education in the form of preparation for the use of these technologies in the work of professionals after graduation. *I.e. the management of higher education should think about the prospects of profile applications of XR and ensure the introduction of relevant fragments in the curriculum.* An example is the experience described above: modern methods of air traffic control system observation on flat screens with the emergence of thousands of online shopping delivery drones (the near future of mass retail) become useless, the solution to the problem is to work in a three-dimensional XR environment with first person view control. This is exactly the kind of experience that OKO Labs' AR-enabled classes provide for the students.

2) The most appropriate type of XR-technologies for use in educational practice is the AR, which is free from negative effects on the vestibular apparatus of students (unlike VR), allows to involve real world objects in the educational procedure and to increase the didactic efficiency due to the advantages of AR compared to VR. These advantages are related to the parallel coexistence of virtual and real objects in AR, among which the following can be emphasized:

a. The real extends the virtual – in VR the user's sensory experience is predominantly limited to video and audio effects, whereas in AR the whole range of real-world sensations is present.

b. The virtual expands the real – in AR it is possible to simulate situations that are impossible or unsafe to create in the real world, while remaining within its framework.

c. Natural interface – in AR the control of virtual objects by pupil movement, voice and gestures makes user-computer interaction extremely easy.

d. Communication between virtual and real objects, effectively maintained in learning systems.

3) When using AR in a regular learning process with dozens of students, the high cost of wearable devices like Hololens or Vision Pro leaves only one opportunity for visual implementation of AR environment – through applications using smartphone cameras.

4) The diversity of mobile device models among students leads to positioning of virtual objects in AR by means of graphical markers with the connection of autonomous SLAM positioning if the mobile device model supports it.

5) "On-the-job" sessions should be preceded by at least 3–4 familiarization and training sessions.

6) The transitional processes associated with mastering a new training procedure using XR last at least 10 sessions, which should be taken into account when planning the training process.

7) Introducing an edutaining, competitive element into the training procedure is an effective means of motivating students to complete tasks thoroughly.

8) It is very useful to motivate students to take the NASA-TLX test after each session, which, when implemented using a computer (e.g., as an Excel spreadsheet with built-in macros, as was the case here), makes testing unencumbered and provides reliable, comparable performance assessments.

References

1. **Marques, B., Santos, B.S., Dias, P.** (2024). Ten years of immersive education: Overview of a virtual and augmented reality course at postgraduate level. *Computers & Graphics*, vol. 124, ID: 104088. DOI: 10.1016/j.cag.2024.104088 (accessed: 12.01.2025).

2. **Zhang, Y., Feijoo-Garcia, M.A., Gu, Y., Popescu, V., Benes, B., Magana, A.J.** (2024). Virtual and augmented reality in science, technology, engineering, and mathematics (STEM) education: An umbrella review. *Information*, vol. 15, issue 9, ID: 515. DOI: 10.3390/info15090515 (accessed: 12.01.2025).

3. **Wang, Q., Li, Y.** (2024). How virtual reality, augmented reality and mixed reality facilitate teacher education: A systematic review. *Journal of Computer Assisted Learning*, vol. 40, issue 3, pp. 1276–1294. DOI: 10.1111/jcal.12949

4. **Sakr, A., Abdullah, T.** (2024). Virtual, augmented reality and learning analytics impact on learners, and educators: A systematic review. *Education and Information Technologies*, vol. 29, pp. 19913–19962. DOI: 10.1007/s10639-024-12602-5

5. **Jagatheesaperumal, S., Ahmad, K., Al-Fuqaha, A., Qadir, J.** (2024). Advancing education through extended reality and internet of everything enabled metaverses: applications, challenges, and open issues. *In: IEEE Transactions on Learning Technologies*, vol. 17, pp. 1120–1139. DOI: 10.1109/TLT.2024.3358859

6. **Pregowska, A., Osial, M., Gajda, A.** (2024). What will the education of the future look like? How have Metaverse and Extended Reality affected the higher education systems? *Metaverse Basic and Applied Research*, vol. 3. ID: 57. DOI: 10.56294/mr202457 (accessed: 12.01.2025).

7. **Al-Ansi, A.M., Jaboob, M., Garad, A., Al-Ansi, A.** (2023). Analyzing augmented reality (AR) and virtual reality (VR) recent development in education. *Social Sciences & Humanities Open*, vol. 8, issue 1. ID: 100532. DOI: 10.1016/j.ssaho.2023.100532 (accessed: 12.01.2025).

8. **Banjar, A., Xu, X., Iqbal, M.Z., Campbell, A.** (2023). A systematic review of the experimental studies on the effectiveness of mixed reality in higher education between 2017 and 2021. *Computers & Education: X Reality*, vol. 3. ID: 100034. DOI: 10.1016/j.cexr.2023.100034 (accessed: 12.01.2025).

9. **Marín-Rodriguez, W.J., Andrade-Girón, D.C., Zúñiga-Rojas, M. et al.** (2023). Artificial Intelligence and Augmented Reality in Higher Education: a systematic review. *Data and Metadata*, vol. 2. ID: 121. DOI: 10.56294/dm2023121 (accessed: 12.01.2025).

10. **Buchner, J., Kerres, M.** (2023). Media comparison studies dominate comparative research on augmented reality in education. *Computers & Education*, vol. 195. ID: 104711. DOI: 10.1016/j.compedu.2022.104711 (accessed: 12.01.2025).

11. **Koumpouros, Y.** (2024). Revealing the true potential and prospects of augmented reality in education. *Smart Learning Environments*, vol. 11. ID: 2. DOI: 10.1186/s40561-023-00288-0 (accessed: 12.01.2025).

12. **Xi, N., Chen, J., Gama, F., Riar, M., Hamari, J.** (2023). The challenges of entering the metaverse: An experiment on the effect of extended reality on workload. *Information Systems Frontiers*, vol. 25, pp. 659–680. DOI: 10.1007/s10796-022-10244-x

13. **O'Connor, Y., Mahony, C.** (2023). Exploring the impact of augmented reality on student academic self-efficacy in higher education. *Computers in Human Behavior*, vol. 149. ID: 107963. DOI: 10.1016/j.chb.2023.107963 (accessed: 12.01.2025).

14. Ríos, L.V., Acosta-Diaz, R., Santana-Mancilla, P.C. (2023). Enhancing self-learning in higher education with virtual and augmented reality role games: students' perceptions. *Virtual Worlds*, vol. 2, issue 4, pp. 343–358. DOI: 10.3390/virtualworlds2040020

15. Gauthama, W., Hendra, O., Aswia, P.R., Amalia, D. (2025). Updating aircraft maintenance education for the modern era: a new approach to vocational higher education. *Higher Education, Skills and Work-Based Learning*, vol. 15, no. 1, pp. 46–61. DOI: 10.1108/HESWBL-11-2023-0314

16. Shahzad, K., Khan, S.A.K.A., Javed, Y., Ahmad, S. (2025). Factors influencing the adoption of extended reality (XR) applications in libraries for sustainable innovative services: a systematic literature review (SLR). *The Electronic Library*, vol. 43, issue 1, pp. 22–40. DOI: 10.1108/EL-06-2024-0188

17. Christou, E., Parmaxi, A., Christoforou, M. (2025). Implementation and application of extended reality in foreign language education for specific purposes: a systematic literature review. Universal Access in the Information Society. 2025. DOI: 10.1007/s10209-025-01191-w (accessed: 12.01.2025).

18. Hart, S.G. (2006). NASA-task load index (NASA-TLX); 20 years later. *In: Proceedings of the human factors and ergonomics society annual meeting*, vol. 50, no. 9, pp. 904–908. DOI: 10.1177/154193120605000909

Список литературы

1. **Marques B., Santos B.S., Dias P.** Ten years of immersive education: Overview of a virtual and augmented reality course at postgraduate level [Электронный ресурс] // Computers & Graphics. 2024. Vol. 124. ID: 104088. DOI: 10.1016/j.cag.2024.104088 (дата обращения: 12.01.2025).

2. **Zhang Y.** Virtual and augmented reality in science, technology, engineering, and mathematics (STEM) education: An umbrella review / Y. Zhang, M.A. Feijoo-Garcia, Y. Gu, V. Popescu, B. Benes, A.J. Magana [Электронный ресурс] // Information. 2024. Vol. 15, iss. 9. ID: 515. DOI: 10.3390/info15090515 (дата обращения: 12.01.2025).

3. **Wang Q., Li Y.** How virtual reality, augmented reality and mixed reality facilitate teacher education: A systematic review // Journal of Computer Assisted Learning. 2024. Vol. 40, iss. 3. Pp. 1276–1294. DOI: 10.1111/jcal.12949

4. **Sakr A., Abdullah T.** Virtual, augmented reality and learning analytics impact on learners, and educators: A systematic review // Education and Information Technologies. 2024. Vol. 29. Pp. 19913–19962. DOI: 10.1007/s10639-024-12602-5

5. **Jagatheesaperumal S.** Advancing education through extended reality and internet of everything enabled metaverses: applications, challenges, and open issues / S. Jagatheesaperumal, K. Ahmad, A. Al-Fuqaha, J. Qadir // IEEE Transactions on Learning Technologies, 2024. Vol. 17. Pp. 1120–1139. DOI: 10.1109/TLT.2024.3358859

6. **Pregowska A., Osial M., Gajda A.** What will the education of the future look like? How have Metaverse and Extended Reality affected the higher education systems? [Электронный ресурс] // Metaverse Basic and Applied Research. 2024. Vol. 3. ID: 57. DOI: 10.56294/mr202457 (дата обращения: 12.01.2025).

7. **Al-Ansi A.M.** Analyzing augmented reality (AR) and virtual reality (VR) recent development in education / A.M. Al-Ansi, M. Jaboob, A. Garad, A. Al-Ansi [Электронный ресурс] // Social Sciences & Humanities Open. 2023. Vol. 8, iss. 1. ID: 100532. DOI: 10.1016/j.ssaho.2023.100532 (дата обращения: 12.01.2025).

8. **Banjar A.** A systematic review of the experimental studies on the effectiveness of mixed reality in higher education between 2017 and 2021 / A. Banjar, X. Xu, M.Z. Iqbal, A. Campbell [Электронный ресурс] // Computers & Education: X Reality. 2023. Vol. 3. ID: 100034. DOI: 10.1016/j.cexr.2023.100034 (дата обращения: 12.01.2025).

9. **Marín-Rodriguez W.J., Andrade-Girón D.C., Zúñiga-Rojas M. и др.** Artificial Intelligence and Augmented Reality in Higher Education: a systematic review [Электронный ресурс] // Data and Metadata. 2023. Vol. 2.

ID: 121. DOI: 10.56294/dm2023121 (дата обращения: 12.11.2024).

10. Buchner J., Kerres M. Media comparison studies dominate comparative research on augmented reality in education [Электронный ресурс] // Computers & Education. 2023. Vol. 195. ID: 104711. DOI: 10.1016/j.compedu.2022.104711 (дата обращения: 12.01.2025).

11. Koumpouros Y. Revealing the true potential and prospects of augmented reality in education [Электронный ресурс] // Smart Learning Environments. 2024. Vol. 11. ID: 2. DOI: 10.1186/s40561-023-00288-0 (дата обращения: 12.01.2025).

12. Xi N. The challenges of entering the metaverse: An experiment on the effect of extended reality on workload / N. Xi, J. Chen, F. Gama, M. Riar, J. Hamari // Information Systems Frontiers. 2023. Vol. 25. Pp. 659–680. DOI: 10.1007/s10796-022-10244-x

13. O'Connor Y., Mahony C. Exploring the impact of augmented reality on student academic self-efficacy in higher education [Электронный ресурс] // Computers in Human Behavior. 2023. Vol. 149. ID: 107963. DOI: 10.1016/j.chb.2023.107963 (дата обращения: 12.01.2025).

14. Ríos L.V., Acosta-Diaz R., Santana-Mancilla P.C. Enhancing self-learning in higher education with virtual and augmented reality role games: students' perceptions // Virtual Worlds. 2023. Vol. 2, iss. 4. Pp. 343–358. DOI: 10.3390/virtualworlds2040020

15. Gauthama W. Updating aircraft maintenance education for the modern era: a new approach to vocational higher education / W. Gauthama, O. Hendra, P.R. Aswia, D. Amalia // Higher Education, Skills and Work-Based Learning. 2025. Vol. 15, no. 1. Pp. 46–61. DOI: 10.1108/HESWBL-11-2023-0314

16. Shahzad K. Factors influencing the adoption of extended reality (XR) applications in libraries for sustainable innovative services: a systematic literature review (SLR) / K. Shahzad, S.A.K.A. Khan, Y. Javed, S. Ahmad // The Electronic Library. 2025. Vol. 43, iss. 1. Pp. 22–40. DOI: 10.1108/EL-06-2024-0188

17. Christou E., Parmaxi A., Christoforou M. Implementation and application of extended reality in foreign language education for specific purposes: a systematic literature review [Электронный ресурс] // Universal Access in the Information Society. 2025. DOI: 10.1007/s10209-025-01191-w (дата обращения: 12.01.2025).

18. Hart S.G. NASA-task load index (NASA-TLX); 20 years later // Proceedings of the human factors and ergonomics society annual meeting, 2006. Vol. 50, no. 9. Pp. 904–908. DOI: 10.1177/154193120605000909

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