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Effectiveness of using augmented reality technology in the educational process

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Abstract. The relevance of studying augmented reality (AR) technology in education is driven by the rapid advancement of digital technologies and the need for modernising education. As society undergoes technological transformation, educational institutions must adapt to ensure high-quality education that meets modern labour market demands. Exploring AR's implementation is crucial for developing innovative methods and tools that align with the needs of today's students. The purpose of the study was to analyse augmented reality technology, identify its types, and examine the possibilities and benefits of introducing augmented reality technologies in educational institutions. The study was conducted using theoretical methods such as analysis, synthesis, generalisation, and systematisation. The article offered the author's vision of the effectiveness of using augmented reality technology in the educational process based on the analysis of research by Ukrainian and foreign scholars who consider this technology to be a modern teaching tool. It analysed the classification of augmented reality systems by the type of transmitted information, receivers, user interaction, and mobility. Given that augmented reality technologies in education are currently in their infancy, the author presented foreign and Ukrainian experiences regarding the use of augmented reality technologies in education and outlined the possibilities and advantages of their use in the educational process. The integration of augmented reality technologies into the educational processes at Stanford, Harvard, and UK universities was highlighted. The practical significance of the study lies in identifying the real advantages and challenges associated with its implementation in the educational process. The results of the study will contribute to the development of methodological recommendations, educational tools, and applications that maximise the potential of augmented reality

Keywords: immersive technologies; virtual reality; visualisation of educational material; digitalisation of education; mixed reality

INTRODUCTION

Modern education is developing rapidly, responding to current requirements and technological advancements in society. One of the innovative tools in the field of education is immersive learning technologies, in particular augmented reality (AR), which allows students to experience a heightened level of interactivity and immersion in the educational process. The use of augmented reality (AR) in educational institutions has the potential to transform

the traditional learning process and provide a unique immersive experience. Students can learn subjects not only from books or screens but also by immersing themselves in virtual environments where they can experiment and interact with materials in a more dynamic way.

Visibility, material focus, manageability, safety, and efficiency (compared to conventional PC use) are key factors enhancing the didactic potential of immersive technologies in education (Kriukova, 2021). With AR, students can not only consume information but also actively interact with it, encouraging a deeper understanding of the material. Augmented reality enables the overlaying of digital content onto the real world, creating an interactive learning environment. This, in turn, personalises the learning process and enhances learning efficiency. The use of augmented reality technology is one of the most significant technological trends in the modern educational process.

Recent research on the use of AR in education highlights the potential benefits of this technology. For instance, M. Kisilova (2021) notes that adopting an integrated approach to education, built on problem-based learning and cross-curricular integration, makes it advisable to use modern educational technologies, including VR, in the classroom. Several studies indicate increased student interest, motivation, and academic performance when using AR.

The introduction of augmented reality technology into the educational process of higher education institutions has been analysed by Ukrainian researchers, such as T. Hruntova *et al.* (2018), who highlight that the adoption of these technologies in education enhances its effectiveness, promotes active student involvement in learning, improves knowledge assimilation and perception, sustains interest in learning, and develops students' research and subject-specific skills. They theoretically justified the use of augmented reality technology and its features in higher technical education institutions. As a result of their research, L. Taranhul & S. Romaniuk (2022) discovered that an effective tool for supporting the educational process in higher education institutions using AR technologies is the HP Reveal platform. This platform offers several benefits, including enhanced visualisation of educational material and improvements to teaching methods and the educational process as a whole.

O. Merzlykin *et al.* (2018) emphasise that the effective teaching of modern students with unique educational needs requires the use of innovative technologies. This includes the use of mobile applications, the organisation of group work, interactive tasks, and the visualisation of educational material. V. Klymniuk (2018) highlights the diverse ways virtual reality can influence educational methodology, expanding the range of teaching methods and introducing new or improved approaches to learning. The researcher stresses that when developing and implementing virtual reality elements in multimedia teaching systems, it is important to consider the resources available at the higher education institution, the professional expertise of the developers, and the time allocated for integrating virtual reality into the educational process.

The rapid pace of technological progress necessitates constant updating of materials used for educational purposes. Educational laboratories are now actively experimenting with the use of interactive whiteboards, modelling software, and virtual reality environments. Although AR has been used in other fields for a long time, research into its potential application in educational institutions has only recently gained momentum. Augmented reality technology is relatively simple to use, but due to its pedagogical advantages, it has successfully attracted the attention of many educators. AR tools are widely used in educational institutions at various levels, from schoolchildren to teachers and PhD students, and for diverse educational purposes, ranging from language learning to astronomy. However, despite the potential benefits, a thorough study is needed to explore the opportunities augmented reality technology provides for educators, offering tools to enhance the learning process. The objective of the study was to analyse augmented reality technology, define and classify its types, and evaluate the possibilities and benefits of integrating augmented reality technologies into the educational process.

MATERIALS AND METHODS

Several theoretical methods were employed to study the effectiveness of augmented reality in the educational process. In particular, the analysis of scientific literature helped to ascertain how other researchers perceive the role of augmented reality in this area. Synthesis facilitated the combination of various data to create a holistic picture of how augmented reality is utilised in the educational process. The comparison of different approaches and models allowed for the identification of the most effective application strategies. Generalisation enabled the formulation of overarching conclusions about the role of augmented reality in modern education.

The research material comprised articles from scientific periodicals, conference proceedings, review articles, and studies by foreign and Ukrainian scientists working in the same area, primarily from the last five years (2019-2024). Older sources were included where their information remained timeless and relevant. The method of system-structural analysis was applied to identify key elements influencing the effectiveness of AR in education, particularly through the representation of foreign experiences, including the integration of augmented reality technologies into the educational processes of Stanford, Harvard, and UK universities. The method of comparative analysis of scientific and pedagogical literature helped to identify general trends, as well as similarities and differences in the authors' perspectives on the problem. It also enabled an assessment of how thoroughly and comprehensively the problem had been studied and identified key concepts and theories. This contributed to the formation of a clear and scientifically grounded understanding of the effectiveness of augmented reality technologies and facilitated the projection of directions for further research and development on the outlined issues.

The method of synthesis of theoretical and methodological provisions enabled the substantiation of the advantages and possible limitations of introducing AR into the educational process. This was achieved because the chosen method incorporates systematic analysis and integration of various scientific and methodological concepts to form a holistic view of the capabilities and advantages of augmented reality technologies. Using the method of data systematisation, a comprehensive view of the impact of AR on the educational process was developed, providing a foundation for informed decision-making regarding the implementation of these technologies. Classifications of augmented reality systems were analysed based on the type of transmitted information, type of receiver, degree of interaction with the user, and degree of mobility.

The method of generalisation was employed to draw overarching conclusions, formulate basic principles, and identify prospects for further research. The main stages of the study included substantiating the relevance of the research topic, studying the state of the object and subject of the research, selecting a research methodology, and discussing the results. These stages were aimed at identifying the main aspects of the subject and object under study – namely, the field of education in Ukraine and the impact of immersive technologies, particularly augmented reality technology. The study formulated conclusions outlining the role of this technology in the educational process, highlighted its main advantages and disadvantages, and identified areas for further research.

RESULTS AND DISCUSSION

Augmented reality, also known as mixed reality, is applied in a wide variety of areas, transforming the way people interact with the world. Augmented reality is a technology that enables the real-time combination of virtual objects with the real world using specialised devices, thereby creating an interactive environment. Unlike virtual reality (VR), which isolates the user from the real world, AR provides the ability to interact with both real and virtual environments simultaneously.

The term "augmented reality" was introduced by Boeing researcher Tom Codell in 1990. The terms "extended reality", "enhanced reality", "enriched reality", and "magnified reality" are often used as synonyms for "augmented reality". However, using these terms in a general sense is inaccurate, as they refer specifically to certain forms and aspects of augmented reality's practical application. According to researcher N. Yermilova (2018), augmented reality is a technology for adding or introducing elements of virtual information into a person's real life, displayed on a screen through technical means. The application of its capabilities in education has the potential to transform the learning process by providing the visual perception of the necessary information and reproducing certain processes with a visual representation of them in real size and dimensions. In the view of N. Honcharova (2019a), augmented reality is one of the most advanced technologies for visualising educational material, which warrants further in-depth scientific research.

In A. Striuk's (2018) research, augmented reality is presented as a novel interactive technology that overlays computer graphics, video, audio, or text information onto real-time objects. Researcher N. Rashevska (2018) highlights the positive impact of using augmented reality technology in teaching fundamental disciplines. I. Mintii & V. Soloviov (2018) note that among the challenges associated with integrating augmented reality into education, the lack of specialists developing educational content and the absence of cooperation between business and education in this area are particularly noteworthy. M. Shmyhol & Yu. Yushkevych (2019) discuss the mechanisms through which virtual reality influences the human worldview and argues that the transition to the virtualisation of modern information society arose from the need to elevate information technology to a qualitatively new level, thereby contributing to the development of the innate human need for creativity and the creation of new realities.

Augmented reality is a forward-looking technology that provides users with real-time data through geolocation and visual tools. Unlike virtual reality, which creates an entirely digital environment, augmented reality combines virtual elements with the real world, enhancing the environment and enabling interaction with reality. Virtual reality provides a simulation of an environment, which can be either real or fictional, using computer technology. Given the interconnectedness and interaction between the virtual and real worlds, users who engage with augmented reality experience a distinctly enhanced environment where virtual information serves as an additional, practical tool to support their daily activities.

Due to augmented reality technology, digital information can be embedded in the real world, significantly expanding the sensory data perceived by humans. This technology aims to enhance knowledge about the environment and improve the perception of information. To create augmented reality, a camera or other device capable of processing a video signal is used. A specialised program generates virtual objects and adds video and audio materials, 3D models, and text content to the image. Augmented reality technologies are capable of projecting digital information (e.g., images, video, text, graphics) beyond device screens and integrating virtual objects with the real environment. According to Z. Turan *et al.* (2018), augmented reality creates an opportunity to merge the virtual and real worlds, which can help students learn abstract and complex subjects. The results of their study showed that AR improves student performance and reduces cognitive demands (Thakral, 2020).

According to the type of information transmitted, augmented reality systems are divided into:

- visual systems, which are based on the principle that people perceive information primarily through visual channels, as this is the most accessible form of perception;
- audio systems, which focus on auditory perception;

- audiovisual systems, which combine the two previous systems, with audio information complementing visual data.

Augmented reality systems for obtaining information from the environment utilise a variety of receiver devices. Based on their types, the following categories are distinguished:

- optical or video information systems – these systems process the video signal received from a camera to create virtual objects in the real world. These systems can be: markerbased systems, which use special markers to detect and recognise objects; markerless systems, which function without markers, instead relying on ordinary images, volumetric bodies, and complex recognition algorithms; spatial tracking systems, which determine the position of objects in space based on real-time video stream analysis;
- geopositioning systems, which rely on signals from GPS global positioning systems;
- combined systems, which integrate both geopositioning and optical data to ensure maximum accuracy in determining the position of augmented reality objects in space.

Augmented reality systems can be classified according to the degree of interaction with the user into autonomous systems and interactive systems. Autonomous augmented reality systems are characterised by the fact that the user plays a secondary role, observing the system's interaction with the environment. The purpose of such systems is to provide auxiliary information about various objects. Interactive systems, on the other hand, use information input devices and allow the user to manage the interaction process independently. Augmented reality systems can also be classified according to their level of mobility:

- stationary systems operate in fixed locations (e.g., widescreen displays equipped with high-resolution cameras). Such systems partially or completely lose functionality when moved;
- mobile systems can move in space, such as smartphones and tablet computers.

In many countries, augmented reality has become an integral part of the strategy of large businesses seeking to use advanced technologies to attract new customers and partners. Additionally, augmented reality is widely employed in socially significant industries such as healthcare, education, and science. J.W. Lai & K.H. Cheong (2022) categorise current research on the use of augmented reality (AR) into two primary groups: projects focusing on the practical application of AR in specific educational contexts to introduce new innovations; and research exploring the potential of AR to assess student achievement. Examples of AR use in higher education include:

- Stanford University: employing AR to train medical students in practising complex procedures on virtual models.
- Harvard University: using AR to study history and archaeology, enabling students to "travel" to different historical eras and locations.
- UK universities: applying AR in engineering and architecture education, allowing students to visualise their projects in real time.

J. Martin-Gutierrez *et al.* (2012) highlight the possibilities of using augmented reality for students' teamwork. This is especially true when performing laboratory and practical work using dangerous equipment that requires constant monitoring by the teacher. Through the use of markers, students can use a tablet or mobile phone to display the educational material and instructions necessary for the proper use or setup of the equipment. One of the key advantages of using AR in foreign educational institutions is the ability to expand the educational environment beyond the classroom. With the help of virtual tours, students can visit any part of the world, explore cultures, and study the diversity of nature and historical events directly from their desks. This makes the learning process more accessible and engaging for students, allowing them to experience the world around them in the most realistic way possible. Interactive applications and games developed with AR technology stimulate dialogue, cooperation, and students' creative development.

For example, Japan introduced an innovative initiative to teach foreign languages, demonstrating originality in its approach. The Tokyo Shoseki Publishing Group has released English language learning materials that contain elements of augmented reality. These materials are not inferior in interactivity to typical language learning apps on an iPad screen; however, they are more accessible within the existing educational system. Readers can use their smartphone by hovering it over the relevant section of the page to hear the dialogue or even try to communicate with fictional characters.

Foreign countries are implementing VR technologies both during university studies and in onthe-job training. In the United States, AR is used to train police officers to deal with riots in certain situations. In addition, some fire departments in the United States, Australia, the United Kingdom, and other countries use the Australian FLAIM Systems platform to train firefighters. This system makes it possible to simulate dangerous situations, such as forest fires or aeroplane fires. VR realistically replicates all the fire, smoke, water, and foam of an extinguisher, as well as heat, thanks to a special thermal suit that can adjust the temperature depending on the firefighter's proximity to the virtual fire. Researchers Y. Asham *et al.* (2023) note that augmented reality (AR) and virtual reality (VR) have become among the most significant technological advances of the last decade. Their use is growing rapidly in various fields. The COVID-19 pandemic and the need for distance learning tools that mimic real-world learning environments as closely as possible have stimulated a deeper study of AR/VR tools. This proves that the use of augmented reality technology in foreign educational institutions is becoming not only an effective teaching tool but also a key factor in training specialists. This innovative practice demonstrates the potential to create a more interactive, accessible, and engaging educational environment.

Augmented reality (AR) technology is one of the most exciting innovations of contemporary time, transforming the way people interact with the world around them. Ukraine, keeping pace with global trends, is also actively utilising this technology across various fields, including business, culture, and education. Thanks to the efforts of Apple and Google, this technology can be applied in diverse areas: marketing, medicine, aviation, tourism, design, sales, and gaming. Ukrainian companies are developing AR applications and technologies for education, facilitating its adoption in the educational sector. Today, this technology is gaining increasing acceptance among teachers and scientists compared to a few years ago. Ukrainian educational institutions are gradually integrating AR technology into the educational process. Through AR, students can gain a clearer understanding of complex concepts and phenomena, thereby enhancing their comprehension of the educational material. For example, when studying biology, students can utilise AR for research. In addition, scholars V. Bykov *et al.* (2020) theoretically substantiated the methodological principles of designing educational tasks for the development of students' competencies in natural and mathematical disciplines while developing models for the use of computer modelling systems and educational tasks in competence development. O. Sokoliuk (2016) highlights the need to address the issue of integrating applications into educational content and the organisation of learning activities, as the rapid development of augmented reality (AR) technologies creates a significant gap between the opportunities they provide and the theoretical foundations necessary for their effective implementation in the educational process.

Speaking of Ukrainian developments in the educational sector, it is worth mentioning an updated mobile application with augmented reality for the Mental Arithmetic course introduced by the SMARTUM Ukraine Intelligence Development Academy. The Mental Arithmetic textbooks interact with the mobile app during training, demonstrating the correct finger placement and helping students perform the exercises accurately without requiring the coach's supervision. The textbook also includes charming illustrations for colouring, which come to life in the app and vividly shimmer with bright colours. The analysis of the essence of augmented reality technology and the content of competencies shows that the introduction of augmented reality in the educational process can effectively contribute to the formation of the following competencies: personal, technological, sensory-cognitive, research, natural and environmental, communicative, artistic and speech, artistic and creative, and digital. Thanks to the immersive experience provided by AR technology, students have the opportunity to learn subjects not only from books or screens but also to immerse themselves in virtual environments where they can experiment and interact with materials in a more dynamic way. According to the researcher I. Dymova (2022), the use of an artificial environment that is as close to real life as possible will not only eliminate external distractions but also reduce monotony in the learning process by providing stimulating visualisation.

With the help of augmented reality tools, the educational process can be made accessible, exciting, and understandable. This technology allows educators to visually demonstrate complex processes that are difficult or impossible to reproduce in real life. It not only enables the creation of audio and video content unavailable in ordinary books but also adds live animation to the book pages, turning reading into an engaging and impressive adventure. Textbooks with augmented reality technology, educational games, training programs, visual modelling of objects and processes, as well as various applications for training skills, can become the most effective tools in education. Thus, researchers Ya. Anhelov *et al.* (2022) emphasised the enhancement of the visual capabilities of electronic (digital) textbooks through the use of interactive augmented reality objects, which contribute to the development of future teachers' competencies necessary for the successful use of AR tools in teaching. Augmented reality technology makes it possible to use virtual objects that realistically fit into the real environment, promoting the development of critical thinking and problemsolving skills. Interactive scenarios allow students to analyse situations, make decisions, and solve problems in real time. It not only strengthens theoretical knowledge but also develops practical skills, which are of great importance for the future.

Some aspects that should be taken into account when working with AR-based educational technologies were highlighted by scholars V. Tymchyna & N. Tymchyna (2020), including the insufficient professional training of teachers, dependence on the availability of AR-supported applications on smartphones for all students, and challenges related to content mobility across various platforms and devices. According to researcher S. Lytvynova (2020), the advantages of implementing augmented reality technology in the educational process include: the visualisation of educational content, which expands its scope and enables detailed study of natural processes, phenomena, or objects; creating conditions for the organisation and delivery of practical and laboratory classes in a safe environment; providing opportunities for unrestricted access to AR objects, allowing students to repeat experiments multiple times, thereby contributing to skill acquisition; developing an individualised learning trajectory that accounts for the innate abilities of students with special needs; adopting an activity-based approach as a foundation for the development of key competencies and transversal skills, thereby emphasising the practical application of theoretical knowledge; producing vivid experiences that stimulate students' cognitive activity; immersing students in virtual experiences or environments, as engaging information tends to remain in memory for longer periods; and equipping students with competencies in AR/VR/XR technologies, which are increasingly vital in many professions today.

Educational content, as noted by (Lytvynova, 2020), created with the help of augmented reality tools offers

several possibilities, including enhancing attention – students are more focused when tasks are performed independently, on their own devices, and at their own pace; activation of all senses – multisensory learning (hearing, vision, touch) improves the quality of personalised learning; increasing the efficiency of perception, understanding, and memorisation of material; developing motor skills – implementing an activity-based approach; stimulating thinking – acquiring essential skills for the 21st century. According to another researcher, N. Honcharova, the use of augmented reality technology in education enhances motivation to learn, improves information retention due to the diversity and interactivity of its visual representation, enables students to conduct parts of their research work through distance learning, improves the learning environment, and promotes the development of research skills, as well as memory, imagination, attention, thinking, and emotional intelligence (Honcharova, 2019b).

Thus, augmented reality is among the most advanced technologies for visualising educational information. Introducing this technology is expected to boost motivation to learn, improve information retention due to the diversity and interactivity of its visual representation, and allow aspects of students' research work to be shifted to the distance learning format. The use of augmented reality in the educational process can not only adapt it to the individual needs of students by providing additional resources and tasks based on their level of training and interests, but also significantly enhance the quality of education by making it more interactive, visually engaging, and accessible to diverse student groups.

CONCLUSIONS

Based on the study of the possibilities of AR technologies in the education system, it can be concluded that the development of content using augmented reality tools has significant potential to improve the effectiveness of learning and meet both the technological and content needs of students and teachers. Primarily, it enhances the understanding of content through visualisation: AR allows students to observe and interact with learning material in three dimensions. This aids in understanding complex concepts that are difficult to explain using text or traditional two-dimensional images alone. Visual and interactive elements also contribute to better retention of information. When learners see and interact with the material, they recall it more easily later because multiple sensory channels are involved. AR makes the learning process more interesting and engaging, thereby increasing motivation to learn the material. The immersive effect creates a sense of presence, promoting deeper engagement in the learning process.

Furthermore, augmented reality can be used to create simulations of real-life situations, enabling students to acquire practical skills in a safe environment. This is particularly important for technical disciplines. AR makes learning more accessible for students with special needs by providing varied formats of information presentation and additional opportunities for adaptation. Such technologies are becoming an important component of the mobile-oriented learning environment in higher education institutions, providing modern learning conditions, modernising methods and forms, and improving the quality of education. Since augmented reality technologies are developing at an extremely rapid pace, research in the fields of education and pedagogy has not kept pace with these changes, making it difficult to theorise and develop a systematic methodology promptly. This highlights the relevance of further research aimed at developing optimal approaches to integrating traditional teaching methods with the use of augmented reality technologies.

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CONFLICT OF INTEREST

None.

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Ефективність використання технології доповненої реальності в навчальному процесі

Анотація. Актуальність вивчення технології доповненої реальності (AR) в освіті зумовлена стрімким розвитком цифрових технологій та необхідністю модернізації освіти. В умовах технологічної трансформації суспільства навчальні заклади повинні адаптуватися, щоб забезпечити якісну освіту, яка відповідає сучасним вимогам ринку праці. Вивчення впровадження доповненої реальності має вирішальне значення для розробки інноваційних методів та інструментів, які відповідають потребам сучасних студентів. Метою дослідження було проаналізувати технологію доповненої реальності, виокремити її види та частково розглянути можливості та переваги впровадження технологій доповненої реальності в навчальних закладах. Дослідження проводилося з використанням таких теоретичних методів, як аналіз, синтез, узагальнення та систематизація. У статті пропонувалось авторське бачення ефективності використання технології доповненої реальності в освітньому процесі на основі аналізу досліджень українських та зарубіжних науковців, які розглядають цю технологію як сучасний інструмент навчання. У ній автори аналізували класифікацію систем доповненої реальності за типом інформації, що передається, за типом приймачів, за ступенем взаємодії з користувачем та ступенем мобільності. З огляду на те, що технології доповненої реальності в освіті наразі перебувають на стадії становлення, автор представив зарубіжний та український досвід використання технологій доповненої реальності в освіті, а також окреслює можливості та переваги їх застосування в навчальному процесі. Зокрема, представлено специфіку інтеграції технологій доповненої реальності в освітній процес Стенфордського, Гарвардського університетів та університетів Великобританії. Практичне значення дослідження ефективності використання технології доповненої реальності полягає у виявленні реальних переваг та викликів, пов'язаних з її впровадженням в освітній процес. Результати дослідження сприятимуть розробці методичних рекомендацій та освітніх інструментів і додатків, які дозволять максимально розкрити потенціал доповненої реальності

Ключові слова: імерсивні технології; віртуальна реальність; візуалізація навчального матеріалу; діджиталізація освіти; змішана реальність