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The effectiveness of a 3D interactive learning environment as a mechanism for sharing and retaining knowledge

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Abstract. The purpose of this study was to develop recommendations for the use of 3D interactive technologies in the educational process to improve the learning of students. The experiment involved 200 students of the same age in two different groups who interacted with immersive or conventional technologies. The task was divided into four stages. In modern world, immersive technologies are constantly evolving, allowing for effective learning and thus the creation of a 3D learning environment. This study covered the significance of 3D interactive environments in the learning process, which affect the long-term retention of knowledge by students. The study analysed the perception and satisfaction of education through interactivity. The potential benefits of introducing 3D interactive learning environments into the educational process were identified. It was proved that interactive 3D learning environments can be an effective way of transmitting and storing information for such reasons as engaging students, visualising material, adapting to individual needs, preserving the information provided, and evaluating the result. The obtained findings helped to determine the effectiveness of understanding, sharing, and retaining knowledge in 3D interactive learning environment. It was established that the use of 3D learning environments helps to increase the interest and activity of students in the learning process. New opportunities are opening for visualising complex concepts and effective learning in a variety of fields. A significant aspect is that the potential of 3D learning environments as an innovative means of transferring and preserving knowledge is significant, and the impact on students is positive. The practical significance of the work is to determine the effectiveness of using interactive 3D technologies in the educational process, which contribute to increasing students' interest, activity and long-term retention of knowledge

Keywords: educational resources; educational platforms; non-formal education; computer graphics; STEAM education

INTRODUCTION

In modern rapidly evolving world, educational institutions and companies are constantly looking for new teaching methods that would be effective and engaging for students. One such type of innovative approach is the use of 3D interactive learning environments (ILEs). In turn, 3D technologies enable students not only to see the material but also to interact with it, which makes the learning process more engaging and effective. They enable a better understanding of the material by visually demonstrating complex concepts and functions. The use of 3D interactive environments can considerably increase the level of learning and retention of knowledge. They allow students and pupils to feel like active participants in the learning process, not just passive observers. However, despite all the benefits, there are certain challenges to using 3D interactive learning environments. Technical limitations, accessibility for all categories of users, and effectiveness in preserving knowledge are just a few of them. Therefore, the question of the effectiveness of 3D interactive learning environments as a mechanism for sharing and retaining knowledge requires a more in-depth analysis and assessment of the impact on the learning process. This issue has received considerable attention among researchers, and there is a sizeable number of relevant studies.

P. Chatwattana *et al.* (2020), X. Sun & E. Ch'ng (2024) found that the effectiveness of the educational process depends on the methodology of teaching and self-cognition, self-government techniques, classroom techniques, and learning environment. Virtual learning implements the idea of imperceptible organic merging of learning methods with a person's physical environment as a useful logical consequence of the full computerisation of life, the introduction of mobile devices and wireless communication. According to G. Bozzelli *et al.* (2019), virtual reality (VR) significantly improves the methodology for sharing and retaining knowledge, provides valuable empirical experience to each participant in the educational process, creating conditions for the personalised and comprehensive development of experimental skills close to reality. Technology also complements the use of immersive learning environments based on real-world simulations and considerably improves the quality of learning.

To unlock the potential of technology as a thinking tool, G.J. Harkema & A. Rosendaal (2020), F. Tian & S. Kim (2024) joined a team of teachers and experts in film studies in the field of university education, VR, and conducted an empirical study. It was found that this reality can make the learning process more interesting, encouraging the active involvement of students. Simulated environments can also motivate them and stimulate the learning process. X. Pan *et al.* (2024) supplemented the above opinion and found that VR devices are designed to become smaller, easier to use, and more accessible to a wider audience. This evolution has enabled the population to enjoy immersive virtual experiences, as well as provide interactive and realistic content. In this regard, VR has become one of the most popular forms of media for various fields of study.

B. Zhang *et al.* (2022) created a new contextual interactive 3D game (3DCG) in a virtual game environment (GVE) based on a unique virtual platform called Terf. Terf helped to observe and record data related to conversations and user behaviour. They have a positive potential for motivating students from different cultures to take part in teamwork and facilitate the exchange of their cultural and linguistic knowledge. The robots use assumptions, and therefore they can localise interactions with the surrounding space and sense their movements. This assumption is embedded in the robot's sensor selection and hard-coded into its cognitive architecture (Georgeon *et al.*, 2024).

Z. Gong *et al.* (2024) note that VR can be used from a psychological standpoint and reduce its cultural impact on creativity through targeted exposure. It was found that there is a considerable impact of immersive technologies on the development of human behaviour and thinking. According to K. Griffin (2023), immersive virtual experiences can be achieved through autonomous cognitive and biometric systems, exercise, and behavioural tracking tools, as well as emotion recognition and situational awareness algorithms. M. Grupac *et al.* (2023) and A. Sudiarno *et al.* (2024) focused on deep learning tools, cloud computing, visual image and ambient sound processing, which are based on immersive 3D VR technology, predictive modelling, and machine vision algorithms. Accordingly, technology was found to help create immersive, photorealistic virtual spaces (Lin *et al.*, 2022).

The purpose of this study was to investigate and analyse the learning outcomes of higher education students who used 3D interactive technologies in comparison with conventional teaching methods. The hypothesis of this experiment was to interact with immersive technologies that increase the level of attention. The following tasks were set to fulfil this purpose:

- to review the literature and previous studies on the use of 3D interactive learning environments and to determine whether they have advantages and limitations in the transfer and retention of knowledge;
- to compare the effectiveness of 3D interactive learning environments with other teaching methods in terms of knowledge acquisition and retention;
- to investigate the impact of using 3D interactive environments on students' motivation, interest, and involvement in the learning process;
- to identify recommendations based on the findings obtained to optimise the use of innovative technologies for their maximised effectiveness in education.

MATERIALS AND METHODS

In this study, an experiment was conducted to investigate the effectiveness of 3D interactive learning environments

as a mechanism for sharing and retaining knowledge. The study used such types of immersive technologies as virtual and augmented reality (AR). 200 participants were selected, who were divided into two groups: control (100 people) and experimental (100 people). The participants of the experiment were 10-11 years old, 55% of whom were boys and 45% – girls. The two groups had the same tasks, but the experimental group interacted with immersive technologies, while the control group interacted with conventional ones. All the standards set out in the Declaration of Helsinki (2013) were followed during the study.

The task encompassed four distinct stages to comprehensively evaluate the impact of immersive technologies on cognitive and social aspects among participants. In Stage I, both groups engaged in a demanding attention and concentration task within a virtual tour, focusing on locating specific objects. Specifically, at the first stage of the experiment, the mind map method was used to search for objects during a virtual tour of the museum for the experimental group and to view images in a textbook for the control group. Evaluation criteria include the number of words by level: low (0-5 words), sufficient (6-10 words), high (11-15 words). Stage II involved inducing emotional responses through an experiment "Creating Your Own Rainbow", measuring participants' physiological reactions like pulse and blood pressure within the virtual environment. The second stage involved measuring the blood pressure after the experiment using a tonometer and the pulse using a heart rate monitor. The results are based on the generally accepted norms of blood pressure and pulse levels for children aged 10-11 years. The pressure level was defined as follows: optimal 110-119/60-69 mmHg, normal 120-130/70-80 mmHg, and elevated 131-139/81-89 mmHg. The pulse rate indicates that the optimal one is 65-69 beats per minute (bpm); normal 70-75 bpm; and elevated – 76-85 bpm.

Stage III assessed memory and cognitive abilities using virtual environments compared to traditional methods, specifically testing knowledge retention on the topic of "Numbers: Actions with Numbers". According to the third stage, the test items were assessed according to the following criteria: low level included 0-4 correct answers, sufficient level – 5-8 correct answers, high level – 9-12 correct answers. Finally, Stage IV simulated social interaction in a virtual scenario on road safety, examining how immersive technologies influenced participants' communication dynamics and emotional reactions throughout the interaction. In the fourth stage, a list of six questions was compiled about the interaction between participants in the educational process and two degrees (low and high) of joint activity were determined using yes/no answers. 3-6 negative answers meant a low degree of social interaction, and 0-3 negative answers meant a high degree. According to the purpose of the study, the results of the performance of students of the control and experimental groups at each stage were evaluated.

RESULTS

Features of 3D interactive learning environment in the modern world

The latest technologies are gaining popularity in education every year. Modern gadgets, including computers, tablets, and mobile phones with round-the-clock internet access, are essential for modern society. Education is directly linked to modern computer technology. Multimedia devices and communication technologies are nowadays increasingly used in the educational process. At the same time, the rapid development of technology is challenging the education system, while 3D (three-dimensional) technology is a modern trend in educational technology that meets all the requirements of modern education (Lee & Wu, 2024). Interactive 3D learning environments can be a highly effective way to share and retain information for a variety of reasons.

1. Involvement of students. The environment can engage students more than conventional teaching methods. They allow simulating real-life situations, making learning more engaging and dynamic.

2. Visualisation and materialisation. Thanks to the 3D function, students can see abstract concepts in a specific format. For instance, one can investigate the molecular structure of a compound or study historical events in a virtual reconstruction.

3. Adaptation to individual needs. The 3D learning environment can be customised to suit the individual characteristics of students.

4. Information security. Through interactive simulations and exercises, learners or students can better retain information and actively engage with the content and help consolidate knowledge.

5. Assessment opportunities. 3D learning environments can also provide students with new opportunities to assess their knowledge. For instance, one can use virtual tests and monitor students' reactions in real time.

There are methods such as anaglyph, which use colour images intended for the left and right eyes to achieve the stereo effect (3D) of a conventional stereo pair of images. To achieve this effect, one needs to wear special glasses that have special light filters instead of dioptre glasses: the left eye is red, the right eye is blue, or a stereo image is a combination of stereo paired images where the red channel contains the image for the left eye and the blue channel contains the image for the right eye. Red and blue anaglyph glasses allow creating the illusion of a 3D image using colour coding (Bekele, 2019).

The use of 3D technologies in education allows diversifying classes, as well as making the learning process effective. The use of 3D content makes it possible to visually explain the material to students, encourages the study of individual elements from the entire structure, adds interactive educational content, including tests, 3D videos, modelling, a virtual laboratory, interactive tasks, games, text, images, and hyperlinks (Table 1).

Table 1. Key aspects of the effectiveness of 3D interactive learning environments

Aspects	Feature	Challenges
Visualisation of complex concepts	Improvement of understanding by visualising and manipulating 3D objects	High demands on graphics hardware and software
Development of spatial thinking	Promotion of the development of spatial thinking skills through work with 3D models	Not all subjects require spatial thinking
Cost of development	Ability to create unique and effective learning content	High maintenance and development costs
Technical requirements	Use of modern technologies for learning	High hardware and internet connection requirements
Obstacles to adaptation	Possibility of individual adaptation for each student	Not all students adapt equally well to innovative technologies
Teacher training	Improvement of teachers' skills through training in innovative technologies	Additional resources and preparation time
Active involvement of students	Engagement through interactive tasks, simulations, and games	Need to train participants in the educational process in innovative technologies
Engagement and motivation	Increase in motivation through gamification elements (achievements, rewards)	Possible development of dependence on gamification incentives
Personalised training	Adaptation of content to the individual needs of students	Excessive costs of developing personalised materials

Source: compiled by the authors

3D interactive learning environments are an effective mechanism for sharing and retaining knowledge due to a range of key factors that enhance both the learning process and the retention of material. The key signs of 3D ILEs' effectiveness include the following.

1. Visualisation and spatial understanding. 3D models allow creating complex concepts, which is vital in industries where spatial understanding is critical (medicine, architecture, engineering). Students can zoom, rotate, and otherwise interact with three-dimensional models, which helps them understand the material better than two-dimensional images or textual explanations.

2. Interactive and active learning. Stimulates the active involvement of higher education students in the learning process, which contributes to a better learning experience. Therefore, instead of passively listening to lectures, students are actively involved in solving problems, simulations, and games, which stimulates critical thinking and better retention of information.

3. Simulation of real-life situations. 3D ILEs allow creating realistic simulations that reproduce real conditions and situations. Higher education students can train in a safe environment that allows them to repeat tasks without risk, practice skills, and apply theory in practice.

4. Customisation of learning. ILEs allow the learning process to be adapted to the individual needs of higher education students, who can learn at their own pace, receive feedback, and revise the material as many times as necessary to master it.

5. Multimedia approach. The combination of sound, text, video, and 3D graphics makes learning more effective. Multimedia content activates a variety of sensory channels, which helps to improve information retention.

6. Motivation and engagement. Interactivity and gamification increase the motivation of students. Game elements, such as achievements, rewards, and levels, make the learning process more interesting and encourage participants to engage in activities.

7. Better retention and application of knowledge. Interactive and active learning contributes to better long-term retention of knowledge. Practical exercises, simulations, and revision allow students to better retain material and apply knowledge in different contexts.

A 3D learning environment is an innovative technological platform that combines elements of VR, AR, and interactive graphics to create an immersive learning experience (Table 2).

Table 2. Main types of 3D learning environments

No.	Types	Feature
1	VR	The use of VR headsets allows students to immerse themselves in a virtual environment that simulates real-life learning scenarios. They can interact with objects and situations created using computer graphics.
2	AR	AR allows superimposing virtual objects on the real world, which creates interactive learning scenarios. For instance, a student can use a smartphone or tablet to explore virtual objects that are projected onto a real environment.
3	Personalised training	Thanks to data analytics and artificial intelligence, 3D learning environments can provide personalised learning materials and tasks that meet the individual needs and knowledge level of each student.
4	Simulations and visualisations	These environments allow recreating complex scenarios and simulating real-life situations, which facilitates learning in areas that require hands-on experience, such as medicine, engineering, or aviation.

Source: compiled by the authors

3D learning environments often have interactive elements that allow students to interact with virtual objects, solve problems, and engage with virtual partners or instructors. Thanks to the Internet, 3D learning environments can be accessed by students from all over the world, allowing them to learn in an online community and communicate with colleagues and teachers from different countries. Immersive technologies are a relatively new tool in education. They cannot completely replace conventional teaching methods, but they can qualitatively complement learning (Table 3).

Table 3. Comparison of immersive and conventional learning technologies

Feature	Immersive technologies	Conventional technologies
Engagement and motivation to learn	High due to its visuality and interactivity	Low due to dependence on the teachers and the methods themselves
Technical requirements	Need for software and special equipment	Basic school equipment
Customisation of learning	As technologies are adaptive, customisation is high	Limited to standard applications
Practical experience	Significant due to simulations providing a sense of reality	Relatively limited in terms of practical classes and laboratory work/workshops
Social interaction	May be limited to a virtual environment	High due to personal communication and activity
Acquisition of the material	Deep due to active involvement	Subject to change, depends on independent activity
Accessibility	Depends on the availability of technology	Accessible to all
Individualisation	Ability to adapt to the needs of the individual	Limited, there may be one programme for all
Activity and orientation	High due to the presence of interactive elements	Probability of passivity

Source: compiled by the authors

Generally, immersive technologies are practice-oriented, facilitate practice, make it easier to understand, and make the learning process interesting. The principal idea behind immersive technologies is to increase the presence, interaction, and engagement of users in virtual or unified (real and virtual) environments. Immersive technologies help to improve the quality of the educational process, make it more interactive, adaptable, and engaging for students; expand learning opportunities and promote better understanding. The use of immersive technologies greatly expands the capabilities of modern professionals in the field of education. VR and AR technologies entail a change in the role of teachers, who create new virtual environment projects, develop scenarios for interacting with visual interactive materials, and help improve the efficiency of the educational process. Immersive technologies have such a component as objective reality (OR), in which the user is located and which they perceive in their senses. It is a world that exists independently of them and their consciousness – AR. Users can add virtual content to the real world using their smartphone camera. In other words, the camera captures the real world and complements it with virtual objects. The AR application works with 3D models, text, images, animations, and videos. VR is a fully simulated reality that uses digital technology to allow users to see, hear, and feel completely differently. To enter VR, users must wear fully enclosed goggles (headsets). Immersive technologies have a massive potential for modernising primary education and making learning more interactive, interesting, and engaging for younger students.

Advantages of 3D technology:

1. Equipping teachers with high quality teaching materials that save time in explaining complex concepts.
2. Visualisation of difficult topics for learning.
3. Incorporating processes and objects in 3D (three-dimensional models) into conventional learning tools, which helps to attract innovation and motivate the learning process.
4. Promoting the systematisation of information.
5. Help in acquiring more knowledge and a positive impact on academic performance.

Notably, immersive technologies are characterised by diversity. A distinctive feature of VR environments is that they produce the effects of image change and presence in real time through sight, hearing, touch, and other senses. AR images reflecting the real world are supplemented with virtual elements. Furthermore, AR will pay more attention to improving the existing environment, while VR helps to fully immerse the student in it. An example of 3D technology is the Magic Planet multimedia digital sphere, which is used for teaching and learning about Earth sciences. Such a technology allows observing the phenomena and processes in their dynamics, which are usually studied in university programmes. The sphere resembles a computer with over 150 programs connected to a projector with a convex lens on which a ball is placed (Klopp *et al.*, 2023). The projector glows inside the ball, and the image rotation around the axis of the ball is simulated using a special program.

There are programs to simulate the images of planets in the sky by controlling the rotation speed, animation speed, as well as to simulate polar inversion. Furthermore, a PC is connected to the Internet, and the digital world works in real time, so scientists and students can observe the origin of hurricanes in certain parts of the world. Panoramic imaging technology is also incorporated into the learning process, allowing 3D models of objects of assorted colours to be created. There is even a special classroom, The Seer, where practical and experimental research in the humanities and sciences is conducted. Moreover, in the modern world, there is a technology called "live 3D sticker" (Tatlow, 2024). For creating demonstrations and illustrations – they have great prospects for use in the modern educational process. The use of various online 3D services to develop didactic materials not only facilitates the teaching of various language activities, but also

allows for individual approaches and enhances students' independent work.

Zooburst is a service for creating 3D books that help the author to fulfil their ideas for creating their space through illustrations, tests, and sounds. 3D books cannot be downloaded to a computer and can only be used online (Tai, 2023). There is a mode that allows interacting with the book using gestures. For instance, pages can be turned simply by waving a hand in front of the book. Virtual tours are a multimedia way to express the surrounding space. Virtual tours are based on panoramas and have an interactive display that differs from conventional photographs. This means that when viewing a panoramic photo, the user can see only the part of the image that interests them at the moment, and if necessary, they can zoom in to see the details. By completing a series of communication exercises, students can easily find themselves anywhere. 3D technologies are aimed at improving the process of learning the necessary educational material, but they do not replace teachers or lecturers. Teachers using modern digital technologies, including 3D technologies, can spend more time encouraging real-life communication and doing exercises. The progress in the development of 3D technologies observed today opens massive opportunities for the future of humanity and allows entering a new technological era. They are the most effective way of learning: learning is provided by personal experience and practical activities.

The current trend in learning is no longer dependent on details or memorisation. There have been considerable changes in the way students learn and absorb educational materials. E-learning content focused on visualisation and storage of information not only modernises lessons, but also helps to track the effectiveness of classes. Based on the above information, it is worth highlighting recommendations for the use of 3D interactive environments in the educational process to improve the learning of knowledge by students:

- selecting the right content – using 3D ILEs for complex and abstract topics that are difficult to understand when using conventional teaching methods (engineering structures, architectural designs);
- interactivity and active learning – the use of interactive elements such as simulations, virtual laboratories, practical tasks, games, and testing (adaptation of educational material to the individual needs and level of knowledge of the student, and therefore it is worth determining the complexity of tasks or providing additional resources for those who need more time to learn the material);
- multimedia approach – a combination of texts, audio, video, and 3D models to create a multisensory learning experience (e.g., using video instructions alongside 3D models to explain complex processes);
- feedback and assessment – feedback and self-testing should be provided for students (interactive tests with automatic feedback after each question);
- collaboration and communication – drafting a scenario for opportunities to work together and discussing virtual projects in groups (group projects in architecture, where students work together to create 3D models of buildings);
- training of each teacher – proper training of teachers to work with 3D ILEs (advanced training courses for teachers, including training in 3D software and interactive methods);
- regular content changes – recommendations on learning content and technologies to keep them relevant and interesting. Example: updating virtual laboratories to reflect the latest research and technological advances;
- integration with other teaching methods – using 3D ILEs with other conventional and modern teaching methods to achieve an integrated approach;
- effectiveness analysis – regular analysis of the effectiveness of using 3D ILEs to adjust teaching strategies (e.g., student surveys, performance analysis, and research to assess the impact of 3D ILEs on learning).

Using educational 3D modelling, one can transform an ordinary lesson into a journey into another world. AR facilitates the "immersion" into the subject of study during classes, moving from the entire structure to individual elements, from complex to simple or vice versa. One of the key features of 3D modelling technology is that it can be taught and learned through personal experience in many areas that may be difficult or impossible, while 3D technology can be invisible, visible, inaccessible, and accessible.

Experimental study of the effectiveness of 3D interactive learning environment

The experimental study involved two groups: a control group and an experimental group, which included 200 participants. The experimental group used immersive technologies in the learning process, while the control group used conventional technologies, as presented in Table 4. The experiment included 4 stages of research and determination of the level of effectiveness of the 3D interactive learning environment as a mechanism for the sharing and retention of knowledge.

Table 4. Analysis of learning technologies used in the experiment

Stage	Immersive technologies	Conventional technologies
I	A virtual tour of the museum with interaction	Viewing of images of the museum in the textbook
II	3D model for creating a rainbow	Using the equipment for the experiment
III	Virtual game	Workbook with test tasks
IV	3D model of traffic and relevant signs	Discussion of the situations depicted in the textbook

Source: compiled by the authors

The first stage of the experiment was a test of attention and concentration. Participants in two groups had to search for historical objects. The experimental group took a virtual tour of the facilities. The control group viewed images of the same objects in a textbook. Afterwards, both groups were tasked with describing the museum's exhibits, using the mind map method to find as many words as possible. Based on the results, according to the evaluation criteria, comparative Table 5 was compiled, which shows the number of participants of the respective level.

Table 5. Results of the first stage of the experiment

Group	Results		
	Low	Sufficient	High
Experimental	22	36	42
Control	22	57	21

Source: compiled by the authors

Based on the results of the first stage of the experiment, it was found that the use of VR, specifically the virtual museum, helped to achieve a prominent level of learning among the majority of participants in the experimental group. The majority of the control group showed a sufficient level of performance. The low level in both groups was the same.

The next step was to analyse the emotional response of the students. The participants of the educational process were given an experiment "Create Your Own Rainbow". The experimental group looked at a 3D model of a rainbow, which was represented by a 3D object consisting of a set of points in 3D space connected by various geometric objects such as lines. The control group used equipment such as a container of water, a small mirror, a piece of paper, and a flashlight. The task was to review an experiment performed by a teacher. After the experiment was completed, the purpose of this stage was to measure physiological parameters (pulse, blood pressure). The results of the comparison, based on the generally accepted norms of blood pressure and pulse levels for students, are presented in Table 6, which shows the number of participants in the respective indicator.

Table 6. Results of the second stage of the experiment

Physiological indicators	Results					
	Control group			Experimental		
	Optimised	Normal	Enhanced	Optimised	Normal	Enhanced
Pulse	20	41	39	19	40	41
Pressure	20	76	4	22	68	10

Source: compiled by the authors

According to the results obtained, immersive methods have shown success and effective involvement of students in the learning process, increasing their motivation to learn the subject. The students were interested in the experiment and were excited about the process and the results.

The third stage was testing the memory and cognitive abilities of the students. After studying the topic "Numbers. Actions with Numbers", the task was to assess the knowledge of the control group with test tasks that included arithmetic operations, comparing numbers, solving problems, and working with decimals. For the experimental group, students played a virtual game where participants receive virtual money to buy goods from a store. They had to choose the goods so that their total amount did not exceed the corresponding amount of money. Accordingly, students had to score 12 correct answers. These tasks helped to assess the level of understanding of the material and identify areas that demand more attention from students. The results are presented in Figure 1.

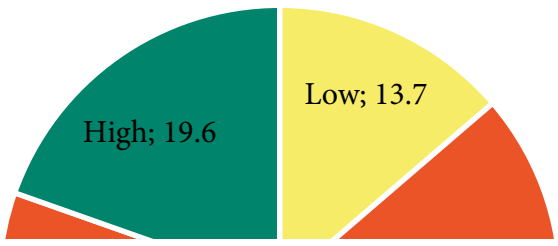

Figure 1. Research results from the third stage of the experiment
Source: compiled by the authors

The last stage was the analysis of social interaction between participants in the educational process to compare VR and conventional technology. The control group discussed the situations depicted in the textbook in relation to the topic of road safety. The experimental group was offered a 3D model of traffic and corresponding signs. Af-

ter completing the task, the control groups were asked six questions about social interaction:

1. Have you discussed situations with your classmates?
2. Did your classmates help you explain the points that you did not understand?
3. Do you agree that it is important to follow the traffic rules?
4. Did you receive any additional materials or advice on road safety from the teacher after completing the tasks?
5. Do you think that these tasks were necessary and did not help you better understand the traffic rules?
6. Have you discussed with your parents why it is important to follow the traffic rules after completing the tasks?

The results of the survey are presented in Figure 2.

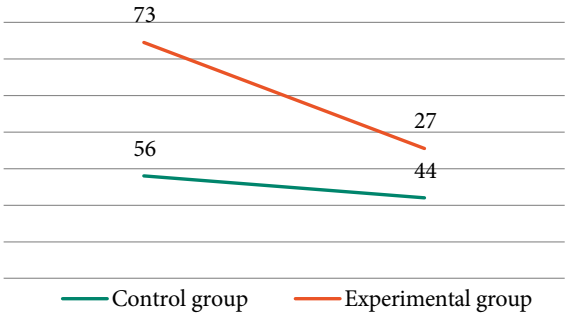

Figure 2. Results of the fourth stage of the experiment
Source: compiled by the authors

These questions helped to assess the extent to which students interact with classmates, teachers, and parents during and after assignments. Based on testing, it was found that learning with conventional technology showed higher social interaction than immersive learning.

According to the four stages of the experiment, it was found that the use of 3D learning environments increases the interest and activity of students in the learning process, as it opens new opportunities for visualising complex concepts and effective learning in various fields of knowledge. Notably, the potential of 3D learning environments as an innovative tool for sharing and retaining knowledge is significant, and their impact on students is positive. There are certain shortcomings, including social interaction, that need to be improved and worked on.

DISCUSSION

Today, there is an ongoing debate among modern researchers about the effectiveness of 3D interactive learning environments as a mechanism for sharing and retaining knowledge. The discourse mainly focuses on the advantages and disadvantages of using 3D technologies in the educational environment.

E.S. Abowardah *et al.* (2019) find that 3D technologies play a key role in the delivery of educational content. Using 3D visualisation technology, students can go beyond static images and textbook descriptions to immerse themselves in a dynamic and interactive learning environment. This opinion is supported in the present study, noting that the use of 3D models, simulations, and VR can help explore complex details, manipulate objects, and observe phenomena that are difficult to understand. This process sparks curiosity, encourages active involvement, and fosters a better understanding of complex concepts. According to F. Canet & S. Sánchez-CastilloView (2024), one of the key advantages of 3D experiments is their ability to engage students and promote active learning. The immersive nature of 3D visualisation brings the motivational component to a more profound level, making the learning process more enjoyable. Clearly, students take an active part in virtual experiments and manipulate objects in a 3D environment, becoming more involved in their learning journey. This active involvement leads to increased motivation, better knowledge retention, and a higher level of understanding.

J. Hu (2024) focused on the technologies that continue to change the educational environment, with 3D experiments standing out as a powerful tool for changing the learning experience. With the ability to engage students, develop a better understanding and bridge the decommunization gap between theory and practice, 3D experiments have massive potential for both teachers and students, using platforms such as Airbook, where teachers discover a world of engaging and interactive educational resources to develop their teaching strategies. Notably, the study continues the researcher's thought and highlights that 3D modelling can be used to create interactive models to illustrate various scientific and technical principles. Students can interact with these models, change parameters, and observe the results, making learning more engaging and informative. Thanks to 3D technologies, distance learning has become more effective and interactive. C. Girvan & T. Savage (2019) provide examples of the practical use of 3D technologies: students can visit virtual laboratories regardless of their physical location, attend virtual tours and interactive classes, and immerse themselves in the learning process. The findings support the assumption that 3D technologies not only contribute to better information absorption, but also develop key skills for the future, such as critical thinking, problem solving, creativity, and innovative thinking. As L. Jiang (2024) suggests in his study, this prepares students for the challenges of the modern world, in which digital technologies play an important role.

The results of the study show that there are many advantages of using 3D learning environments, but despite the many benefits, the integration of 3D technologies into the educational process also faces challenges, such as the need for relevant equipment and the need to train teachers and students to work with the latest technologies. However, as M. Wahid & S. Muslim (2019) point out, the possibility of using such technologies in education is worth the cost of solving these problems. The effectiveness of 3D technologies in education opens a wide range of opportunities to improve the quality and efficiency of the educational process. This not only provides a better understanding of the learning materials, but also motivates students to take an

active part in learning and encourages creative and innovative thinking. There are also negative aspects to organising a 3D learning environment. According to C. Price & A. Archer (2022), these include many aspects, namely: technical limitations, as in the modern world, many students still have limited access to the necessary equipment and Internet connection, which makes it difficult to take part in a 3D learning environment; lack of necessary skills to perceive 3D learning, which makes it impossible to engage with the learning material; distracted attention, as virtual technologies can be distracting, especially if students are not experienced in its use.

S. Segear *et al.* (2024) highlight negative trends and thus continue the previous opinion of the above-mentioned researchers. They believe that the problems in 3D learning environments are frequent fatigue of students, especially when such learning requires prolonged concentration or movement, and lack of social interaction. The latter is a very common problem, as in some cases virtual learning does not allow for personal interaction with the participants in the learning process, which can affect their social development. The findings of the study were confirmed by the studies of X. Pan *et al.* (2024) and M.Z. Iqbal *et al.* (2021), which highlight that developing and maintaining a 3D learning environment can require considerable software, hardware, and staff training costs, and some 3D platforms may have complex or inconsistent interfaces that can make them difficult for users to navigate and use. All the above problems and shortcomings can be solved by improving technology and raising user awareness.

Implementing a 3D learning environment today can be challenging for several reasons. Firstly, creating 3D environments requires considerable knowledge and skills in computer graphics, programming, design and engineering, from object design to functional programming, which is a lot of work. Some 3D learning environments require powerful hardware for graphics and data processing. As T. Sparrow *et al.* (2024) point out, this can make it difficult to access for users with disabilities. Secondly, R. Spick & J. Walker (2019) identify the creation of an intuitive and user-friendly interface in a 3D environment as a major challenge. It is necessary to ensure convenient navigation, clear interaction with objects and other users. Developing and maintaining a 3D learning environment can be a costly process, especially if one needs to use specialised software or hire a professional designer or developer. Thirdly, according to M. Camilleri (2024), despite these challenges, the development and use of 3D learning environments has great potential to engage learners, enhance learning, and create interesting and engaging educational experiences. To ensure effective learning, it is important to consider learning principles when designing a 3D learning environment. This may require collaboration with educators and education specialists.

The findings have revealed a new perspective on the organisation of 3D learning environments, which enables the creation of a high-quality, efficient, and effective learning environment using innovative virtual technologies. For this, one can employ such technologies as VR, AR, interactive 3D models. Generally, these types of 3D learning environments allow students to learn the necessary educational material in an exciting way. The integration of the latest technologies into 3D learning environments can improve the process and concept of learning in general. 3D interactive learning environments enhance the process of knowledge sharing and retention through interactivity, gamification, customisation of learning, visualisation, simulation of real-life scenarios, and a multimedia approach. They promote active learning, critical thinking, and long-term retention of information, making them an effective tool in modern education.

The reliability of the findings obtained was influenced by the data and information obtained as a result of the study. The study was also based on the authoritative opinions of contemporary researchers. Certain aspects of this issue have not been studied, as 3D learning technologies are still under development and are constantly being improved.

CONCLUSIONS

3D interactive learning environments enhance the process of sharing and retaining knowledge through interactivity, gamification, customisation of learning, visualisation, simulation of real-life scenarios, and a multimedia approach. They promote active learning, critical thinking, and long-term retention of information, making them an effective tool in modern education. To improve learning through 3D interactive learning environments, a comprehensive approach should be employed, including content adaptation, active student engagement, feedback, collaboration support, and regular updating of learning materials. It is also important to provide teachers with proper training and continuously analyse the effectiveness of these technologies in the learning process.

The findings presented in this study prove that investigating the effectiveness of 3D learning environments for schoolchildren can have such consequences in the modern world as the process of improving the learning of educational materials. In this study, an experiment was conducted to investigate the effectiveness of 3D interactive learning environments as a mechanism for sharing and retaining knowledge. The hypothesis was proved, which noted the positive impact of interaction with immersive technologies, which increases the level of attention. 3D environments can contribute to better learning by visualising information. This study helped to assess how students interact with classmates, teachers, and parents during and after homework. Based on the tests, it was found that learning using conventional methods demonstrates a higher level of social interaction than immersive learning. According to the 4 stages of the experiment, it turned out that the use of a 3D learning environment increases the interest and effectiveness of students in the learning process, as it creates new opportunities for visualising complex concepts and conducting effective training in various fields of knowledge.

Notably, the potential of 3D learning environments as an innovative tool for knowledge transfer and preservation is significant, and its impact on learners is positive.

The study confirmed that 3D modelling can turn an ordinary activity into a journey into another world. AR makes it easier to move from the entire structure to individual elements, from complex to simple or vice versa. One of the key features of 3D modelling technology is that it can be taught and learned directly. The use of 3D learning environments contributes to the retention of students' knowledge, but further research in this area is needed, considering individual needs and capabilities. As a promising area of research, studies can investigate the impact of using 3D environments on the development of certain skills, such as spatial thinking, creativity, and problem solving. A limitation of this study was the results dependent on a concrete learning environment, its features and resources. Another limitation of this study included the insufficient use of 3D in the modern educational process to improve the acquisition of the learning material and the formation of students' knowledge. A promising area of research is the development and ways of incorporating 3D technologies into the educational process by any accessible means.

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CONFLICT OF INTEREST

None.

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Ефективність 3D інтерактивного навчального середовища як механізму обміну та збереження знань

Анотація. Метою даного дослідження була розробка рекомендацій щодо використання 3D інтерактивних технологій у навчальному процесі для покращення засвоєння матеріалу студентами. В експерименті взяли участь 200 студентів одного віку у двох різних групах, які взаємодіяли з імерсивними або традиційними технологіями. Завдання було поділено на чотири етапи. У сучасному світі імерсивні технології постійно розвиваються, що дозволяє ефективно навчатися, а отже, створювати 3D навчальне середовище. Це дослідження висвітлило значення інтерактивних 3D-середовищ у навчальному процесі, які впливають на довготривале збереження знань студентами. У дослідженні було проаналізовано сприйняття та задоволеність освітою через інтерактивність. Визначено потенційні переваги впровадження 3D інтерактивних навчальних середовищ в освітній процес. Доведено, що інтерактивні 3D навчальні середовища можуть бути ефективним способом передачі та зберігання інформації з таких причин, як залучення студентів, візуалізація матеріалу, адаптація до індивідуальних потреб, збереження наданої інформації та оцінка результату. Отримані результати допомогли визначити ефективність розуміння, обміну та збереження знань у 3D інтерактивному навчальному середовищі. Встановлено, що використання 3D навчальних середовищ сприяє підвищенню зацікавленості та активності студентів у процесі навчання. Відкриваються нові можливості для візуалізації складних понять та ефективного навчання в різних галузях. Важливим аспектом є те, що потенціал 3D навчальних середовищ як інноваційного засобу передачі та збереження знань є значним, а вплив на студентів – позитивним. Практичне значення роботи полягає у визначенні ефективності використання інтерактивних 3D технологій у навчальному процесі, що сприяють підвищенню зацікавленості, активності та довготривалому збереженню знань студента

Ключові слова: освітні ресурси; освітні платформи; неформальна освіта; комп'ютерна графіка; STEAM освіта