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ORIGINAL

Virtual simulations as an innovative technology for the modernization of medical education

Simulaciones virtuales como tecnología innovadora para la modernización de la educación médica

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ABSTRACT

The study is focused on highlighting the features of virtual simulations as an innovative technology of modern medical education. The study used economic and statistical analysis, systematization, sec-ondary data analysis, and comparative analysis to assess the development of the virtual reality mar-ket in education and to classify virtual simulations in medical education and evaluate their ad-vantages and limitations. It has been found that virtual reality in education is becoming increasingly popular due to its potential to transform the educational process, and it has been determined that predictions until 2028 indicate a significant growth of this market due to increased investment and demand for innovative educational solutions. The main types of virtual simulations for teaching healthcare specialties are systematized and graphically presented, in particular: virtual patients for training clinical skills, clinical procedure simulators, virtual laboratories for online experiments, spe-cialized programs for diseases, and an interactive table for learning to work with medical equip-ment. The advantages of virtual simulations, such as safe experimentation, simulation of complex situations, and the possibility of individualizing learning, are thoroughly identified. The influence of virtual simulations on the development of critical thinking, communication skills and the ability to adapt to changes in the professional environment is investigated. This study has made important con-clusions about the effectiveness of virtual simulations as a useful tool for preparing future medical professionals for the challenges of the modern labor market.

Keywords: Clinical Scenarios; Debriefing; Interactive Learning; Virtual Patient; Virtual Reality.

RESUMEN

El estudio se centra en destacar las características de las simulaciones virtuales como una tecnología innovadora de la educación médica moderna. El estudio utilizó análisis económico y estadístico, sis-tematización, análisis de datos secundarios y análisis comparativo para evaluar el desarrollo del mer-cado de realidad virtual en la educación y clasificar las simulaciones virtuales en la educación médica y evaluar sus ventajas y limitaciones. Se ha encontrado que la realidad virtual en la educación está ganando cada vez más popularidad debido a su potencial para transformar el proceso educativo, y se ha determinado que las predicciones hasta 2028 indican un crecimiento significativo de este mercado debido al aumento de la inversión y la demanda de soluciones educativas innovadoras. Se sistemati-zan y presentan gráficamente los principales tipos de simulaciones virtuales para la enseñanza de especialidades sanitarias, en particular: pacientes virtuales para el entrenamiento de habilidades clínicas, simuladores de procedimientos clínicos, laboratorios virtuales para experimentos en línea, programas especializados para enfermedades y una mesa interactiva para aprender a trabajar con equipos médicos. Se identifican minuciosamente las ventajas de las simulaciones virtuales, como la experimentación segura, la simulación de situaciones complejas y la posibilidad de individualizar el aprendizaje. Se investiga la influencia de las simulaciones virtuales en el desarrollo del pensamiento crítico, las habilidades comunicativas y la capacidad de adaptación a los cambios en el entorno pro-fesional. Este estudio ha llegado a conclusiones importantes sobre la eficacia de las simulaciones vir-tuales como herramienta útil para preparar a los futuros profesionales médicos para los retos del mercado laboral moderno.

Palabras clave: Escenarios Clínicos; Debriefing; Aprendizaje Interactivo; Paciente Virtual; Realidad Virtual.

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INTRODUCTION

Virtual reality (hereinafter referred to as VR) in medical education and clinical practice has grown significantly in recent years. Educational programs with VR are aimed at improving the clinical skills of healthcare specialists by providing opportunities to apply theoretical knowledge in real healthcare settings.[1] As a result, VR is becoming an alternative to traditional methods of clinical training. The traditional system of medical education, which includes training in hospitals or the use of mannequins, has certain limitations related to time and space factors, as well as a limited number of clinical cases available for training. Moreover, the variety and completeness of clinical situations that students may encounter are also limited.

VR technologies have been developed as alternatives and complements to overcome these limitations. Digital transformation, including the launch of Hololens in 2015 and Oculus (now MetaQuest) in 2016, as well as the COVID-19 pandemic, have accelerated the adoption of VR education. These devices allow recreating realistic clinical scenarios, providing users with the opportunity to learn more interactively and effectively, without the limitations of traditional approaches.[2] VR-based educational programs provide healthcare professionals with the ability to repeat training scenarios anytime and anywhere, allowing them to encounter a wider range of real-world clinical situations.[3]

The analysis of the scientific basis of the study demonstrates the gradually gaining momentum and relevance of the use of virtual simulations in healthcare, in particular in the training of medical students and practicing doctors. There are various aspects and perspectives of using virtual simulations that are studied in scientific articles. Scott et al.[4] examined current practices of using virtual simulations in neuroscience. The authors noted that virtual simulations give students the opportunity to interact with realistic clinical situations, which is an effective tool for teaching neurosurgery and other complex disciplines. Therefore, virtual simulations open up new horizons for medical training, in particular, in preparation for clinical practice, where real conditions are not always available.

The study conducted by Shao et al.[5] showed that virtual reality is an effective tool for teaching neurosurgery, in particular for practicing techniques that cannot be trained on real patients. This allows students and doctors to acquire practical skills that cannot be obtained through traditional teaching methods. According to the authors, the use of VR in medical education can significantly enhance students' practical skills, reducing the number of mistakes in real-life clinical scenarios.

The study by Lerner et al.[6] proves that multi-user virtual reality in emergency medical simulations allows students to directly participate in learning situations that bring them closer to real-life conditions. Their research also points to the need for improved technologies to raise the effectiveness of learning. The research of Gasco et al.[7] focuses on virtual simulations of surgeries that help students to learn complex surgical techniques. Simulations allow students to practice various manipulations without risk to patients, which is an important achievement in medical education. These simulations need to be integrated with traditional teaching methods to achieve a more comprehensive learning experience.[8]

Mariani et al.[9] confirmed in their study that virtual simulations improve the quality of medical education by providing students with the opportunity to study clinical cases in a controlled environment. Additional research and improvement of existing methods are needed to fully realize VR in medicine. In conclusion, many authors, including Wu et al.[10], emphasized the need to expand research in this area, as the use of virtual simulations has many advantages, and further research is needed to assess the long-term effectiveness of such training methods.

There are many studies on this topic, but the issue of using virtual simulations as an innovative tool for teaching medical students requires additional development. The purpose of the article is to highlight the features of virtual simulations as an innovative technology of modern medical education. In accordance with the objective, the study has the following tasks:

1. To review the development of the global virtual reality market in education.
2. To systematize the main types of virtual simulations in medical training.
3. To reveal the effectiveness of using virtual simulations in teaching medical students by highlighting its capabilities and advantages.

METHOD

The research methodology consisted of three main stages, each aimed at a detailed study of various aspects of the introduction of virtual simulations in medical education. The initial stage of the study included an overview of the development of the virtual reality market in education. Methods of economic and statistical analysis were used for this purpose, including analysis of market dynamics and prediction of its development. The VR market in education was assessed using data from recent reports, such as The Business Research Company[11], Mordor Intelligence[12], providing a complete understanding of trends and forecasts until 2028.

The next stage of the study was to systematize the main types of virtual simulations used in teaching medical students. The author analyzed the existing technologies and programs used in different countries to train medical personnel. Several categories of virtual simulations were identified, such as surgical simulations, simulators, virtual patients, and multi-user platforms for team training in emergency situations. The main characteristics of each type of simulation were identified and a graphical representation was created, which made it possible to demonstrate in a detailed manner the variety of VR capabilities and functions in medical education.

The final stage of the study included an assessment of the opportunities and limitations of using virtual simulations in medical education. The evaluation was carried out by comparing the advantages of VR systems, including realistic training, safety for patients and the ability to learn at any time, with the limitations associated with high equipment costs, the need for constant software updates and the lack of sufficient experience of teachers.

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RESULTS

In 1939, the first virtual reality device was patented in the United States. It was a portable non-electric device that created a three-dimensional environment using slides. This invention became the basis for the further development of virtual reality technology. The technology has improved substantially during the following decades and has transformed many fields, such as healthcare, education, and entertainment.[13] Nowadays, virtual reality has evolved from a simple slide display to innovative wearable devices that can create interactive three-dimensional environments for users to interact with their surroundings. As a result, virtual reality has become a multi-billion-dollar industry, led by tech leaders such as Facebook, Sony, and Microsoft.

The figure 1 demonstrates the dynamics of the virtual reality market in education with a forecast until 2028.

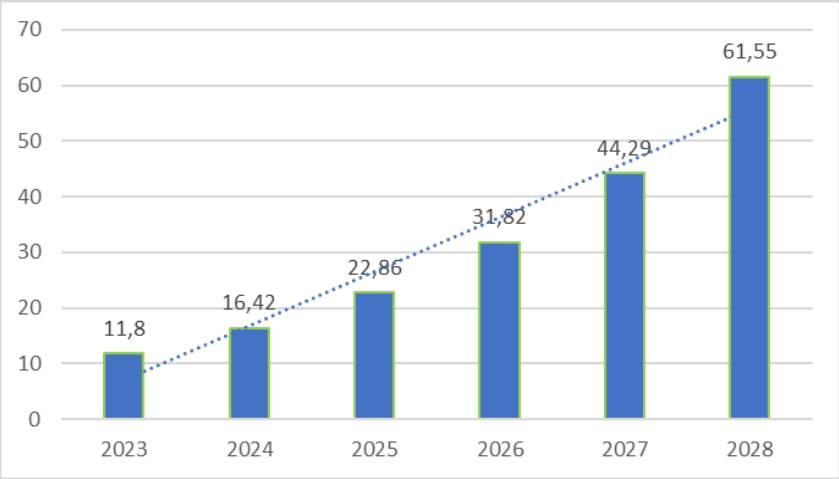
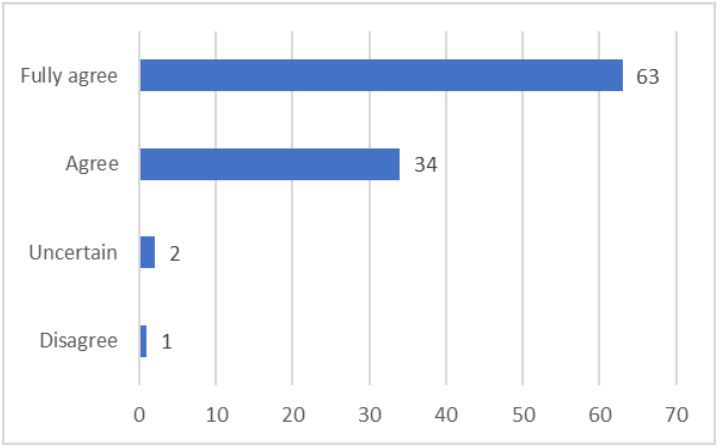


Figure 1. Dynamics of the virtual reality market in education with a forecast until 2028

The graph (figure 1) shows that the virtual reality market in education shows significant potential for growth in the coming years. According to forecasts, the market size will reach 61,55 billion USD by 2028, with an average growth rate of 39,1 %. This rapid growth is largely driven by the growing demand for interactive and personalized educational experiences, as well as the increasing use of virtual learning environments. These trends are caused by the widespread introduction of Internet technologies in the field of education, which contributes to the increased accessibility and mobility of educational materials, as well as the replacement of traditional physical materials with virtual analogues.[14]

The growing interest in this technology and the decreasing cost of virtual reality systems are expected to increase its usage in the education sector. The Perkins Coie and XR Association survey of more than 160 professionals found that 63 % of respondents strongly agree that immersive technologies will significantly improve the educational process over the next five years (figure 2).[12]



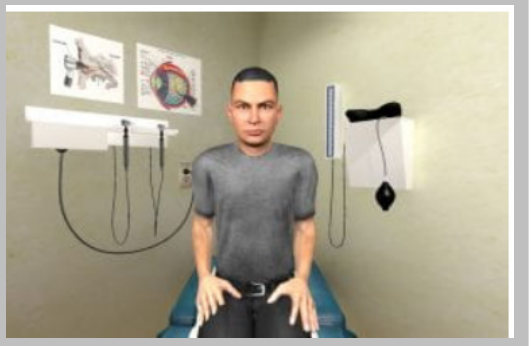
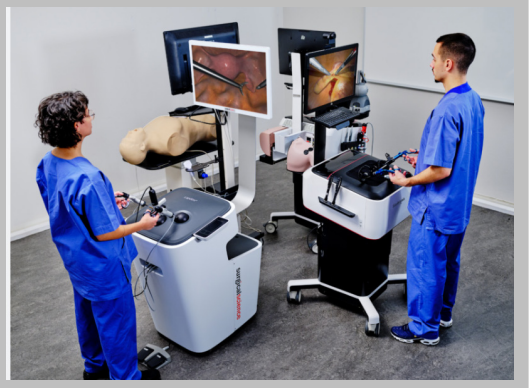
Source: Mordor Intelligence[12]

Figure 2. Percentage of respondents who agree with the statement: Immersive technologies will contribute to considerable progress in education over the next five years, in %

The report identifies the increasing popularity of online education and training, as well as the active use of virtual reality technologies in educational institutions of various levels, as the main factors contributing to this growth. It is predicted that the market will continue to grow in the coming years due to investments in research and development in VR education and the integration of the latest technologies, such as analytics to monitor learning outcomes and the use of augmented reality to improve the educational process.

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Table 1. Main types of virtual simulations in medical students' education

No	Types	Description	Images
1	Virtual patients (VPS)	VPS enables a unique approach to assessing important skills such as case history and clinical decision-making. Virtual patients are avatars representing standardized patients who can be interviewed by students. Students complete a case history and develop a differential diagnosis for the VPS, similar to a typical or real patient.	
2	Clinical procedure simulators	Clinical procedure simulators are advanced tools that allow students to practice in conditions that are as close to real as possible, as they mimic the structure of the human body, the functions of organs, and the patient's reactions to various manipulations. Such simulators can be presented in the form of mannequins and special training devices. The main advantage is that students can train without risking the health of real patients, which significantly increases their level of preparation for work.	
3	Virtual laboratories	Virtual laboratories provide students the opportunity to conduct laboratory experiments online and learn concepts and theories without physical presence. This is especially significant during the pandemic, when it becomes a valuable alternative to traditional learning. There are different types of virtual laboratories, from simple video animations to interactive 3D learning environments, providing an immersive experience for students.	
4	Disease Specific Programs	Disease specific programs help patients to get individualized recommendations, monitor their health status, and provide convenient access to treatment by using technology.	
5	Interactive table	Virtual tools for practicing with medical equipment used in the practice of neurology.	

Virtual simulation in medical education is a method that uses computer technology to create virtual environments that imitate clinical situations and symptoms associated with various diseases. These virtual simulations allow to recreate real clinical situations that future healthcare professionals may encounter during their professional activities.

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Virtual simulation tools have also been successfully used to create three-dimensional models that facilitate the study of complex neuroanatomical disciplines. In addition to virtual models, VR is used as an educational resource through 360-degree videos demonstrating surgical approaches and neurological pathologies. The videos are a unique tool for students and medical residents, as they help prepare for the analysis of specific clinical cases and improve operational skills.[5] In general, virtual simulations have become an indispensable tool for improving the quality of education and training of future medical specialists in the field of neurology.[15]

The study conducted by Gasco et al.[7] compared two groups of medical students who were installing screws in a model of lumbar vertebrae. The first group used the Immersive Touch virtual reality simulator, while the second group was trained with traditional visual and verbal instructions. The results showed that students who studied with the VR simulator outperformed the control group on all criteria.[7] The study demonstrates the promise of using VR simulations in medical education despite the small number of participants (only 26 students divided into two groups) and the lack of experience of the participants compared to residents or doctors.

Virtual reality simulators have also been used to teach complex procedures, such as tumor resection during endoscopic nasal surgery and cerebral aneurysm clipping.[5] The integration of VR simulators into the training of medical professionals contributes to the development of psychomotor skills, increased patient safety, and reduced training costs.[4] To assess the importance and potential of introducing virtual simulations in medical education, it is worth paying attention to their main types (table 1).

Thus, table 1 demonstrates the types of virtual simulations used in medical student education. Virtual patients create a unique learning environment that includes modeling clinical scenarios, examination, diagnosis, and treatment in a virtual environment. These programs allow future doctors to practice important skills, such as taking case histories and developing differential diagnoses, as close as possible to real-life patient care.[16]

Virtual reality can also be used in medicine to help students improve their empathy skills. Empathy plays a crucial role in the healthcare field. Healthcare professionals often have to give patients disappointing news or have sensitive conversations. Virtual reality simulations give students the opportunity to practice such interactions, practice various scenarios, and realize the possible reactions of their interlocutors. This approach helps to prepare them better for the real challenges they will face during their professional internships.

Clinical procedure simulators allow students to acquire basic techniques and work with complicated cases in a safe environment, modeling the reaction of tissues and kinematics of a human body, which significantly improves the quality of training, as students gain practical experience without risking the health of patients. Virtual laboratories provide students with the opportunity to conduct experiments and learn theoretical concepts online, which is especially relevant in a distance learning environment. This includes both simple models and interactive 3D environments, creating a diverse learning experience.[17]

These technologies are an integral part of modern medical training, providing students with the opportunity to obtain a high level of professional preparation in a realistic and controlled environment. Beginners can use these methods to gain confidence and build muscle memory for basic procedures and tasks that are often performed in real-world practice. Experts can use simulations to master new and advanced technologies that are rapidly being introduced into medical practice. This includes minimally invasive surgery, catheter therapy, robotic procedures, etc.[18]

Clinical simulation creates unique opportunities for practicing complex procedures or treating rare diseases that are difficult to encounter in everyday practice. Previously, real patients were needed to study such cases, which limited the learning process. Modern simulation technologies partially solve this problem. Scenarios are useful for both beginners and experienced professionals. It is possible to simulate situations related to heart attacks in an outpatient setting, severe allergic reactions, or the treatment of malignant hyperthermia during surgery.

The article by Lamé et al.[19] highlights that virtual simulation provides researchers with a unique opportunity to analyze events that would otherwise remain beyond their direct observation. It allows them to work in a controlled and safe environment, which significantly reduces risks. The scientists also emphasized that simulation conditions create an opportunity for students to practice safely. Clinical simulation has been actively used to improve healthcare systems and procedures, in particular to diagnose problems and test new approaches before they are implemented in real practice.

Clinical simulation has become one of the most effective methods of training besides providing access to training at any time and in different circumstances. The reality of healthcare in its dynamic pace often does not allow for in-depth analysis of events, so simulation fills this gap. The main objective is to teach students to analyze reasons why certain situations occurred and to find solutions to enhance performance. Simulations can be supplemented with video recordings or debriefings that allow for detailed analysis of students' actions. This helps to better understand mistakes and prevent them from occurring again.

Modern virtual clinical simulators, such as surgical models and task simulators, collect large amounts of data on student performance. This analytical data, in the form of performance maps and logs, can provide valuable feedback to learners. These materials also help instructors identify areas for improvement, providing effective training for successful clinical practice performance. Debriefing should also be highlighted as an important part of simulation training for future doctors. Medical students often have a limited understanding of the events that are happening to them when they are involved in them, especially when they are in the center of the situation. Therefore, debriefing becomes an important part of simulation training, turning it into a conscious practice that prepares students for the profession emotionally and physically.

Debriefing is the process of discussing and analyzing the actions and emotions of participants after completing a specific task or situation in order to receive feedback, reflection, and improvement of future results.[20] An atmosphere of trust during the debriefing is crucial for successful simulation training.

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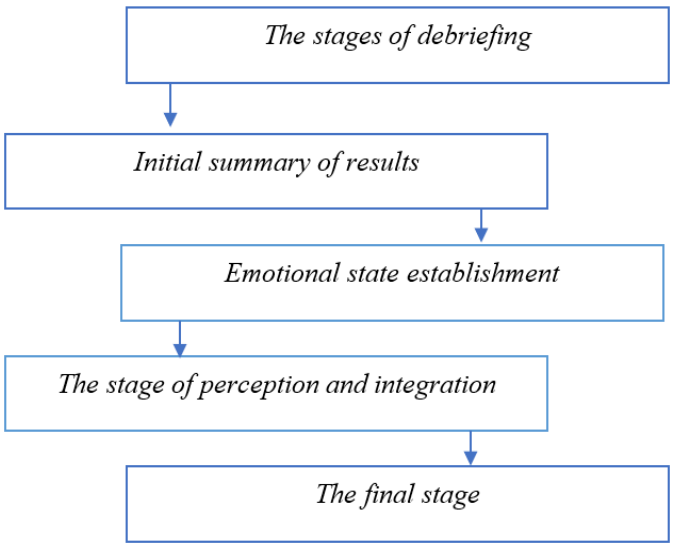


Figure 3. The stages of debriefing as part of simulation training

It is important that the instructor considers the individuality of the future doctor, including their cultural background, personality, skills and abilities. If the lesson involves video recording, the consent of the students should be obtained by signing a confidentiality agreement. The instructor should actively listen, providing only necessary instructions and asking questions to keep students' attention and interest, and to stimulate reflective thinking throughout the debriefing session.[20]

The structured debriefing is an important element of an in-depth analysis of a simulation training and consists of a number of stages (figure 3).

1. Initial summary of results, during which students should be seated so that they can see each other and the instructor, discuss confidentiality issues, explain the objectives of the simulation, the role and expectations of the instructor, and describe the debriefing process in detail.
2. The emotional state establishment, during which students exchange opinions and impressions, emotional relaxation, role-playing, and relaxation take place.
3. The stage of perception and integration, which includes watching videos, analyzing events in detail, and evaluating positive aspects and mistakes.
4. The final stage summarizes the lessons learned, reviews skills and abilities, and identifies tasks for further work.

Debriefing should be concluded on a positive note. The use of effective debriefing techniques significantly increases the effectiveness of the training, so special attention should be paid to them. There is some evidence that the use of virtual simulations significantly increases students' engagement in the educational process and improves their exam results compared to traditional methods. These studies indicate that virtual reality is a perspective tool that can substantially improve the quality of education at all levels, from elementary school to medical universities.

DISCUSSION

The study demonstrates the importance of using virtual technologies to train medical students, including virtual simulation training. This has considerable potential to improve the quality of medical education, especially in complex specializations such as neurosurgery and intensive care. The results confirm that virtual simulators and virtual patients allow students to develop practical skills, which is consistent with the conclusions of Wu et al.[10], who also emphasized the benefits of virtual simulation in preparing students for real clinical situations.

The results of the current study are also consistent with the study by Lerner et al.[6], who confirmed the effectiveness of multi-user virtual simulations in teaching teamwork skills. The current study also found that simulations contribute to the formation of confidence in decision-making in complex environments, which is similar to the research of Sung et al.[2], which reported the effectiveness of VR in improving students' professional competence in the healthcare sector.

The current study questioned certain aspects of VR use in specific areas of medical education, such as the study of highly specialized topics. This conclusion does not coincide with the results of Shao et al.[5], indicating the versatility of VR in teaching neurosurgery. It is also important to note that, despite the significant potential of VR, the effectiveness of such approaches may depend on the quality of virtual content and interactive features, which requires further research. The results of the current study also fit into the context of Yurii et al.[1], who examined Ukraine's experience in implementing virtual simulations for training doctors in emergency situations.

An interesting study was conducted by Edgar et al.[21]. They interviewed 80 medical students for this study and came up with a number of important conclusions:

1. Virtual simulation was perceived by students as quite realistic, allowing them to be part of the work process even when they are in an online environment. This increases their interest in learning and engagement in the process.

2. The realism of the virtual simulation is supported by several types of accuracy: contextual, conceptual, functional, and task. Elements that resemble the real conditions of an optometric clinic, such as patient rooms and displayed glasses, are important.

3. The students expressed the opinion that virtual simulation helps to apply theoretical knowledge in practice, contributing to better learning and improving education.

4. Virtual simulation helps students to develop basic professional skills, such as clinical thinking, which is necessary to work in a real-life optometry environment.

5. Participation in virtual simulations allows students to better understand their future professional role, increasing their confidence in their future as optometrists.

The results of the current study indicate that the use of VR in medical education is an essential tool for training highly qualified specialists, although there are aspects that warrant additional study.

CONCLUSIONS

The conclusion is that virtual technologies are becoming a useful instrument for training highly qualified medical professionals measure up the labor market requirements. An analysis of the development of the modern virtual reality market in education has shown that this technology is gaining popularity due to its potential to transform the educational process. Forecasts until 2028 indicate a significant growth of this market, which confirms the increase in investment in this area and the growing demand for innovative educational solutions.

Studies of different types of virtual simulations for medical students have revealed a wide range of methods used to train clinical skills, from simulations of surgical procedures to crisis situations. There are also some limitations to the use of virtual simulations in medical education despite their advantages.

These technologies provide significant opportunities for student learning, but they require significant financial investment and high-quality hardware, which may not be available to some medical institutions. Moreover, simulations cannot completely replace practical experience with patients, which is an important component of medical training.

A limitation of the current study is the lack of real-world data on the effectiveness of virtual simulations in practice at medical institutions. The study focuses on the theoretical aspects of implementing these technologies, and further empirical research is needed to confirm the results. This will allow for a deeper understanding of their real impact on the educational process at medical universities.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Kateryna Tiazhkorob.
Research: Kateryna Tiazhkorob.
Methodology: Kateryna Tiazhkorob.
Drafting - original draft: Kateryna Tiazhkorob.
Writing - proofreading and editing: Kateryna Tiazhkorob.

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