Immersive learning technology for ensuring quality education: Ukrainian university case

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Abstract

The article considers the problem of using immersive learning in the educational and scientific activities of the university. Literature survey revealed that there is a need for an integrated approach for introduction of immersive learning at the university. It involves the creation of a specialized laboratory of virtual and augmented reality with appropriate technical equipment, introduction of immersive learning methodology in university educational programs, development of software and hardware solutions for immersive learning, and research on the immersive learning effectiveness. We present the description of a specialized university department acting as a developer of software products for immersive learning. We show original developments in the field of immersive education for exact sciences and arts and humanities students. The article describes products that are designed to fulfill the third university mission: to ensure the citizens well-being. We propose "immersive institute" model which can be implemented both at the level of the university in general and at the level of its educational and scientific departments.

Keywords

immersive learning, virtual reality, augmented reality, immersive institute

1. Introduction

The process of learning at the university is not always associated with the use of real objects or phenomena as a demonstration. The educational material is mostly explained on imaginary models of processes or objects. It is also not always possible to interact with such models. Therefore, the whole process of learning (discovery of the world) is very indirect and largely depends on the developed imagination of the student. In this case, the effectiveness of teaching largely depends on teacher's ability to convey the essence of the model and the student's ability to imagine it.

A flat two-dimensional surface (black- or whiteboard, an interactive board or just a slide projector) usually remains a teacher's tool aimed to help students form the idea without possibility of its dynamic change over time. Current generation of young people perceives information differently and students' ability to think imaginatively does not get better, and largely depends

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on the methods of conveying information, visualizing images. Therefore, the printed textbook today is less satisfying for students than in recent years. Even video content is not always effective enough for describing a complex model, idea or process. All this in general has a negative impact on the quality of education, especially with a low level of student motivation. In this case, the need arises for proposing new tools to create additional practice-oriented learning incentives on the university side and increase the level of student motivation. One such tool is immersive learning.

Technologies of full or partial immersion in the virtual world or various combinations of "live" tools (F2F) and virtual reality – immersive technologies – allow to provide the effect of full or partial presence in an alternative space. These technologies are implemented through software and hardware solutions of VR (virtual reality), AR (augmented reality) and MR (mixed reality) [1].

VR and AR currently have the greatest impact on human perceptual organs, and their potential for education is not yet fully explored. The following properties form their prospects:

1. *Visual orientation.* In a virtual space, one can freely view any process or object in detail from different angles, which is much more interesting than looking at static pictures in the textbook.
2. *Concentration.* In a virtual environment, one cannot be distracted by external stimuli, which allow strong focusing on the material.
3. *Maximum involvement.* Stereoscopic images and surround sound create a complete illusion for the human senses. Tracking student movements and positions in a virtual environment adds a presence effect. Some technological solutions allow realizing even tactile sensations. In addition, immersive technologies provide the ability to fully control and change the learning scenario. The student can witness historical events, conduct an experiment in physics or chemistry, or solve a problem in playful and understandable form. In fact, student interacts almost naturally with objects of study or research.
4. *Safety.* One can unsuccessfully perform a complex operation, try to control a space shuttle, conduct an experiment with dangerous chemicals or explosives, while suffering many failures and not cause real harm to oneself or others.
5. *Effectiveness of learning and quality of knowledge acquisition*, which is confirmed, e.g. by research conducted by Microsoft [2], and Eutsler and Long [3].

That is why immersive technologies are already actively used in education [4].

Immersive technologies change the content and develop the typology of educational materials: printed; printed with multimedia applications; electronic as an analogue of printed; electronic with multimedia content, navigation and hyperlinks to external sources; printed with augmented reality objects; virtual and mixed books. The integration of new AR technology into the old environment has a synergistic effect and positively influences the students. AR books (Visually Augmented Books, Traditional AR Book), which usually contain both 2D static and dynamic content, and 3D content: static and dynamic models, sound depending on user actions and location, etc. became popular recently.

It is very important to note that immersive technologies should not be associated exclusively with technical objects. It is also important to reveal their relevance, for example, in medical

education and arts and humanities field. The main purpose of this article is to present a comprehensive approach to the use of immersive technologies in classical university.

The object of research is the e-learning ecosystem at the university.

The subject of research is immersive learning as an e-learning tool.

The novelty of the work is a new comprehensive approach to the introduction of immersive learning at the university, which includes:

- creation of a specialized laboratory of virtual and augmented reality with appropriate technical equipment;
- introduction of the immersive learning methodology in the university educational programs;
- development of proprietary software and hardware solutions for immersive learning;
- study of immersive learning effectiveness based on the overall student achievements.

Practical significance: for the first time on the basis of the classical university we work out the algorithm for creation of AR and VR tools considering features of knowledge branches. The algorithm is implemented for educational programs of engineering, medical and socio-humanitarian direction.

2. Literature review

The development of immersive technologies and the growth of their popularity is clearly shown in figure 1. Over the past 10 years, the annual number of scientific publications on "immersive technology" has increased 4 times (according to https://www.scopus.com/). However, despite such a significant increase, the annual number of publications is not high, which indicates the stage of formation of this research area.

United States of America occupy the leading position in this research area (figure 2). Figure 2 also lists the origin countries of the authors that published 100+ scientific papers in the field of "immersive technology". Ukraine is just beginning its journey in this direction, which confirms the relevance of the material proposed in this paper for application in Ukrainian universities.

A detailed query for the keywords "immersive technology education" (VOSViewer is the tool, data for analysis is taken from https://www.scopus.com/) allowed to identify 2000 most cited articles in the last 10 years and identify a set of relevant keywords that combined in different clusters. The analysis of these clusters allowed to determine the activities of universities to implement immersive technologies in education (figure 3).

Combining VR and AR tools, e-learning technologies, interactive tools and game-based learning allows creating a flexible educational environment that can quickly respond to changing trends in particular field of knowledge.

To assess the prospects of the immersive learning technologies introduction in university educational activities we conduct a detailed analysis of scientific achievements in specific fields and identify the most popular areas where there is an urgent need to introduce new approaches to learning (analysis tool is SciVal https://www.scival.com). Among the most popular topics are the following:

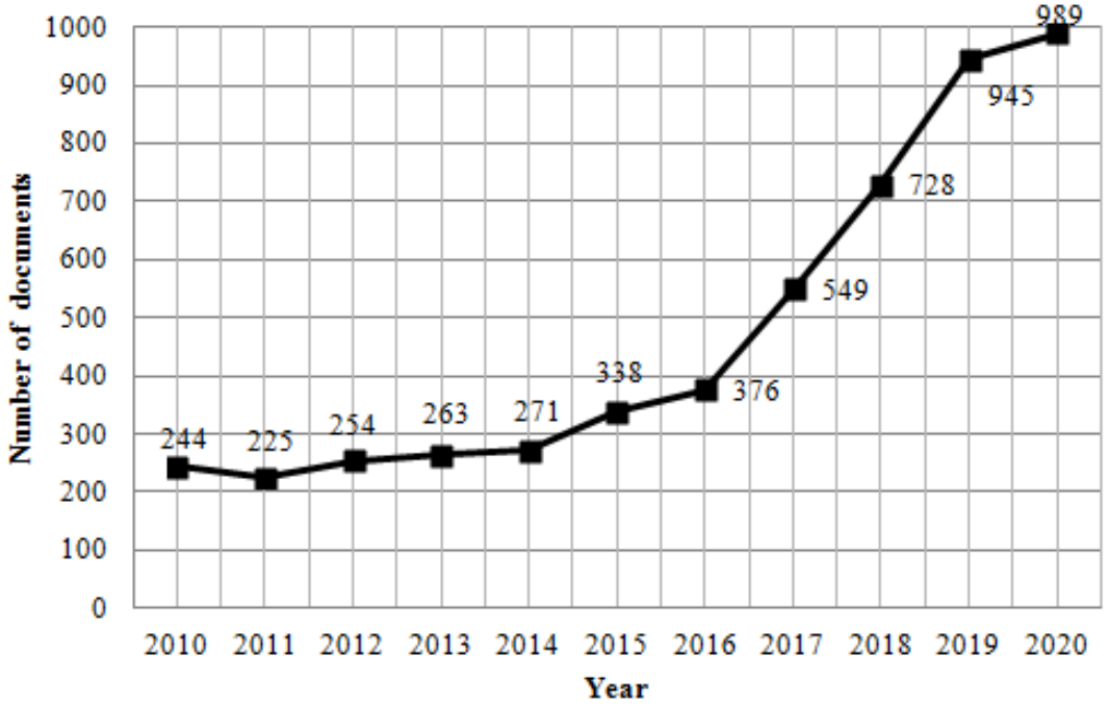

Figure 1: Publication activity in the field of "immersive technology" (data of https://www.scopus.com/).

- Game-Based Learning;
- Educational Games;
- Gamification;
- Augmented Reality;
- Authoring Tools;
- Online Learning;
- Social Presence;
- Virtual Worlds;
- Virtual Learning Environment;
- Pedagogical Support;
- Educational Process;
- Professional Competence.

These topics formulate the main activities of the classical university in immersive technologies implementation and in the creation of an effective strategy for new products to enter the educational market, as well as the creation of commercial products for industry and business. Analysis of the connection of individual topics in agglomerates (clusters of topics) gives grounds for expanding the role of immersive technologies for extracurricular activities and the implementation of the third mission of the university:

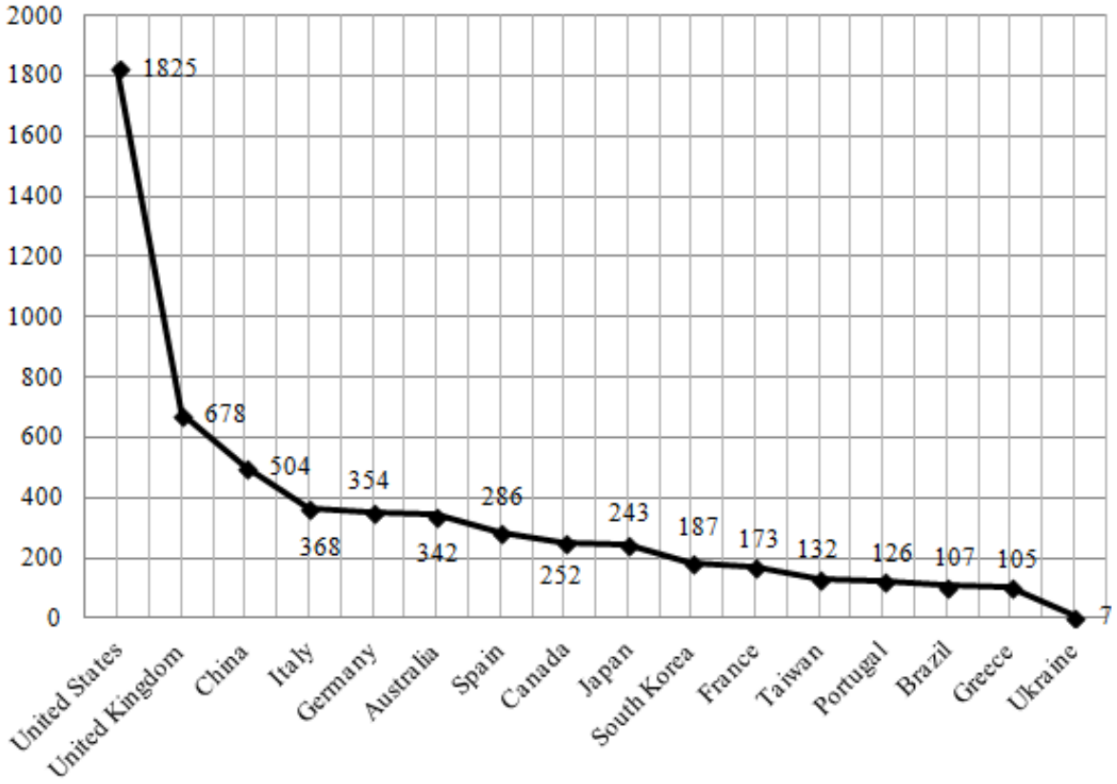

Figure 2: Publication activity of authors from different countries in the field of "immersive technology" (data of https://www.scopus.com/).

- Algorithms; Computer Vision; Models;
- Students; Medical Students; Education;
- Attention; Brain; Learning;
- Work; Personality; Psychology.

Analysis of the article content (according to https://www.scopus.com/) in the direction of development and implementation of immersive technologies and education quality assurance in general allowed to identify the following areas that can be successfully implemented by the classical university:

- development of the educational environment with the use of immersive learning tools [5, 6, 7, 8, 9, 10, 11];
- immersive learning tools in medicine [12, 13, 14, 15, 16];
- immersive learning tools in engineering and physics [17, 18, 19];
- immersive learning tools in arts and humanities [20, 21, 22];
- pedagogical innovations based on immersive learning [23, 24, 25] [23-25]
- application of immersive technologies in university subdivisions, e.g. library [26, 27];

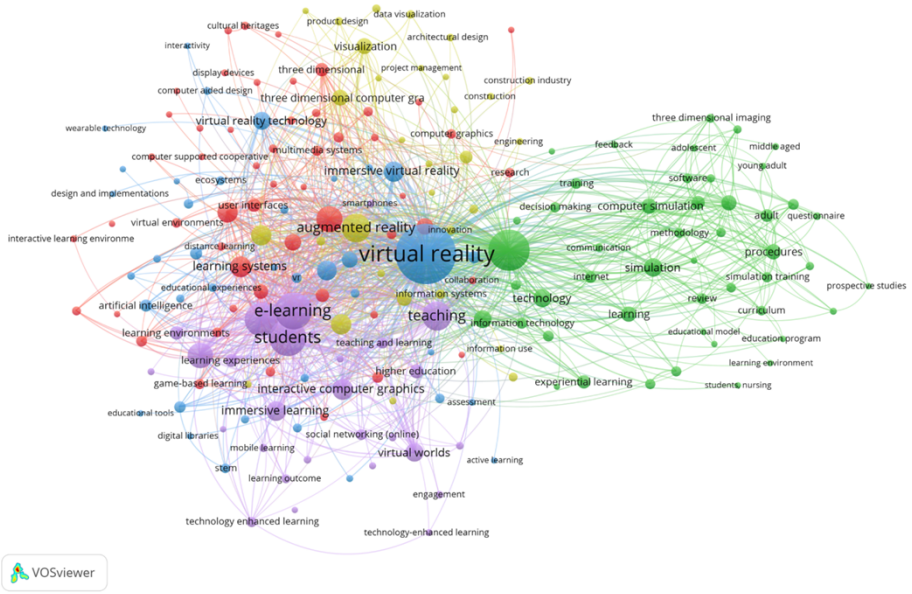

Figure 3: The results of bibliometric analysis on the query “immersive technology education”.

- immersive technologies for scientific research [28, 29];
- fulfillment of the third university mission and social activity to ensure the citizens well-being [30, 31, 32, 33, 34, 35, 36];
- education digitalization [37];
- state regulation and management of education quality [38, 39];
- ensuring the quality of education in subject areas [40, 41];
- quality of education and sustainable development goals [42].

When forming a strategy for the university development in terms of immersive technologies introduction in educational and scientific activities one should also pay attention to the experience of other educational institutions, which can be learned, e.g. through Immersive Education (iED) Summits [43], Immersive Learning Research Network (iLRN) [44], Women in Immersive Tech Europe [45], etc.

Technology companies’ specialists are also working on the development of immersive technologies. Here are some examples of world-famous companies’ developments.

Lenovo has developed a specialized virtual classroom that allows one to create a blended learning environment. The class consists of various devices (virtual reality helmet, tablet, router), as well as software and comprehensive training programs [46].

Microsoft is actively researching and developing immersive technologies [47]. One of the directions is the use of mixed reality technology with the help of HoloLens from Microsoft [48].

zSpace offers a hardware and software solution that provides an interactive experience by integrating the latest AR/VR technology into an all-in-one computer and laptop. zSpace uses three sensory characteristics to create a natural and intuitive product:

– immersion perception;
– possibility to look around;
– kinesthetic realism [49].

OVAL (Oklahoma Virtual Academic Laboratory [50]) supports the operation of virtual class Portals, within which you can share learning experiences in VR environment. For example, in this way, students studied the inner part of Arizona cave system.

Immersive technologies are already used actively in university education. At North Carolina State University, virtual reality is used in the study of the natural sciences [51]. During virtual field research, students find, observe and study organisms in their natural habitat.

At Pennsylvania State University, students attend practical classes equipped with virtual reality technology. During the practical classes, they learn about situations that they may potentially encounter in the future. This approach increases the learning effectiveness and prepares students for real work situations [52].

Graz University of Technology (Austria) has developed a learning VR platform "Maroon" and is actively using it to study STEM [53].

The first significant steps in this direction at Sumy State University were made by the author's team members of this work [54, 55].

3. Research methodology

The concept of Sumy State University (SumDU) immersive technologies application is not a trivial replacement of real laboratory or practical work with virtual ones.

We see the main effect in methodological approach that immerses the student in a certain case inherent in the educational program, discipline or topic, with the obligatory interactive stages that cause a strong emotional reaction.

These can be accidents or critical situations at production site or in the workplace, ones related to equipment or interaction with colleagues and customers, and so on.

The causalities designed for such situations are a strong impetus for other learning activities (in or out of the classroom). Regular application of immersive technologies can significantly increase the training effectiveness. We can get as close as possible to the natural way of interaction with the object of study through immersive technologies. Along with this, we fully exploit the emotional component of interaction and create powerful motivating effect for further application of classical learning activities.

An engineer can start a reactor, compressor or aircraft. The doctor can save the patient, perform an autopsy or examine the pathology. Military trainees can navigate the area or adjust artillery fire. In each of the cases there may be a critical situation when the reactor explodes, the patient is on the verge of death, and the shells do not hit their target. Through periodic immersion in virtual, most realistic cases with obvious consequences, the student is able to form a clear, logical structure of interrelated needs for knowledge in various disciplines.

VR and AR tools in the hands of a trained teacher can bring the learning process as close as possible to natural, direct interaction, and in some cases can even open greater opportunities.

Simulations represent some part of the surrounding reality thus allowing to study aspects of reality that cannot be studied in another way for reasons of safety, ethics, high cost, lack of

necessary technical support or scale of the investigated phenomenon. Simulation is a structured scenario with a detailed system of rules, tasks and strategies that are created for a specific purpose: to form specific competencies that can be directly transferred to the real world. Simulations help to visualize abstract concepts. Students understand the essence of the studied phenomenon due to the possibility of manipulating its parameters. Two basic components are allocated within the simulation. First, the working model of professional environment or the structural and organizational scheme in which possible variants of behaviour and staff interaction are enclosed. Second component is the scenario (plot) of the simulation process, aimed at the application of knowledge, intuition development and finding alternative non-standard ways to solve the problem.

Hands-on algorithms to develop the above mentioned components for educational course are not described in literature. We are still individually searching for effective approaches to the implementation of VR and AR technologies for each educational program, discipline, topic, etc.

The context of each program is individual, so the simulator script is not born immediately. In any case, it is important to remember that any technology is a tool to achieve the learning goals.

4. Results and discussion

During 5 years of immersive technologies introduction in SumDU, the AR textbooks and information materials are published, training VR simulators are developed.

Over the years, SumDU has improved its own e-learning ecosystem of (https://elearning.sumdu.edu.ua). SumDU specialists created training and research laboratory of VR and AR (https://ulab.sumdu.edu.ua) with appropriate technological conditions to conduct training sessions. These sessions allow immersion of a group of students in various virtual cases inherent in the educational program, discipline or topic, with mandatory interactive stages of interaction with the equipment or between participants.

The number of simultaneous participants in VR-simulations significantly affects the potential of learning scenarios. Therefore, Ulab laboratory is designed to conduct classes with one academic group of students. It has three zones: VR/AR zone, control zone, group zone (figure 4).

VR/AR-zone is designed for the simultaneous participation of four students. It is equipped with four powerful PCs, four HTC Vive VR headsets with two Lighthouse base stations and a surveillance camera. All surfaces of the VR/AR zone (four walls, floor and ceiling) are textured with unique high-contrast images. The VR/AR area is equipped with a special backlight that prevents direct rays from entering the camera lens of the participant's smartphone, tablet or other device. All this provides reliable positioning in the VR/AR zone when using optical recognition methods used in AR.

We planned our laboratory to maintain constant contact between students. When four participants are in VR, the rest of the group can watch their actions and make voice comments. The verbal connection between students remains.

This can be used in different ways, depending on the task of the VR-simulator: students can help with calculations, the teacher can advise how best to do various actions. To do this, students in the group zone have the opportunity to observe the events in the VR/AR zone and see the action on four screens the same as four participants in the simulation. Radio microphones are

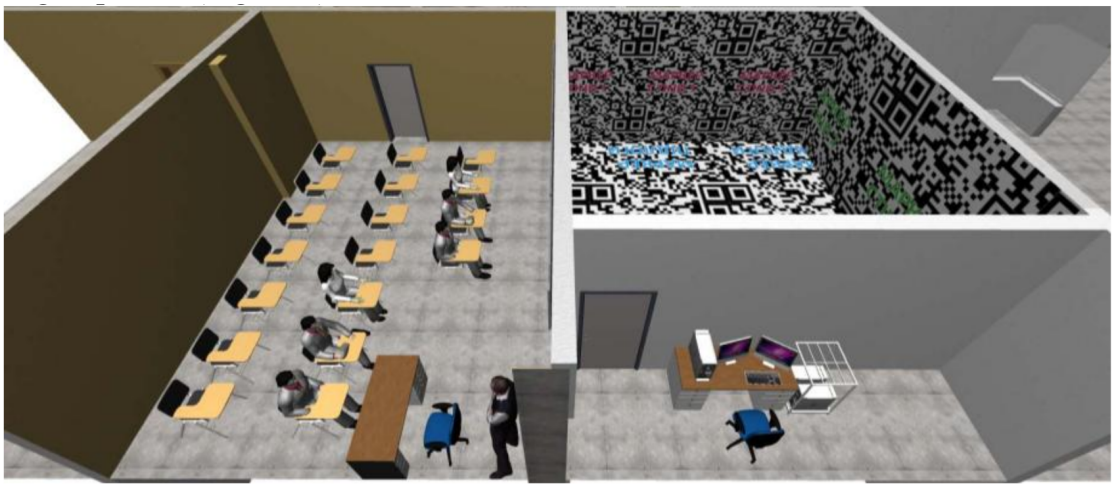

Figure 4: Ulab laboratory.

installed in the group area for voice communication. The VR/AR zone uses built-in microphones in HTC Vive VR headsets. Video and audio streams are controlled by specialized matrix switches located in the control area.

Qualified specialists in the control area maintain equipment performance. They monitor all processes during VR simulations, as well as the actions of participants.

It is important to understand that student immersed in VR practically loses control over the real world: he/she does not see walls, obstacles and other participants, may lose his/her balance, make sudden unexpected movements, and so on. Orientation in space can also change under the influence of VR content.

Examples of SumDU VR developments:

1. Technically oriented simulator of the natural gas drying is designed as multi-user simulator for simultaneous work of students together with the teacher (figure 5). Students getting trained in educational programs related to chemical engineering, oil and gas production equipment and production automation first get acquainted with the gas drying plant, study its design and can even look inside, which is impossible in real conditions. The simulator allows trainees to study the design and operation of unit equipment. The teacher can secretly initiate an emergency mode, and students will have to change the parameters in a short time to avoid an accident. It is extremely difficult to do this without understanding the basic principles of the installation. Working in the simulator allows student group to practice teamwork skills, solving problems in time lacking conditions and take responsibility for the decisions made. These skills, in addition to specialized knowledge, are demanded in the job market. Every accident on the simulator is remembered and motivates to study the theoretical material deeply.

The simulator is developed in the Unity environment (https://unity.com) and uses a client-server architecture to implement multiplayer mode, in which the position of each participant

Figure 5: Natural gas drying unit simulator.

in the simulation, his/her movements and actions are synchronously transmitted to the Photon Unity Networking server. It re-implements and enhances the features of Unity's built-in networking. Under the hood, it uses Photon's features to communicate and match players (https://www.photonengine.com/pun).

The software module of each user takes into account the position of the user during each frame of 3D scene rendering to determine the angle of observation and the position of all other participants according to the data obtained from the server.

2. The virtual tour around the Military Training Department was developed with the Unity environment for mobile devices based on OS Android equipped with a gyroscope to provide three degrees of freedom (3DoF) to the user. Movements in space are carried out by means of the software implemented controller. The simulator not only introduces future officers to the laboratories and classrooms of the department, but also allows to demonstrate samples of military equipment and weaponry in the field on a virtual range (figure 6).

3. The best way to study history is to immerse yourself in times long gone, experience the peculiarities of another culture, see everything live or visit a virtual museum, where all the famous artworks are collected.

This VR simulator is also designed in the Unity environment for HTC Vive with multiplayer mode support. Students can share their impressions of the exhibits directly in VR, either in the Ulab or even in another city or country (figure 7).

Figure 6: Virtual tour around the Military Training Department.

4. Another format for studying local history is realized with the help of Sumy city tour guide that uses AR technology. Specialized multimedia content is played in AR by the Ulab AR mobile application, developed by SumDU specialists and available for mobile devices with iOS 9+ and Android 6+ operating systems. Specialized multimedia content for this case is created: animated virtual 3D-models of famous Sumy patrons Ivan Kharitonenko and Gerasim Kondratiev with unique audio for 37 locations of the tourist route around Sumy (figure 8).

The Ulab AR application is designed to use augmented reality marker technology and allows user to match the specified collection of images to the appropriate multimedia content in both video and 3D format. Positioning of virtual content is carried out relative to the image-marker. Collections of markers and multimedia content for them are formed into special albums, which are downloaded using unique QR code into the Ulab AR program. To install the application, the user scans the QR code placed on advertising and information materials on stands located around city. To play AR content, user only need to point the camera with application running on a special plate located at each of the 37 locations of the route.

5. SumDU is currently working on a series of VR medical simulators. They are based on the anatomical model of human. More than 2,500 model objects make it possible to visualize any composition of selected anatomical model objects, systems and their components. The model may be movable rather than static as usual (figure 9).

Full body tracking technology allows to synchronize the movements of the anatomical model with the movements of the student or teacher. We use specialized software that based on a set of special HTC Vive trackers to analyze the position of all moving parts of the user's body in VR (figure 10).

Figure 7: Virtual museum.

The number of potential usage scenarios in medical education programs is almost limitless. It can be a simple study of human anatomy with the ability to "disassemble the body" to the last muscle and bone. User can study the anatomy of individual organs, supplementing the model with a set of possible pathologies. By combining the anatomical model with virtual models of medical diagnostic equipment (tomography scanner, X-ray, cardiograph, etc.), it is possible to implement virtual scenarios of real patient examination, surgical procedures, etc.

The VR-simulators scenarios can be scaled from single-user to group with the distribution of participants roles. In the future, it will be possible to implement even a full-fledged clinical department or operating room with medical staff and patients, specialized facilities and more. The possibility of remote VR sessions opens up a wide range of opportunities for such approaches, especially during quarantine restrictions, when participants can be physically distributed in space, but able to interact directly in virtual environment performing tasks, making mistakes and correcting them.

5. Conclusions

The e-learning system based on immersive technologies increases the educational process efficiency and is an essential part of the system bound to ensure educational activities quality and overall quality of higher education at SumDU. Internal and external assessment tools are used for evaluation of the implementation of immersive learning effectiveness and its impact on the education quality. One of internal assessment tools used is a survey of students and teachers on the applicability and prospects of immersive educational materials in specific knowledge

Figure 8: City tour guide.

areas. External evaluation of the educational programs quality criteria were proposed by the National Agency for Higher Education Quality Assurance of Ukraine (https://naqa.gov.ua/). Within the framework of each educational program, the university must create appropriate conditions for the practical skills formation along with the theoretical base.

In 2019, SumDU project took part in the competition for educational technologies in London Reimagine Education Awards. In total, more than 1500 projects from technology companies, universities and other educational service providers from 84 countries took part in this competition.

SumDU experience allows to introduce a model of "immersive institute" as an environment for all stakeholders aimed to increase entrants level of interest in learning, to provide student-centered and close to natural interaction learning model, and to act as a carrier of social mission (figure 11).

United States and Ukraine is almost synchronous. New software and hardware solutions

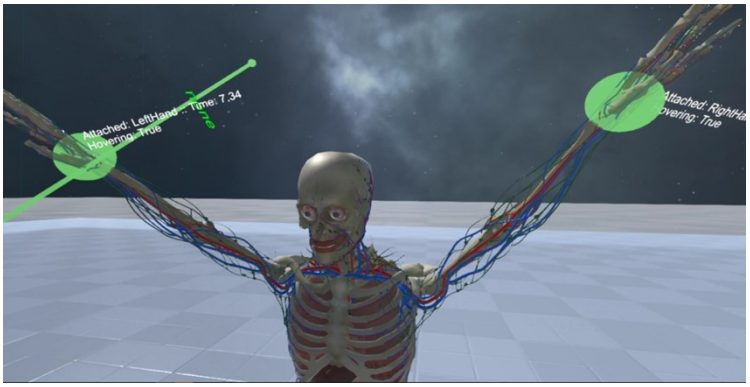

Figure 9: Medical simulator.

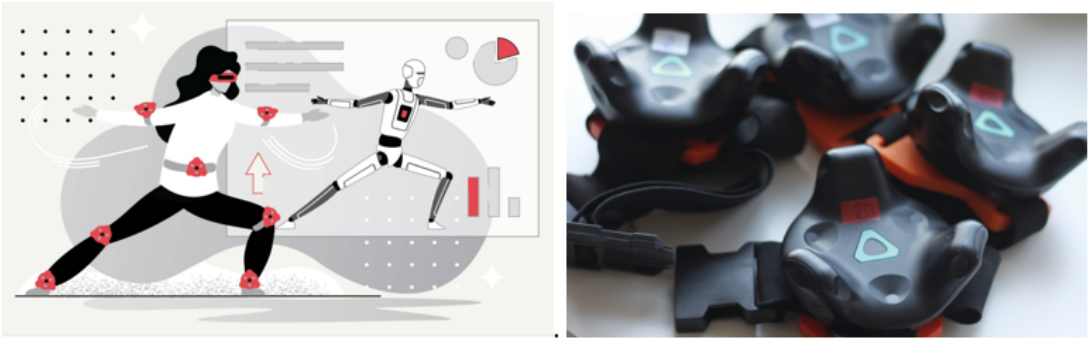

Figure 10: Full body tracking technology application.

appear almost every year and give impetus to the further development of technology.

In a few years, VR equipment will be widely adopted, as there are smartphones today. At that stage, the learning possibilities of immersive technologies will be difficult to overestimate, especially in situations similar to quarantine restrictions.

At SumDU , the e-learning system is improving and there are conditions for this: motivated teachers and staff developers (Unity3D programmers and modelers) who create training simulators. However, the prospect of cooperation and joining efforts of several educational institutions opens up much greater opportunities for the introduction and development of immersive learning in Ukrainian higher education institutions.

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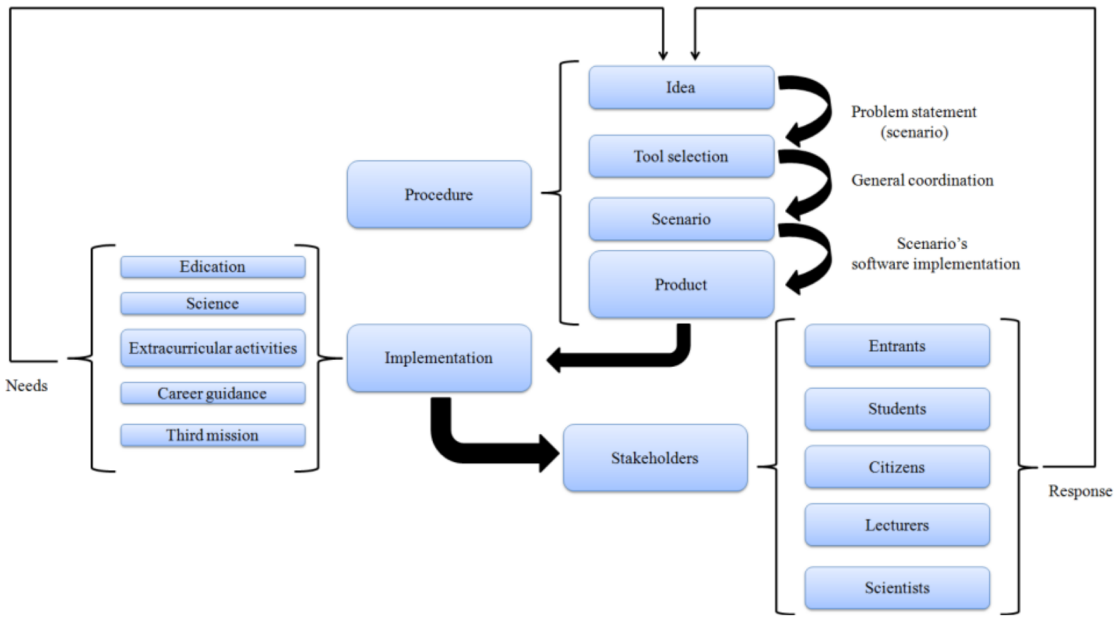

Figure 11: "Immersive institute" model.

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