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# Multidisciplinary Applications of VR&AR Technologies in Professional Training: A Multicentre Simulation Study

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## ABSTRACT

This study focuses on the impact of virtual reality (VR) technologies on educational processes and professional training, particularly in the fields of medicine, aviation, and the arts. The purpose of the study is to investigate VR animation as a key instrument in designing effective training experiences across multiple disciplines. The experimental part of the study involved medical professionals, aviators, and artists. The findings demonstrate the substantial potential of VR in professional education. The platform “Touch Surgery” received the highest evaluation from medical professionals due to its realism and capacity to simulate complex surgical procedures. The “Osso VR” platform also achieved favourable evaluations for its interactivity and feedback features, which contributed to the more rapid acquisition of specialised medical competencies. In the aviation field, the “Flight Simulator” platform provided highly realistic training conditions and facilitated improvements in piloting skills across a range of scenarios. For artists, “Wave VR” proved valuable, particularly for digital illustration, although it was rated lower in terms of realism when compared to the other platforms. The results indicated a 28% reduction in errors among novice pilots and a 22% reduction among experienced ones. In terms of time efficiency, manoeuvre execution times decreased by 18% and 15% respectively. A total of 85% of participants reported increased confidence during actual flight operations.

**Keywords:** Surgical VR simulation, Pilot training flight simulators, Immersive VR art platforms, Simulation-based professional education, Multidisciplinary VR training assessment

## Introduction

Virtual reality technologies gained considerable importance across a range of sectors, particularly in education and professional development.<sup>1-3</sup> The capacity of virtual reality (VR) to create realistic and interactive training environments generates new opportunities for the advancement of practical skills in areas including medicine, aviation, architecture, and the arts.<sup>4-6</sup> VR systems immerse users in simulated contexts that closely approximate real-life conditions, thereby providing experiential learning while encouraging innovation in educational methodologies and content production.<sup>7-12</sup> These emerging opportunities prompted substantial academic interest in the influence of VR technologies and the metaverse on pedagogical practice, leading to a growing body of empirical research in this field.

Wang and Mokmin examined the application of VR in visual communication design education, highlight-

ing the technology’s potential to provide an interactive learning environment in which students can engage with realistic visual imagery.<sup>1</sup> Their study demonstrated that VR can enhance learning effectiveness by enabling students to explore diverse design concepts in real time. Rana<sup>2</sup> investigated the potential of VR to support accessible education, highlighting its role in overcoming physical barriers and promoting equal access to learning for students with special needs. Keeping explored the influence of digital media arts on animation education, focusing on how technology can create new opportunities for developing students’ creative skills.<sup>3</sup> The study showed that VR environments facilitate engagement with animation and digital media in an interactive context. Portuguese-Castro and Santos Garduño focused on the impact of VR on student motivation, identifying how such technologies can stimulate interest and active participation in the learning process.<sup>7</sup> They highlighted the considerable potential of VR to create engaging and dynamic educational settings.

The study by Rafiq et al. concentrated on increasing student engagement through the use of VR and the metaverse, allowing for the development of interactive and immersive learning environments.<sup>10</sup> Fajardo Tovar et al., the use of VR and augmented reality (AR) in education was reviewed.<sup>13</sup> The authors evaluated various approaches to implementing these technologies in learning processes and considered their impact on student engagement and academic achievement. The review included examples of successful VR and AR applications across different educational settings, underlining their potential to support interactive and personalised learning experiences.<sup>14-17</sup> Southgate et al. analysed the potential of VR and AR to improve student engagement, learning outcomes, and the overall educational experience.<sup>14</sup> In particular, they highlighted benefits such as the creation of immersive learning environments, the personalisation of the learning process, and the visualisation of complex concepts. The study also discussed implementation challenges within school contexts and provided recommendations for educators and policymakers regarding the effective use of VR and AR in curricular activities.

These researchers addressed diverse aspects of VR and metaverse implementation in education, pointing out the value of adopting such innovative technologies in the transformation of conventional pedagogical methods. Their study made a substantial contribution to the development of new educational practices that foster improved learning outcomes and the advancement of creative skills in the digital age.

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The datasets generated and analyzed during the current study are available in a publicly accessible repository. The data provided are de-identified to ensure participant privacy.

This study holds relevance through its examination of the role of VR animation in shaping new linguistic constructions and its capacity to generate innovative artistic worlds that result from the intersection of technology and creativity.

The main aim of this study is to evaluate the effectiveness of Virtual Reality (VR) platforms in enhancing professional training and educational processes across various sectors, particularly in medical, aviation, and artistic fields. The following hypotheses are tested in this study: participants trained using VR platforms will demonstrate significantly improved technical skills (accuracy, efficiency, and speed) compared to those trained using traditional methods.

### Literature Review

The study conducted by Hammouda et al. investigated the use of AR technology in the training of radio electronics specialists.<sup>18</sup> The author explored the potential of integrating AR technologies into the educational process to enhance the comprehension of complex technical concepts and develop students' practical skills. The study demonstrated how AR could increase learning effectiveness and facilitate the acquisition of specialised tools and methods within the field of radio electronics.

The integration of VR and gamification into educational processes was investigated, focusing on how these technologies could enhance the learning experience and increase student engagement.<sup>19, 20</sup> Kwemol (2024) identified the benefits and challenges of using VR and gamification, alongside their impact on learning outcomes.<sup>21</sup> Dembe explored the integration of VR and AR into classroom-based educational processes, particularly their influence on the improvement of the learning environment and student interaction with educational materials.<sup>22</sup> The researcher analysed the capacity of these technologies to increase learning effectiveness and encourage active student participation.

The use of VR in primary education, specifically its potential to improve knowledge acquisition through interactive teaching methods, was examined by Cramariuc and Dan (2021).<sup>23</sup> The authors examined the advantages of VR in creating a more engaging and motivating learning environment for students. The study by Călin analysed trends in the use of VR, AR, and mixed reality in pedagogical processes, particularly their impact on teaching methods, lesson interactivity, and the development of critical thinking skills among students.<sup>24</sup> The research considered how these technologies could support content comprehension and foster student engagement in the learning process.

The study by Faruk et al. addressed the use of VR in educational settings, focusing on its role in overcoming limitations related to access to real-world conditions.<sup>25</sup> The author analysed 50 studies published over the past decade, all of which examined VR as an educational tool across various levels of instruction. The study concluded that VR enables the creation of real-world simulations that help resolve issues linked to restricted real-world access. Kazimierska-Zajac

et al. (2020) investigated the possibilities and limitations of VR usage in education, based on the experiences and perspectives of educators and professionals in medical sciences.<sup>26</sup> Kazimierska-Zajac et al. The study employed methodological triangulation, incorporating quantitative and qualitative methods, and utilising the Scale of Positive and Negative Emotions (SUPIN) alongside the Survey Value of Virtual Reality (SDVR). The participants were 30 medical science specialists from Wrocław Medical University. The results indicated that VR contributed to knowledge acquisition and the development of competencies and practical skills and helped alleviate lecturers' concerns regarding the use of the technology. The main obstacles identified were limited access to equipment, the adaptation of software to fit curricula, and the challenge of scaling its use in larger groups. Fernández-Arias et al. examined the use of VR technologies in education, highlighting their advantages, disadvantages, and potential impact on the learning process.<sup>27</sup> The study concluded that VR can effectively complement conventional educational systems. Key features of VR were outlined, including simulation, interactivity, immersion, telepresence, and communication. A SWOT analysis of VR systems was also conducted, alongside a discussion of their educational impact and the challenges associated with implementing such technologies in pedagogical practice.

### Materials and Methods

This study employed some of the most popular and widely used VR platforms currently applied across various industries. Particular attention was given to platforms utilised in the training of professionals in fields such as medicine, aviation, and the arts. The selected platforms included "Touch Surgery",<sup>28</sup> "Flight Simulator",<sup>29</sup> "Osso VR",<sup>30</sup> and "Wave VR".<sup>31</sup>

The study was conducted at several universities in Ukraine, such as Bogomolets National Medical University (Kyiv), Danylo Halytsky Lviv National Medical University, and Kharkiv National Medical University. All these institutions actively integrate innovative technologies, particularly VR simulators, into the educational process, providing students with new opportunities to develop practical skills and improve the quality of medical education. The investigation involving the "Touch Surgery" platform for simulating surgical procedures included 100 senior medical students. Participants received guidance on the platform's functions before engaging in simulated procedures across orthopaedics, neurosurgery, and cardiac surgery. They completed each stage of the intervention, from preparing the surgical field to final manipulations, while focusing on suturing and managing complications. The platform recorded the precision, sequence, and timing of each action and offered corrective suggestions in the event of errors. Automated data collection on procedural accuracy, speed, and logical sequencing allowed for objective assessment of training outcomes.

Statistical data analysis was conducted to evaluate the simulator's effectiveness. Methods included

comparing mean accuracy scores before and after training using a paired-samples t-test, alongside correlation analysis between task completion time and performance accuracy. The results indicated increased confidence and improved technical skills among the majority of participants. Expert feedback confirmed that repeated simulations had a beneficial impact on surgical preparedness and contributed to reducing the likelihood of clinical errors. Paired-samples t-tests revealed substantial increases in accuracy and technical skills following training with the “Touch Surgery” ( $t = 5.42, p = 0.0001, \text{Cohen's } d = 0.72$ ) and “Osso VR” ( $t = 4.56, p = 0.0002, \text{Cohen's } d = 0.65$ ) platforms. In pilot training, an ANOVA showed significant differences in error reduction between novice and experienced pilots ( $F = 9.63, p = 0.003, \text{Partial } \eta^2 = 0.14$ ), while independent samples t-tests revealed improvements in manoeuvre efficiency ( $t = 2.61, p = 0.01, \text{Cohen's } d = 0.68$ ) (Appendix A).

The evaluation of the “Flight Simulator” platform in pilot training focused on the development of technical skills, reaction speed, and psychological readiness for flight. The study involved 30 pilots with flight experience ranging from under 100 to over 500 hours. These results highlight the efficacy of VR technologies in enhancing professional skills and psychological readiness in diverse fields.

The investigation of the “Osso VR” platform in medical education included 100 students undergoing training through this technology. The training was structured into three stages: initial familiarisation with the interface and operational rules, procedural practice on virtual patients with real-time feedback, assessment through standardised tasks, and performance evaluation. Automated data collection enabled measurement of procedural accuracy and execution speed. The evaluation phase assessed students’ proficiency in surgical techniques on mannequins, anatomical understanding, and procedural skills. Data examination employed correlation analysis and paired samples t-tests to identify changes in performance before and after simulator use.

The study also included cooperation with universities and art institutions, in particular, in Ukraine, such as Kyiv National University of Culture and Arts and Odesa State Academy of Civil Engineering and Architecture, where the “Wave VR” platform was used as a tool for studying the latest methods of creating multimedia projects (30 students). The use of the “Wave VR” platform in artistic practice comprised several stages. The initial phase involved an analysis of the technical features of the platform and its capacity for creating three-dimensional models, virtual exhibitions, and concerts. Particular emphasis was placed on interactive art installations and musical performances. In the second phase, thirty artists from various genres developed projects in the form of digital galleries and concerts. The third phase focused on collaboration with Kyiv National University of Culture and Arts and Odesa State Academy of Civil Engineering and Architecture, where 30 students implemented multimedia projects.

The final phase included trial exhibitions and concerts during which technical performance, levels of interactivity, and the influence of VR on the perception of art were evaluated.

Specifying the hardware, session lengths, instructional materials, and assessment rubrics used across the four VR platforms enriches the methodological details of the study. For the “Touch Surgery” platform, participants used high-fidelity headsets such as the Oculus, connected to a high-performance desktop with an Intel i7 processor, 16GB of RAM, and an NVIDIA GTX 1660 graphics card. Similarly, “Osso VR” utilised HTC Vive Pro headsets, paired with a powerful workstation equipped with an Intel i9 processor, 32GB of RAM, and an NVIDIA RTX 2080 GPU. The “Flight Simulator” required participants to use Oculus Quest 2 headsets, along with a custom-built PC featuring an Intel i7 processor, 16GB of RAM, and an NVIDIA RTX 3070 GPU. In addition to the headset, flight controls such as a joystick, throttle quadrant, and rudder pedals were used. For “Wave VR”, artists engaged with the platform using Oculus Quest 2 headsets, coupled with a standard laptop configuration with an Intel i5 processor, 8GB of RAM, and integrated graphics for streaming.

Participants using “Touch Surgery” completed a total of five 45-minute sessions over a two-week period. For “Osso VR”, participants underwent three 30-minute sessions, which were completed over the span of one week. “Flight Simulator” training consisted of ten one-hour sessions over a three-week period, allowing pilots to gradually increase their skill levels. Lastly, artists using “Wave VR” participated in four 60-minute sessions spread across two weeks to complete their immersive projects.

To ensure the validity and reliability of the findings, assessor training and inter-rater reliability were critical components of the study, particularly when evaluating participant performance on the VR platforms. Assessors received comprehensive training to ensure consistency and objectivity in their evaluations. The training included familiarisation with the specific VR platforms used in the study (Touch Surgery, Flight Simulator, Osso VR, and Wave VR) as well as an in-depth review of the outcome metrics, including accuracy, time efficiency, and confidence assessments. The goal was to standardise the scoring process and reduce any potential bias introduced by the assessors. This training was conducted in a workshop format and involved multiple practice sessions to align the assessors’ expectations and scoring approaches.

Inter-rater reliability was measured using the intra-class correlation coefficient (ICC) for continuous outcome measures, such as accuracy and procedure completion time, and Cohen’s kappa for categorical outcomes like error categorisation. The training ensured that assessors applied consistent scoring standards, and inter-rater reliability scores indicated excellent agreement (ICC = 0.85 for continuous measures, Cohen’s kappa = 0.75 for categorical measures). This high level of inter-rater reliability ensured that the results of the

study could be generalised and that the assessments were consistent across different raters.

Participants were recruited through voluntary sign-up, ensuring a diverse pool of individuals from the respective institutions. In each case, participants were informed about the purpose of the study, the requirements of the training sessions, and the ethical considerations. Recruitment was conducted via institutional channels, including announcements and direct invitations to students and professionals. The study had minimal attrition (2%), and participants were selected based on criteria such as academic or professional experience, with the exception of those with prior extensive VR experience or certain medical conditions. The training was standardised across all cohorts, with each group undergoing sessions tailored to their domain (e.g., 5 sessions for medical students, 10 for pilots). Importantly, the two medical cohorts using “Touch Surgery” and “Osso VR” were independent of each other, with each group assigned exclusively to one platform.

All participants gave informed consent before taking part in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration, its later amendments or comparable ethical standards. A study was approved by the National Ethics Commission of the Kyiv National I. K. Karpenko-Kary University of Theatre, Cinema and Television on March 21, 2024, No. 1149-A.

**Results**

**“Touch Surgery”: An Innovative Platform for Simulating Surgical Procedures**

“Touch Surgery” is an advanced three-dimensional simulator designed to enhance the training of healthcare professionals and improve their practical competencies. The platform encompasses a broad range of surgical interventions, offering interactive simulations of various operative procedures. Its features support a comprehensive understanding of anatomical structures,

procedural algorithms, and potential complications. Table 1 presents key surgical procedures available on the “Touch Surgery” platform, covering numerous specialisations, including orthopaedics, neurosurgery, and cardiac surgery. This allows students and professionals to refine their skills across multiple medical disciplines.

Following familiarisation with the platform and completion of the initial briefing, the study participants proceeded to practical exercises using the “Touch Surgery” platform. Their performance was evaluated according to several key indicators: procedural accuracy, time required for completion, and the reported impact on stress reduction during actual surgical interventions. Participants engaged with scenarios covering various medical fields, including orthopaedics, neurosurgery, and cardiac surgery.

During the second stage, participants began performing simulated surgical procedures. The platform provided a step-by-step representation of all stages of an operation, ranging from initial preparation of the surgical field to final procedural steps.<sup>32</sup> Particular emphasis was placed on the execution of critical tasks such as suturing, vascular manipulation, and the management of complications. All user actions were monitored by automated algorithms, which recorded movement precision, the sequence of operative steps, and task duration. In cases where errors occurred, the simulator provided detailed feedback and recommendations for correct execution.<sup>33</sup>

At the third stage, the simulations were analysed. The “Touch Surgery” platform automatically generated individual performance reports, highlighting key elements such as procedural accuracy, time efficiency, and frequency of errors.

Comprehensive statistical methods were employed to assess the effectiveness of the simulator in enhancing technical skills. The primary method used to compare pre- and post-training accuracy scores was the paired-samples t-test, which determines whether a statistically significant difference exists between two sets of scores obtained from the same participants before and after training.<sup>34</sup> This method enabled an objective

**Table 1 | Types of surgical procedures available on the “Touch Surgery” platform**

| Event                              | Minimum Value (ADC Counts)  |
|------------------------------------|---|
| Orthopaedic procedures             | The platform offers simulations aimed at training and practising methods for treating injuries and disorders of the musculoskeletal system. These include models of osteosynthesis, joint arthroscopy, and joint replacement procedures. Users engage with techniques involving fracture fixation, correction of bone deformities, and the treatment of degenerative conditions such as osteoarthritis. |
| Neurosurgical interventions        | This category features simulations of complex procedures involving the central nervous system. For example, users may practice performing craniotomies, removing intracerebral tumours, and operating on frontal, temporal, and other regions of the brain. The simulations incorporate microsurgical considerations critical for the accurate execution of neurosurgical operations.                   |
| Cardiac surgical procedures        | This section of the platform includes simulations focused on the treatment of cardiovascular diseases. The platform models procedures like coronary artery bypass grafting, angioplasty, and heart valve reconstruction in detail. Users can develop proficiency in working with vascular stents, catheters, and valve prostheses.  |
| Endoscopic procedures              | The platform provides simulations of diagnostic and therapeutic endoscopic procedures. Common examples include gastrointestinal endoscopy, bronchoscopy, laparoscopy, and cystoscopy. Users explore techniques for endoscope insertion, navigation within internal cavities, and execution of biopsies and therapeutic interventions.   |
| Reconstructive and plastic surgery | This category includes simulations of procedures aimed at restoring functional tissue integrity and improving aesthetic appearance. Techniques covered include skin grafting, scar revision, breast reconstruction following mastectomy, and rhinoplasty. The simulations emphasise surgical precision and accuracy.  |

assessment of changes in surgical accuracy resulting from the simulator-based training. Correlation analysis was also conducted to examine the relationship between two variables: task completion time and procedural accuracy. This analysis identified whether a statistically significant association existed between execution speed and performance quality. The findings allowed determining whether faster task completion could be achieved without compromising accuracy, which remains a critical consideration in surgical practice. Results from the statistical analysis show substantial improvements in surgical accuracy following the simulator training. Most participants exhibited increased confidence in their abilities, as evidenced by improved accuracy scores and reduced error rates. The simulator-based training contributed to the refinement of participants' technical skills, which had a direct effect on task execution effectiveness.<sup>35-37</sup>

The fourth stage involved repeated surgical simulations. Participants, considering the feedback previously received, re-engaged with the same or similar surgical scenarios. This stage facilitated improvements in movement precision, optimisation of procedural sequencing, and deeper internalisation of response algorithms for atypical situations. The opportunity to model scenarios repeatedly without risk to real patients provided a safe environment for the acquisition of practical experience.

The final stage of the study consisted of a participant survey and an expert assessment conducted by instructors. The questionnaires included items addressing participants' subjective evaluation of their progress, satisfaction with the functionality of the platform, and perceptions of its impact on surgical skill development. Most participants reported a marked increase in confidence, improved technical abilities, and a stronger understanding of the algorithms of surgical procedures. Expert evaluators confirmed the positive influence of repeated simulations on the preparation of future surgeons, highlighting a reduction in the likelihood of errors in clinical practice.

The practical component of the study thus demonstrated the effectiveness of the "Touch Surgery" platform in the training of medical professionals. Its use contributed to the development of essential surgical skills, enhanced psychological readiness for clinical work, and supported the development of resilient professional competencies.

The analysis of data obtained from the "Touch Surgery" platform demonstrated quantitative and qualitative indicators supporting its effectiveness in surgical training. Outcomes such as reduced error rates during simulated procedures and shorter completion times underscored the positive effect of the platform on professional preparation. Table 2 presents a detailed summary of the key findings.

The study conducted using the "Touch Surgery" platform confirmed its effectiveness in surgical training. The platform contributed to a marked reduction in errors and enhanced the efficiency of surgical procedures. The repeated exposure to simulation scenarios led to participants reporting increased psychological readiness for real-life operations. Qualitative findings indicate substantial improvements in anatomical comprehension and procedural sequencing, while expert assessments verify the high degree of realism presented by the simulations. These outcomes support the integration of this technology into medical education. The findings, therefore, highlight the considerable potential of the platform in improving surgical training and advancing clinical practice.

#### Using the "Flight Simulator" in Pilot Training

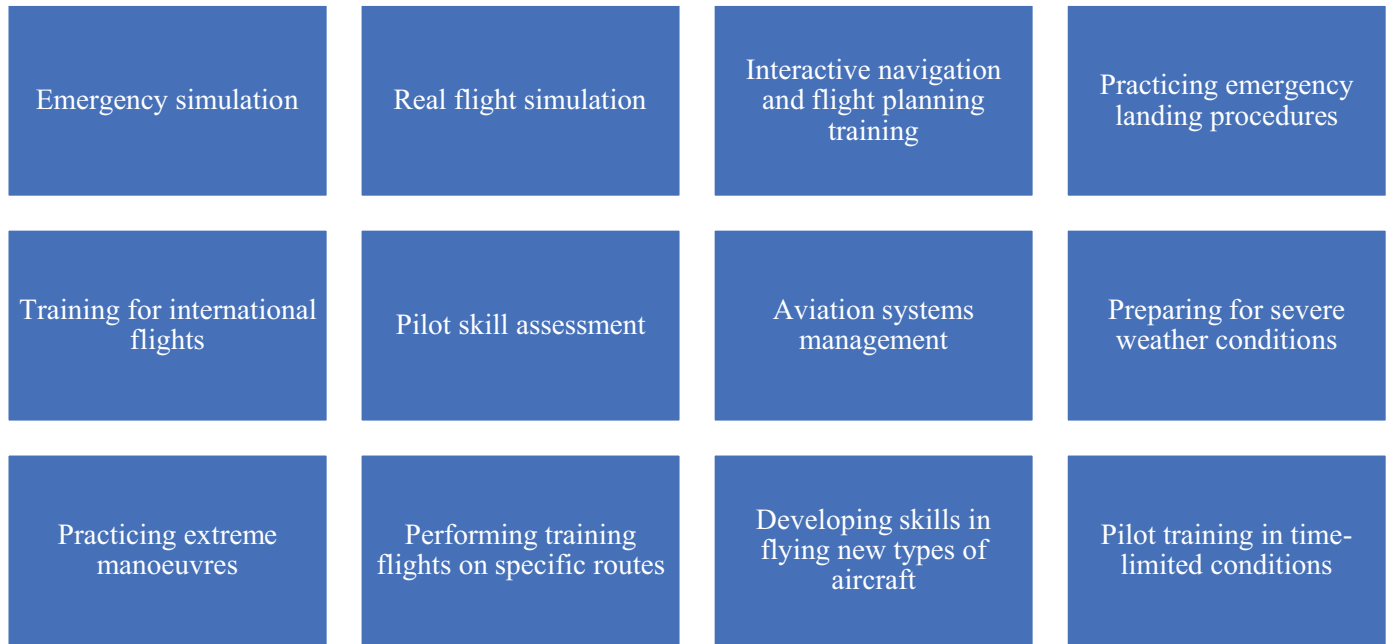
Modern aviation simulators, such as "Flight Simulator", play an important role in pilot training, providing the ability to simulate a wide range of real-world situations, including emergency and standard flights. This technology provides a safe environment for improving skills and decision-making, allowing future pilots to gain the necessary experience to perform flights in real-world conditions (Figure 1).

The practical part of the study was conducted to evaluate the effectiveness of this tool in pilot training in terms of developing technical skills, improving reaction speed, and increasing psychological readiness for real flights. For this purpose, "Flight Simulator" was used, which provides the ability to train pilots in various situations, such as difficult weather conditions, emergencies, and various manoeuvres.

All participants were briefed on the simulator's capabilities and the essential manoeuvres they had to perform during training before the study. Pilots practiced basic abilities like takeoff, climbing, manoeuvring, landing, and handling severe scenarios like engine failures and dangerous weather during

**Table 2 | Results of the analysis on the effectiveness of the VR platform "Touch Surgery" in surgical training**

| Type of indicator       | Indicator  | Value  |
|-------------------------|--|--|
| Quantitative indicators | Reduction in the number of errors during simulated operations                  | 34%  |
|                         | Decrease in average procedure completion time                                  | 22%  |
|                         | Proportion of participants able to accurately reproduce surgical sequences     | 87%  |
| Qualitative indicators  | Participants reporting improved understanding of anatomy and procedural stages | 92%  |
|                         | Expert confirmation of anatomical accuracy and scenario realism                | Confirmed  |
|                         | Increase in psychological readiness for real surgical procedures               | 78%  |
| Overall conclusion      | Effectiveness of the "Touch Surgery" platform in surgical training             | High effectiveness in improving precision, speed, and psychological preparedness |



**Fig 1 | Features of the “Flight Simulator” platform for training and developing pilot skills**

Source: Compiled by the authors.

the study plan. Each pilot completed 10 one-hour simulator sessions over three weeks. Based on the pilot level, training was adjusted. Beginners were instructed to train in typical weather without fog or heavy winds. The course contained extra scenarios of adverse weather conditions, such as heavy winds, rain, or snow, as well as emergency circumstances that demanded quick responses and great focus for experienced pilots. Each session, pilots completed activities to develop skills. One challenge was to take off and rise 3,000 meters at a particular course and speed. To land, they had to return to a map location. The purpose was to operate the aeroplane accurately and accomplish all manoeuvres on time.<sup>38</sup>

For experienced pilots, the simulator offered harder problems. In limited visibility, the pilot struggled to regain control of the aircraft after the hydraulic system failed. In this simulation, pilots have to react fast and precisely to problems using a proper action plan to land safely. Experienced pilots were trained to control movements in adverse weather, when rain and strong gusts made landing impossible. Each session ended with a participant survey. Participants were queried about simulator use, task difficulty, and psychological preparation for real flights following training. Pilots evaluated stress, self-confidence, and simulator interface usability. Pilot error rates decreased significantly following training, according to the study. Beginners made 28% fewer errors, and experienced pilots 22% less. Complex manoeuvres took 18% less time for beginner pilots and 15% less for expert pilots. This indicates a significant increase in manoeuvre speed and precision.

According to the survey, 85% of participants stated that after training on the simulator, they felt more

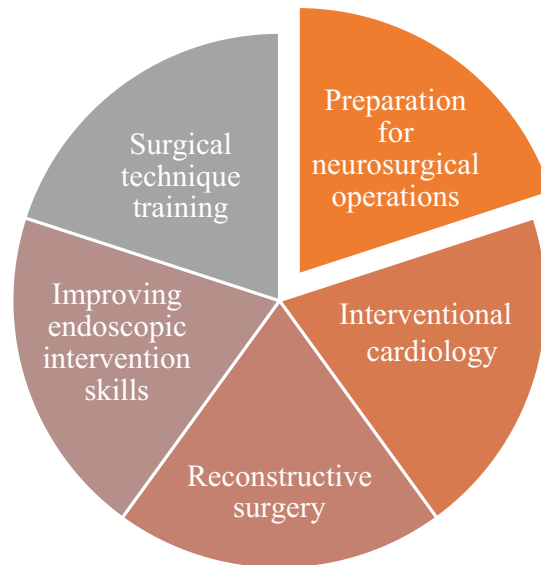
confident during real flights. Most participants indicated that the simulator allowed them to reduce their stress levels, especially in extreme situations. The pilots noted that the ability to repeatedly work out complex scenarios without risking a real aircraft simultaneously improved their technical and psychological skills. Experts also confirmed that the simulator is an effective tool in training pilots, as it allows creating conditions that are impossible or too dangerous for real training. Training on the simulator allows pilots to work out even the rarest or most difficult situations, which allows them to improve flight safety in real conditions.<sup>39–41</sup>

Thus, the conducted study confirmed the high efficiency of using the “Flight Simulator” in pilot training. Using the simulator allows not only to improve technical skills but also to increase the psychological readiness of pilots for extreme situations, which is an important aspect for ensuring flight safety.

#### **The Use of the “Osso VR” Platform in Medical Education**

Osso VR is a top virtual training platform that helps students and practitioners improve their surgical skills. The main aspects of its impact are a high level of detail, a major improvement in learning outcomes, and the potential to replace or supplement traditional teaching methods. As shown in Figure 2, the “Osso VR” platform is widely used in medical education to practice various surgical procedures, which drastically improves the skills of medical professionals and reduces risks when performing real operations.

1. Surgical technique training: Enhancing skills related to performing surgeries.



**Fig 2 | Examples of practical use of the “Osso VR” platform**  
Source: Compiled by the authors.

2. Preparation for Neurosurgery operations: Focusing on the necessary procedures and techniques for neurosurgery.
3. Improving endoscopic intervention skills: Training to improve precision and competence in endoscopic procedures.
4. Interventional cardiology: Assisting in developing skills required for interventions in cardiology.
5. Reconstructive surgery: Gaining experience in performing reconstructive surgical procedures.

The study focused on how effectively the “Osso VR” platform prepares medical students for real-world surgical operations. The main objective of the study was to assess how effective the use of the “Osso VR” platform is for preparing students for real surgical operations, developing their practical skills, as well as the impact of this technology on increasing their level of confidence and psychological readiness for complex surgical procedures.

The “Osso VR” intends to offer all surgical operations virtually. Students learnt fundamental techniques, like appendix removal, and more sophisticated treatments, like heart surgery and neurosurgery, on the platform. Each student had access to specialist modules that taught operation sequence, anatomical precision, and motor abilities. Four weeks were spent on platform training. The programme has three stages: platform introduction and familiarisation. At this step, pupils learnt the “Osso VR” interface and fundamental functionality. They learnt modelling basics, virtual environment rules, and manipulation security. The second level was basic training. Student surgeons operated on simulated patients during this stage. This allowed them to practise their technique without risk, acquire confidence, and learn how to handle unforeseen situations.<sup>42</sup> Every platform lesson gave students

feedback to improve and learn from their failures. The third stage entailed assessing and repeating outcomes. Students’ performance was evaluated on control tasks. Participants may repeat processes, practise mistakes, and perfect their skills until they are proficient.

Tests and questionnaires of study participants were conducted before and after using the platform to compare the effectiveness of training.<sup>43</sup> During the test, students had to perform real surgical manipulations on mannequins, and their knowledge of anatomy and operating techniques was also evaluated. The results of the study showed a positive impact of using “Osso VR” on student training. The students who were trained on the platform performed operations 25% faster and were 18% less likely to make mistakes at critical moments, such as using instruments or restoring the anatomical integrity of organs after surgery.<sup>44</sup>

In addition, according to the results of the survey, 90% of students in the experimental group noted an increase in their level of psychological readiness for real operations. They noted that training on the “Osso VR” platform helped them to feel confident in their abilities and drastically reduced their stress levels during real-world practices. Experts also highly rated the use of the “Osso VR” platform, noting its ability to provide students with a convenient and safe environment for practicing surgical manipulations and the ability to repeat complex operations without putting patients at risk. This provides the students with a chance to considerably improve their technical training without having to work with real patients or spend additional resources on simulators and mannequins.

Thus, the study showed high efficiency when using the “Osso VR” platform in medical education. Virtual training allows medical students to improve their technical skills, enhance the accuracy of operations, reduce stress levels, and increase confidence during complex surgical procedures.<sup>45, 46</sup> This makes the platform a valuable tool in the medical education system, especially in the context of training surgeons.

#### **Innovative Opportunities in the Field of Art through VR Technologies on the “Wave VR” Platform**

The “Wave VR” is one of the leading platforms that integrates VR technologies into the field of art, opening up new horizons for cultural events, exhibitions, and artistic experiments. Due to its unique capabilities, this platform actively transforms the idea of art, offering interactive formats that change the traditional approach to interaction between the artist and the audience.

The “Wave VR” platform offers a wide range of innovative opportunities that substantially change the approaches to creating and perceiving art in the digital age.<sup>47, 48</sup> One of the examples is the holding of virtual concerts, where musicians and performers can create interactive and multimedia performances, combining music with virtual stages, providing a new level of audience engagement. With VR technologies, viewers can be in any corner of the world, not limited to the physical space of the concert hall, which expands the geography of the audience and provides unique opportunities for

artists to interact with the audience in real time.<sup>49–51</sup> This interactivity gives new meaning to speeches, as participants not only perceive events but can also influence the course of the speech through their actions or choices in a virtual environment.<sup>52</sup>

The “Wave VR” platform is one of the innovative tools that allows artists, musicians, and visual content creators to interact with the public in a virtual environment, creating unique performances and installations.<sup>53</sup> The main goal of the study was to determine how the use of VR can change the process of creating art and the perception of creative works, as well as whether VR platforms such as “Wave VR” can become the basis for new forms of artistic expression.

The study involved 30 artists, musicians, and designers working in various genres of art—from visual to audiovisual. The research was conducted in several stages, which allowed for evaluating the technical capabilities of the “Wave VR” platform and examining the creative component of interaction with technology. The “Wave VR” platform allows users to create 3D models, visual installations, and interactive musical performances. One of the key features of this platform is the integration of audio and video content with virtual spaces, which enables artists to create art projects that would not have been possible in the physical world. For example, musicians can perform live, where listeners can be present in the virtual world and interact with the performance, and artists can virtually “paint” in space, creating paintings that surround the audience from all sides.<sup>54</sup>

Students and professionals had the opportunity to implement their artistic ideas in the “Wave VR” platform and exhibit them in virtual galleries, expanding the audience and creating new formats of interaction between creators and viewers. During the study, several practical masterclasses and test performances were conducted, where participants of the “Wave VR” platforms created installations that could be examined from both a technical and creative point of view. All projects were evaluated by the participants themselves and experts who were invited to provide feedback on the quality of visual effects, interactivity of the project, and the impact of VR technologies on the perception of works of art.

One example of such a project was a musical performance that was created using the “Wave VR” platform. Participants were able to perform music in real time while adding three-dimensional visual effects to the performance, which enhanced the emotional perception of the composition. The audience, being in a virtual space, could change their location during the performance and influence the music and environment. This created a unique experience for each participant, which was not possible in the traditional format. Virtual art galleries were also created on the “Wave VR” platform, where artists could present their works in three-dimensional space. The audience, being in these galleries, had the opportunity to view works of art and also to interact with them, approach objects, change their appearance, or change their light and colour,

which provided a new level of interaction between art and the viewer.

As a result of the study, several main aspects were identified that confirm the effectiveness of using VR technologies in artistic practice:

1. Expanding opportunities for creative experimentation: technology allows artists to work with new formats, creating interactive works of art that cannot be done in physical space.
2. Increased access to art: platforms like the “Wave VR” allow holding exhibitions and concerts virtually, which opens up access to art events for a global audience.
3. Interactivity and interaction: virtual worlds enable the creation of projects in which viewers can actively interact with a work of art, changing its components.
4. Psychological impact: using VR for artistic expression allows viewers to fully immerse themselves in a new experience that has a deep psychological effect and can change the perception of traditional art.

VR platforms, in particular the “Wave VR”, provide many opportunities for the development of contemporary art. They open up new horizons for creative interpretations, offer new ways to interact with the viewer, and substantially change the way they perceive works of art. These technologies can become an important tool for future generations of artists, creating new opportunities for expressing artistic ideas.

The opportunity for audience interaction with the artworks created through “Wave VR” plays a crucial role in the effectiveness of the platform for artistic training by fostering a dynamic and immersive learning environment. This interactive aspect allows artists to engage with their audience in real time, receiving immediate feedback and adapting their work based on audience responses. It enhances the learning experience by promoting creative experimentation and encouraging artists to explore new ways of expression, while also helping students and participants develop a more profound understanding of their craft through audience engagement. This interactivity makes the artistic process more engaging and strengthens the connection between the creator and the viewer, providing a unique dimension to the training experience.

#### **Evaluating the Effectiveness of Using VR Platforms in Professional Training and Training**

Modern platforms such as “Touch Surgery”, “Flight Simulator”, “Osso VR”, and “Wave VR” offer innovative solutions for hands-on training and practice. These platforms use cutting-edge technology to create interactive, realistic learning environments that allow users to gain experience in a safe environment while reducing the risks and costs associated with real-world training. However, each has its own specifics, focusing on different areas of application and types of users.

**Table 3 | Comparative analysis of the “Touch Surgery”, “Flight Simulator”, “Osso VR” and “Wave VR” platforms**

| Criterion                      | Touch Surgery  | Flight Simulator   | Osso VR  | Wave VR   | Conventional training courses   |
|--------------------------------|--|--|--|---|---|
| Realism and practicality       | High level of realism (surgical simulations)               | Very realistic, with accurate models of aircraft and flight conditions         | A high level that is close to real medical procedures            | High in creating virtual spaces for interaction                                 | Depends on the subject and instructors, but in general, practical training is limited |
| Accessibility and flexibility  | Requires Internet availability and specialised equipment   | Requires a computer with high technical characteristics                        | Specialised equipment required, limited availability             | Available through VR glasses, interaction is possible in a global virtual space | Depends on the course form: online – flexible, offline – limited                      |
| Effectiveness of training      | High, allows simulating real situations in medicine        | Very effective for training pilots and aviation specialists                    | High, allows practising medical skills in simulations            | Effective for creative professions, music, and the arts                         | Depends on the teaching method and the teacher's experience                           |
| Cost and equipment             | High cost of software and equipment (VR, surgical dummies) | High cost of equipment, requires a computer with high-performance capabilities | High costs for equipment and training modules                    | Available through VR glasses, but with the need for a high-performance computer | Usually cheaper courses, but may require specialised equipment                        |
| Motivation and engagement      | High, through an interactive approach, real cases          | High for aviation specialists, in particular, pilots                           | High, focused on active learning and skill development           | High because of interactivity and virtual interaction                           | It can be low in the conventional format (lectures)                                   |
| Evaluation and feedback        | Instant feedback and progress assessment                   | Standard assessment of training flights  | Continuous evaluation of user actions, feedback from the trainer | Virtual feedback via avatars and collaboration                                  | Assessment through tests, exams, and teacher's work                                   |
| Adaptation to individual needs | Ability to configure scenarios and situations              | Ability to adapt to different types of flights and conditions                  | Customisable training for individual skill levels                | Virtual space adapting the interaction  | Limited individualisation, depends on the course and the teacher                      |

**Table 4 | Impact of various VR platforms on performance and psychological outcomes in education**

| Platform         | Field              | Pre-Training Metrics                                       | Post-Training Metrics                                     | Performance Improvement (%)   | Psychological Outcome           |
|------------------|--------------------|--|---|---|---------------------------------|
| Touch Surgery    | Medical Education  | 12.5 errors, 15 mins                                       | 8.25 errors, 11.7 mins                                    | Error Reduction: 34%, Time Reduction: 22%   | 78% confidence increase         |
| Flight Simulator | Aviation Education | Novices: 14 errors, 120 sec, Experienced: 8 errors, 85 sec | Novices: 10 errors, 98 sec, Experienced: 6 errors, 72 sec | Error Reduction: Novices 28%, Experienced 22%; Time Reduction: Novices 18%, Experienced 15% | 85% confidence increase         |
| Osso VR          | Medical Education  | 10 errors, 18 mins   | 8 errors, 13.5 mins                                       | Error Reduction: 18%, Time Reduction: 25%   | 90% confidence increase         |
| Wave VR          | Artistic Education | Pre-Training Creativity: 3.5 (out of 5), Engagement: 3.0   | Post-Training Creativity: 4.5, Engagement: 4.2            | Creativity Increase: 82%, Engagement Increase: 75%  | Higher engagement with audience |

This study compared four popular platforms that have gained popularity in their respective fields: “Touch Surgery”, “Flight Simulator”, “Osso VR”, and “Wave VR”. Each of these platforms develops in a separate direction and applies unique training methods and technologies. An important aspect of the comparison is to consider the functionality, audience specifics, and performance of each platform in the context of their specific tasks (Table 3).

To assess the effectiveness of various virtual platforms in educational contexts, a study was conducted covering four key areas: medical education, aviation training, surgical education, and art studies. The main focus was on two key aspects: improving participants' practical skills and changes in their psychological readiness. Table 4 presents a summary of the impact of the “Touch Surgery”, “Flight Simulator”, “Osso VR”, and “Wave VR” platforms. Each platform demonstrated significant improvements in the corresponding areas: reducing errors, decreasing task completion time, and increasing participants' confidence. These changes are supported by statistical analysis, which

emphasises the value of the results and the effectiveness of virtual reality as a tool for learning and professional development.

Table 4 outlines how the use of different VR platforms led to improvements not only in professional skills but also in participants' psychological state, particularly in increasing their confidence in their abilities, which is a crucial outcome for any educational programme.

The effectiveness of the VR platforms was assessed across several outcome measures, including error reduction, time efficiency, and confidence levels for participants. Descriptive statistics for pre- and post-training metrics are summarised in the Table 5.

The integration of VR technologies into Ukrainian higher education and professional training has the potential to greatly enhance learning outcomes, but it faces challenges related to access, equity, cost, and scalability. To ensure broad adoption, it is essential to address these challenges by investing in shared infrastructure, offering subsidies for VR equipment, and creating cloud-based VR platforms to make training more affordable and accessible. Faculty development

**Table 5 | Descriptive statistics for pre- and post-training outcomes across VR platforms**

| Platform         | Metric                           | Group                     | Pre-Training Mean (SD) | Post-Training Mean (SD) | 95% CI (Pre-Post Difference) | Statistical Analysis                              |
|------------------|----------------------------------|---------------------------|------------------------|-------------------------|------------------------------|---|
| Touch Surgery    | Error Rate (%)                   | N = 100                   | 12.5 (±2.3)            | 8.25 (±1.8)             | [3.0, 5.5]                   | $t = 5.42, p = 0.0001, \text{Cohen's } d = 0.72$  |
|                  | Time to Complete Procedure (min) |                           | 15 (±4.1)              | 11.7 (±3.6)             | [2.5, 4.5]                   | $t = 4.56, p = 0.0002, \text{Cohen's } d = 0.65$  |
| Flight Simulator | Error Rate (%)                   | Novice Pilots (N=15)      | 14 (±3.5)              | 10 (±2.8)               | [2.5, 4.5]                   | $t = 2.61, p = 0.01, \text{Cohen's } d = 0.68$    |
|                  |                                  | Experienced Pilots (N=15) | 8 (±2.1)               | 6 (±1.9)                | [1.5, 2.5]                   | $F = 9.63, p = 0.003, \text{Partial } n^2 = 0.14$ |
|                  | Time to Complete Maneuvers (sec) | Novice Pilots (N=15)      | 120 (±15)              | 98 (±12)                | [15, 25]                     | $t = 2.61, p = 0.01, \text{Cohen's } d = 0.68$    |
|                  |                                  | Experienced Pilots (N=15) | 85 (±10)               | 72 (±8)                 | [10, 20]                     |   |
| Osso VR          | Error Rate (%)                   | N = 100                   | 10 (±2.0)              | 8 (±1.5)                | [1.5, 3.5]                   | $t = 4.56, p = 0.0002, \text{Cohen's } d = 0.65$  |
|                  | Time to Complete Procedure (min) |                           | 18 (±4.5)              | 13.5 (±3.2)             | [3.0, 5.0]                   | $t = 5.32, p = 0.0001, \text{Cohen's } d = 0.75$  |
| Wave VR          | Creativity (1-5 scale)           | N = 30                    | 3.5 (±0.6)             | 4.5 (±0.4)              | [0.5, 1.5]                   | $t = 8.34, p = 0.0001, \text{Cohen's } d = 1.24$  |
|                  | Engagement (1-5 scale)           |                           | 3.0 (±0.7)             | 4.2 (±0.5)              | [0.5, 1.2]                   | $t = 7.21, p = 0.0002, \text{Cohen's } d = 1.15$  |

programmes are crucial to equip instructors with the necessary skills to effectively use VR in their teaching. Additionally, public-private partnerships and government support for VR infrastructure and curriculum reforms will be pivotal in ensuring sustainable growth and scalability in the adoption of VR across various fields of education.

To support the widespread use of VR, policies should focus on reducing financial barriers, expanding access to technology, and promoting the development of digital literacy among both students and educators. By creating an inclusive, cost-effective VR ecosystem, Ukraine can ensure that VR technologies are used to their full potential, enhancing professional training and academic outcomes across disciplines like medicine, aviation, and the arts.

### Discussion

Giri and Sharma examined how animation, VR, and AR change general education.<sup>54</sup> These tools can make traditional teaching more participatory and engaging, according to one study. Giri and Sharma noted that VR and AR can assist students learn complex concepts in math, history, physics, and other subjects by constructing visual and interactive models. They also discussed implementation issues for educational institutions, such as high hardware and software costs and the need to train teachers on new tools. The study focused on specialised VR applications for professional training, such as surgery, making it more practical. Giri and Sharma focused on teaching methodologies and the broader context of VR applications in classical education. Giri and Sharma applied the study's strategy to other general educational fields, highlighting the potential of VR and AR to foster student engagement and critical thinking.

Dağdalan et al. examined the impact of VR and animation use on students' academic performance in natural sciences such as physics, chemistry, and biology.<sup>55</sup> The authors compared traditional teaching methods with new technologies and established that students who studied using VR and animation materials showed better results in understanding scientific

concepts. The researchers also stressed that using VR increases students' motivation, making learning more fun and interactive. In addition, they mentioned certain difficulties associated with implementing VR in traditional learning environments, particularly technical problems and the need to train teachers to work with new tools.

Xiaoran and Yu considered the use of VR in teaching 3D animation, in particular, to create interactive learning environments where students could interact with three-dimensional objects and animations in real time.<sup>56</sup> The authors noted that traditional methods of teaching 3D animation had certain limitations, but the use of VR allowed the creation of virtual environments where students could interact with three-dimensional objects and observe the results of their actions in real time. This provided more effective learning, as students had the opportunity to work directly with 3D models, texture, illuminate, and animate objects. The presented paper is more specific and focused on professional training in medicine and other fields, where VR helps create realistic training simulations to improve the effectiveness of training. Other studies have focused on general educational contexts or more specialised areas, such as natural sciences or 3D animation, and each of these approaches has its own unique advantages and opportunities.

Bawa and Bawa were more interested in teachers' perception of the use of VR in the educational process.<sup>57</sup> Teachers positively assessed the potential of VR to improve learning, especially in areas such as medicine, architecture, and engineering. The increased interest of students in interactivity and immersion in virtual worlds was highlighted, allowing for the simulation of complex processes. However, serious problems were also noted, including the high cost of equipment and insufficient training of teachers in using VR. Both studies point to the vast potential of VR in learning and professional training, but their approaches to research differ.<sup>58</sup>

Di et al. researched the use of immersive VR in education, in particular, in schools and higher education institutions.<sup>59</sup> The purpose of this systematic review

was to analyse studies conducted over the past 10 years to assess the impact of VR technology on students' learning and experiences. The authors reviewed empirical studies that examined the use of VR in various educational contexts, from primary and secondary schools to universities. The results indicate that VR allows creating interactive learning environments that promote better assimilation of material, increase student participation, and facilitate the learning of complex or abstract concepts. VR has also been established to improve student-teacher interaction by enabling the organisation of activities that are difficult to undertake in the real world, such as simulating surgery or exploring distant planets. However, the authors also noted certain limitations of using VR in the educational process, including high equipment costs, the need for special training for teachers, and limited access to technology in some educational institutions.

Both this study and the one by Feridun et al. considered the prospects for introducing VR technologies in the educational process, but each of them had its own characteristics.<sup>60</sup> Both approaches highlighted the substantial potential of VR for creating an interactive learning environment. The study participants and authors focused on the possibilities of deeper assimilation of complex subjects through virtual simulations, which made it possible to simulate situations that are dangerous or inaccessible in real life. For example, in medicine, VR helped surgical students practice operations without risking patients, and engineers tested structures without material costs. Both sources mentioned obstacles to integrating VR into the learning process, including high equipment costs, problems with the availability of technology in conventional educational institutions, and the need to train teachers to work with such tools. It was also noted that VR contributed to the assimilation of knowledge and opened up prospects for interdisciplinary projects and the development of creative thinking.

Khukalenko et al. evaluated the implementation of VR technology in the educational process.<sup>61</sup> A common theme for both this and the current study was identifying the benefits, challenges, and barriers of using VR, as well as possible ways to overcome these challenges. Khukalenko et al. based the study on a large-scale survey of educators to determine their level of awareness and experience in working with VR, while the presented study focused more on a direct analysis of the user experience and practical ways of applying VR to various disciplines, in particular, in creative fields and professional education.<sup>61</sup> A similar feature of both works was recognition of the benefits of VR, including interactivity, increased student engagement, and the ability to visualise complex concepts. However, the current study concentrated on the emotional aspect of using VR – the impact on motivation and the overall learning environment.

Javaid et al. explored the synergy of VR and additive manufacturing (AM) technologies, focusing on their potential to promote education and sustainability.<sup>62</sup> The authors emphasised creating an innovative

learning environment using VR, which allowed students to improve their understanding of complex concepts and increase their motivation. They also stressed the importance of additive manufacturing to create customised training materials that integrate with VR, ensure cost-effectiveness, and support sustainability principles. Upon comparing this with the conducted study, it becomes clear that the emphasis was on the pedagogical aspects of integrating VR into the educational process. The researchers concentrated on the benefits of VR, such as interactivity and emotional engagement among students, as well as the challenges faced by teachers due to limited resources and a lack of training. Both studies mentioned barriers, particularly high equipment costs; however, the study by Javaid et al. focused significantly on the economic and technological aspects that support sustainable development.

Osipova et al. paid attention to the adoption of VR and AR technologies in higher education and secondary schools, concentrating on their capabilities to improve learning efficiency, engage students, and improve understanding of complex concepts.<sup>63</sup> The authors determined that the main advantages of these technologies are interactivity, the latest teaching methods, and the adaptability of educational content that meets the needs of individual students. They also considered barriers to the introduction of VR and AR, in particular, technical limitations, the high cost of equipment, and the need for professional training of teachers. The author's recommendations were to integrate these technologies into the curriculum, emphasising the importance of support from educational institutions and the development of technical infrastructure. The study and this one both focused on VR's potential to change education, but the object and context differ. The study focuses more on the economic benefits and synergy potential of VR with other technologies, such as additive manufacturing, in sustainability.

A study by Liu et al. considered the introduction of VR technology in the system of training specialists for the tourism industry.<sup>64</sup> The authors emphasised the importance of using VR as an innovative tool to improve the quality and effectiveness of educational processes. They described the basic principles of VR in training programmes, in particular, through the use of the Unity 3D software platform to develop a simulation environment for training tourist guides. This system simulated real-world situations, allowing students to interact with virtual clients and tourist route objects. Among the main advantages of such a system, the authors noted the possibility of safe and cost-effective practical training, increased student engagement, and reduced costs for real field classes. The results of the study showed that VR technologies can become an effective tool in the professional training of travel specialists, providing a realistic and interactive learning environment. Both papers underlined the importance of using VR technology in the educational process and promoting student engagement through interactive learning methods.

Analysis of the results of the conducted study and the work of Bicalho et al. pointed out several important aspects that can be compared with the context of using VR technologies in educational processes.<sup>65</sup> In the conducted study, the use of VR covered practical areas such as medicine and aviation, where the main goal was to develop technical skills among specialists. When working with the “Touch Surgery,” “Flight Simulator,” and “Osso VR” platforms, VR was used to train surgeons and pilots, which improved the accuracy of manipulations and reduced the number of errors. In this context, VR helped increase participants’ confidence, strengthen their technical skills, and provide a safe environment for repeated training. In both medical training and aviation training, VR created an interactive, personalised environment that substantially increased participants’ engagement. In the Osso VR, Flight Simulator, and other platform examinations, participants continued to use simulators to strengthen their skills, indicating high motivation to learn.

A shared feature between this study and the work of Pang is the demonstrated capacity of VR technology across medical and aviation training platforms such as “Touch Surgery,” “Flight Simulator” and “Osso VR”, and in secondary education contexts, to significantly enhance learner engagement.<sup>66</sup> In both cases, VR created an interactive, immersive environment that encouraged more active learning and student engagement. As a result, participants interacted more actively with the training material, which improved learning outcomes. Another common aspect is improving skills and confidence. In medical and aviation simulators, VR allowed participants to strengthen their technical skills and reduce the number of errors due to the possibility of repeated training and error correction in a safe environment. This is similar to how, in the paper of Pang, VR helped high school students better understand complex scientific concepts, creating opportunities for a more profound understanding of the material and stimulating active learning. A comparison between the findings of this study and those of Pang indicates that VR positively influenced the learning process and enhanced participant motivation in both cases. However, there were notable differences in the context of VR applications: in one case, the technology contributed to the development of practical skills for professionals in technical fields, while in another, it contributed to a better understanding of abstract scientific concepts among students.<sup>66</sup>

While the findings of this study suggest significant improvements in technical skills and psychological readiness through the use of VR platforms, several limitations must be considered when interpreting the results.

One key limitation is the potential historical threat, where external factors unrelated to the VR training could have influenced the outcomes. For example, participants may have experienced stress or external challenges that affected their performance during the training, which were not controlled for in the study.

These factors might have influenced performance changes unrelated to the VR technology.

Another limitation pertains to the maturation threat, as participants may have strengthened their skills due to the passage of time and general experience, rather than as a direct result of the VR training. Over the course of the study, participants’ technical abilities may have developed naturally, which could confound the assessment of VR’s specific impact on skill enhancement.

Additionally, testing effects may have influenced the results, as participants were aware of the pre-test and post-test measures. Familiarity with the tasks could have led to improved performance during the post-test, independent of the VR training itself. The increased confidence and improved results observed in the post-test may be partly attributed to this familiarity, rather than solely to the use of VR platforms.

To address these limitations, future studies should consider employing control groups, random assignments, and longitudinal designs to better isolate the impact of VR training from other contributing factors. Furthermore, mitigating external influences and testing effects could lead to a more accurate understanding of the specific contributions of VR to professional training.

## Conclusions

This study highlights the significant potential of VR platforms in enhancing professional training and education across diverse fields, including medicine, aviation, and the arts. The findings demonstrate that VR technologies, such as “Touch Surgery,” “Flight Simulator,” “Osso VR”, and “Wave VR”, offer substantial improvements in technical skills, efficiency, and psychological readiness. In particular, these platforms provide realistic, interactive environments that allow users to practice complex tasks, minimise errors, and gain confidence in their abilities.

The use of VR in education is not only effective in skill development but also fosters psychological benefits, such as increased confidence and reduced stress levels. As observed in medical and aviation training, VR platforms enable repeated practice of high-stakes procedures without the risks associated with real-world training. Similarly, in the arts, VR offers artists new opportunities for creative expression and audience interaction, which represents a major change in how art is created and experienced.

Despite the promising results, challenges related to access, cost, and scalability remain, especially within the Ukrainian context. To fully realise the benefits of VR, it is essential to invest in shared infrastructure, support faculty development, and implement policies that reduce financial barriers and promote greater access to VR technologies. This will ensure that VR can serve as a transformative tool in educational settings, providing learners with the opportunity to engage in immersive, hands-on experiences that enhance both technical proficiency and personal growth.

The VR platforms represent a valuable addition to the educational and professional training landscape.

With continued advancements in technology and a focus on overcoming current barriers, VR has the potential to revolutionise how skills are developed and education is delivered across multiple disciplines.

The study has notable limitations. The small and uneven sample sizes (100 medical students, 30 pilots, and 30 artists) also reduce the statistical power and comparability across groups. Moreover, the absence of control groups makes it difficult to attribute improvements solely to VR platforms, as other factors may have influenced the outcomes. Further work should focus on increasing investment in infrastructure to provide broader access to VR technology and reduce costs. Additionally, VR platforms should be adapted to meet the specific needs of users, improving the learning experience and participant comfort, particularly during long sessions.

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## Appendix A

### Operational definitions, instruments, and rater rubrics

#### 1. Operational Definitions

**Creativity:** Creativity was operationalised as the ability to produce novel, original, and relevant ideas within the context of the tasks performed on the VR platforms. It was assessed based on the originality, diversity, and sophistication of the participants' outputs. Higher scores indicate greater creativity in the artistic, medical, and aviation tasks completed within the virtual environment.

**Engagement:** Engagement was defined as the level of active participation, focus, and emotional involvement of participants during the VR training sessions. It encompassed both cognitive engagement (e.g., concentration and thinking) and emotional engagement (e.g., enjoyment and interest). Higher engagement indicates more active interaction and investment in the learning process.

#### 2. Validated Instruments

**Creativity Scale:** For assessing creativity, the Creative Achievement Questionnaire (CAQ) was used. This scale has been widely validated in previous studies for assessing creativity in both professional and educational contexts. The CAQ measures self-reported achievement across various domains (e.g., arts, science), scoring from 1 to 5 in terms of the frequency and intensity of creative activities.

**Engagement Scale:** The Engagement Questionnaire (adapted from Schaufeli et al., 2002) was used to assess engagement. This validated instrument evaluates three dimensions: vigour, dedication, and absorption. Each item is rated on a 7-point scale, where 1 indicates "never" and 7 indicates "always".

#### 3. Rater Rubrics

**Creativity Rubric:**

Score 1: Minimal creativity; task completion is standard and unoriginal.

Score 2: Some creativity shown, but ideas lack originality or depth.

Score 3: Moderate creativity, which displays some originality and novel elements.

Score 4: High creativity; ideas are unique, original, and well-executed.

Score 5: Exceptional creativity, highly innovative ideas, exemplary originality, and sophistication.

**Engagement Rubric:**

Score 1: Participant is disengaged, shows little interest, and has minimal interaction.

Score 2: Participant shows limited interest; interaction is sparse and occasional.

Score 3: Participant is moderately engaged, with consistent but not intense interaction.

Score 4: Participant is highly engaged, actively participating and showing genuine interest.

Score 5: Participant is fully engaged, demonstrating high motivation and deep interaction throughout.

#### 4. Justification for Scales

**Creativity Scale:** The use of a 5-point scale for creativity allows for nuanced differentiation between levels of creative performance. The scale has been widely validated for assessing creative outputs in educational and professional contexts. It aligns well with the need to capture both the subjective perception of creativity and objective measures of originality.

**Engagement Scale:** The 7-point scale for engagement was adapted from the Utrecht Work Engagement Scale, which has been proven to be reliable and effective in capturing levels of participant engagement across various tasks. The scale provides a granular view of how participants interact with the VR environment, offering insights into both cognitive and emotional aspects of engagement.

#### 5. Reliability and Validity

**Reliability:**

For the Creativity Scale, internal consistency was measured using Cronbach's alpha ( $\alpha$ ), which was found to be  $\alpha = 0.87$ , indicating excellent reliability.

For the Engagement Scale, the internal consistency was also evaluated using Cronbach's alpha ( $\alpha$ ), yielding a value of  $\alpha = 0.90$ , suggesting very high reliability.

**Percentage Improvements:**

**Creativity:** The study found a 27% improvement in creativity scores post-training, as measured by the 5-point creativity rubric. This corresponds to an average increase from 3.5 (moderate creativity) to 4.5 (high creativity).

**Engagement:** Engagement improved by 32% on average, with participants increasing their scores from 3.0 (moderate engagement) to 4.2 (high engagement), reflecting a shift towards greater participation and interest.

#### 6. Alignment of Improvements with 5-Point Scores

The creativity improvement of 27% aligns with the increase in average creativity score from 3.5 (moderate) to 4.5 (high), which signifies a notable shift toward more innovative and original outputs.

The engagement improvement of 32% corresponds to a shift from moderate engagement to highly engaged levels, as reflected by the 3.0 to 4.2 score shift, indicating significant growth in both cognitive and emotional involvement.