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Analysis of the influence of introductory instruction time in virtual reality on the effects of the training

Analiza wpływu czasu instruktażu wprowadzającego w wirtualnej rzeczywistości na efekty szkolenia

Key words: virtual reality training, asbestos, immersive virtual reality, VR training, introductory instruction VR.

Abstract: The study described in this paper is focused on the attempt to determine the optimal time that should be devoted to introductory instructions provided in immersive virtual reality (IVR) in order to use the time dedicated to the entire training process in the most effective way possible. It was assumed that instruction efficiency would be determined by the number of mistakes committed and the time taken to successfully accomplish the test task intended to examine the course participants' ability to use the IVR application and to apply theoretical knowledge in IVR-based practical exercises. To conduct the planned study, it was assumed that there is an optimal time that is worth devoting to instructions in IVR, and that exceeding this time does not yield any further measurable effects in the form of a significantly reduced number of mistakes committed and shortened time taken to successfully accomplish the test task. The study was conducted during VR training courses.

Słowa kluczowe: szkolenie w wirtualnej rzeczywistości, azbest, immersyjna rzeczywistość wirtualna, szkolenie VR, instruktaż wprowadzający VR.

Streszczenie: Opisane w niniejszym artykule badanie koncentruje się na próbie określenia optymalnego czasu, jaki powinien zostać poświęcony na instruktaż wprowadzający do immersyjnej wirtualnej rzeczywistości (IVR), aby jak najefektywniej wykorzystać czas przeznaczony na cały proces szkoleniowy. Założono, że efektywność instruktażu zostanie określona na podstawie liczby popełnionych błędów oraz czasu potrzebnego do pomyślnego wykonania zadania testowego, mającego na celu zbadanie umiejętności uczestników kursu w zakresie korzystania z aplikacji IVR i zastosowania wiedzy teoretycznej w ćwiczeniach praktycznych opartych na IVR. Do przeprowadzenia zaplanowanego badania przyjęto założenie, że istnieje optymalny czas, który warto poświęcić na instruktaż w IVR, a jego przekroczenie nie przynosi dalszych wymiernych efektów w postaci istotnie zmniejszonej liczby popełnianych błędów i skrócenia czasu potrzebnego na pomyślne wykonanie zadania testowego. Badanie zostało przeprowadzone podczas szkoleń VR.

Introduction

Training courses utilising IVR have been the subject of various studies for several years, and the validity of their use has been confirmed numerous times, including by Kurillo, Bajcsy, Nahrsted and Kreylos (2008), Paiva, L.d.S. Machado and T.V.V. Batista (2015), and Pei et al. (2016).

In their publication titled *Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design*, Hamilton, McKechnie, Edgerton and Wilson (2020) also demonstrated the benefits of using IVR in training where teaching is particularly focused on making the participants develop spatial imagination. Furthermore, as revealed by the cross-sectional literature study by Bian Wu, Xiaoxue Yu and Xiaoqing Gu (2020), encompassing 35 scientific papers published in the years 2013-2019, there is a clear improvement in training efficiency when employing IVR technology relative to other, non-immersive methods of teaching. It should however be noted that the study by Wu et al. (2020) also indicated that in 34% of cases, the use of IVR yielded no positive results or the effect was negative. The research conducted by Chen, Chang & Chuang (2021), described in the publication titled Virtual reality application influences cognitive load-mediated creativity components and creative performance in engineering design, confirmed that there are grounds for using virtual reality technologies in education. The use of VR applications has a clear influence on vocational training and creative motivation. According to Chen et al. (2021), utilising VR presents numerous benefits but may also result in increased and unnecessary cognitive burden by exposing the individual immersed in VR to too many stimuli at the same time.

The conducted analysis demonstrated that employing modern technologies such as IVR in education still requires numerous studies and verifications concerning the method of IVR implementation in training course programs. This will make it possible to optimise and continuously improve the applied teaching methods.

Per the approach proposed by Frein and Ott (2015), it was decided that the training courses which served as the basis for the study presented in this paper would use IVR technology involving a Head Mounted Display (HMD) system, primarily due to the necessity to isolate the course participants from the actual work conditions characterised by risks of exposure to carcinogenic asbestos dust, and due to the necessity of providing the participants with practical training in terms of carrying out specific procedures and learning manual skills related to the dismantling and securing of asbestos containing materials. As demonstrated by Chen et al. (2018) in their publication titled *ImmerTai: Immersive Motion Learning in VR Environments*, IVR yields beneficial results in situations where one of the training goals is to have the participants master specific manual skills. Chan, Leung, Tang and Komura (2011), Di Natale, Repetto, Riva and Villani (2020), and Li, Zhang, Sun, Wang and Gao (2017) also confirmed this notion in their works.

Chen et al. (2018) attempted to evaluate the efficiency of training utilising two IVR systems: 1 – Cave Automatic Virtual Environment (CAVE); 2 – Head Mounted Display (HMD) and one VR system based on a personal computer (PC). As demonstrated in their work, the IVR systems were better received by the course participants and resulted in their greater commitment to the learning process compared to the control group using VR on the PC. Although it was also revealed that the teaching efficiency using HMD was slightly lower relative to the other systems, the authors of this publication believe that this difference does not invalidate the benefits related to the higher level of immersion, which provides the training course participants with a greater degree of involvement in the virtual workspace.

Furthermore, another study conducted by Huang, Roscoe, Johnson-Glenberg & Craig (2021), described in the publication titled Motivation, engagement, and performance across multiple virtual reality sessions and levels of immersion, revealed that a higher level of immersion also results in a greater motivation and stronger engagement on the part of the participants. The presented conclusions demonstrate the validity of IVR use in education. In the case of vocational training, another argument in favour of using IVR technology is the possibility of isolating the course participants from work conditions that are often hazardous.

The subject of the studies described in this publication was the testing of various methods for conducting introductory instructions in an IVR application. The scope of the training encompassed issues related to the safe handling of materials containing carcinogenic asbestos. Exposure to asbestos dust constitutes a significant hazard to human health. Patti Kratzke (2018) described the respiratory system diseases caused by asbestos and the associated requirements regarding comprehensive radiologic examinations. Diseases after asbestos exposure often remain invisible for decades, which is why the development of aetiology was very slow, as presented by Smith (2005). Świątkowska (2017) described the examinations of individuals with occupational risk of exposure to asbestos as part of the Amiantus Program in Poland. The issue of cancer development risk as a result of the influence of asbestos fibres is still valid despite the increasingly better occupational safety in handling asbestos. The incidence of malignant tumours, particularly lung cancer and pleural mesothelioma, is strictly associated with the concentration of asbestos fibres in the air, which in turn is influenced by the number and condition of installed and utilised asbestos containing materials and the level of environmental contamination. Asbestos migration into the air from contaminated water was described by Avataneo et al. (2022).

Asbestos containing material removal requires following strict procedural guidelines, using the appropriate personal protective equipment and applying theoretical knowledge skilfully in practice.

Asbestos fibre concentrations during renovation work and the risks for individuals conducting such work were described by Obmiński (2010).

The authors undertook a challenge related to the testing of actions supporting the optimisation of IVR application use in vocational training aimed at individuals who will engage in the dismantling of asbestos containing materials in the future. The goal of the presented study was to discover the answer to the question as to how introductory instructions in IVR applications should be conducted so that the combined time dedicated to the instruction and the actual training could be used in the most efficient manner possible.

Materials & methods

All the work was conducted based on an immersive virtual reality (IVR) environment supported by Head Mounted Display (HMD) sets working in multiplayer mode. The equipment used in the study included two VR sets consisting of HTC VIVE goggles and controllers coupled with portable computers. Each VR set operated within the environment of applications named *Student 1* and *Student 2*, which formed a network with a third computer acting as a server by means of the Photon software.

Student 1 and *Student 2* are IVR learning applications enabling the conduction of a synchronous practical training process for two persons simultaneously.

The desktop application *Teacher* was installed on the server, which allowed the teacher to communicate with the students in real time, including by instructing them or issuing commands, to highlight and indicate selected VR scene elements and to conduct evaluation. Both the application functionality and all the training scenarios were developed with the involvement of the authors of this publication.

The applications *Student 1 and 2* were developed in Unity, an environment enabling the representation of a fully realistic workspace and the entire range of actions that the course participants must employ in order to be able to perform the tasks assigned to them. The training room was designed in such a way so as to maximise the effectiveness of IVR sensations by means of various sensory stimuli (Erfanian, Tarng, Hu, Plouzeau, Merienne, 2017).

The applications used the scans of a full male body in several variants differing in the applied clothing. Avatars were prepared in both civilian outfits, unfit for work in contact with asbestos, and in a protective uniform encompassing one-piece coveralls and various types of gloves, face and head protection and safety harnesses for working at height. Each participant received an identical avatar at the start of the course, which could then be modified by equipping specific, individually selected protective uniform elements.

Fot. 1 and Fot. 2. Screenshots from the VR application – full body avatars

Source: author: S. Łagosz.

Both the course participants worked in one space, defined over a floor area of about 5 m x 5 m. The physical movements of the participants were represented in the application through the motions of each participant's avatar. Motion tracking was accomplished using two base stations that transferred physical motion into VR by connecting with the sensors installed in the goggles and controllers. It was decided to refrain from using additional trackers attached to the waist, knees and feet of the participants, and leg motion representation was simulated based on the behaviour of the three other sensors (head and two arms).

Movement in the application is accomplished in two ways, depending on the distance that a given participant wishes to cross. Single steps during work, within an area of about 4 m^2, are taken physically and transferred to the application by the base stations. Longer distances are crossed using a virtual laser that teleports the avatars into the selected locations.

The training scope encompassed selecting the protective uniform and the appropriate tools as well as conducting work related to the removal and securing of asbestos containing materials. With this in mind, the applications were designed in such a way so as to enable the participants to undertake virtual, supervised practical exercises whose elements corresponded to the accomplishment of individual training goals. All the 3D models of the asbestos materials implemented in the application constituted faithful representations of real materials and were obtained through the photogrammetric scanning of actual products installed in buildings as well as of asbestos waste remaining after dismantling.

The VR scenery where the action took place encompassed a work site with an area of about 50 a, consisting of two buildings and additional elements typical of a construction site. The first building was a day quarter with work and street clothing changing rooms and a tool shop, the other a three-storey building where the work was to be conducted.

Fot. 3. Screenshot from the VR application – main building where asbestos removal works are carried out

Source: author: S. Łagosz.

Twelve training locations were made available to the VR-immersed participants, including: the streetwear changing room, the workwear changing room (for removing contaminated protective clothing), the tool shop, a point for marking and securing the work area, a waste disposal point and seven workstations. Using such a number of locations enabled the training to encompass the most frequently performed work related to the disposal of asbestos containing materials, including both hard (asbestos cement sheets) and soft products, such as insulating boards or asbestos rope, whose removal presents a particularly large health risk. Furthermore, the large number of locations available in the VR also made it possible to plan and carry out the experiment constituting the subject of this publication.

The person supervising the course of the training with regard to the substance had access to the desktop application *Teacher*, whose main function was to synchronise the actions of both the participants. It also enabled the continuous supervision of all the actions taking place in the IVR. The teacher himself was not immersed in VR and provided the participants with tasks, commands and instructions intended to enhance the teaching process through the available communication channels. Thus configured, the connection between the VR-immersed participants and the teacher operating by means of the external desktop application enabled the simultaneous supervision of the participants' progress and work with the list of observations defined for the study.

After putting on the HMD goggles, a semi-transparent lung icon appeared in the upper left corner of the participant's field of view. This was a visualisation of the participant's risk of exposure to asbestos dust. During the conducted work, in situations where the participant committed mistakes that under real circumstances would result in asbestos dust intrusion into the lungs, the icon gradually filled up with red. This was a signal for the participant that the applied work methods and the protective uniform and tools selected beforehand should be analysed again.

At the same time, thanks to this icon, the teacher could easily verify whether the participants carried out their assigned tasks correctly.

The application also has an additional exam mode where the teacher can assign an evaluation result to each exam task stage. This function is discussed in more detail in the description of the research method adopted for the experiment constituting the subject of this publication.

The study group consisted of 122 individuals aged 16 to 25, and included high school pupils and university students training to become professionals in building engineering. The educational institutions that hosted the study were located in two countries, i.e. in Poland: Pszczyna, Bielsko-Biała, Opole, Kłodzko, Głogówek, Jelenia Góra, and in Czech Republic: Opava, Jesenik. The study encompassed eight educational institutions in total.

A study group this numerous was selected because, as demonstrated by Bower and Jong (2020) in the conclusions of the publication *Immersive virtual reality in education*, considering the significant expenses related to such types of studies in education, they are often conducted on samples that are too small, which may potentially have an influence on the representativeness of the obtained results. In the aforementioned study, the average sample size was about 100, but only 3 out of the 13 analysed studies were based on a sample consisting of a hundred or more individuals. The two biggest study groups encompassed 131 (Makransky, Petersen, Klingenberg, 2020) and 566 individuals (Jong, Tsai, Xie, Wong, 2020), which confirms that the number of persons involved in this experiment can be deemed sufficient.

When preparing the study, it was decided that the location for measuring the efficiency of the conducted instruction would be the training location on the roof of the main building, where the participants carried out their test tasks related to dismantling corrugated asbestos cement sheets and transporting the removed sheets from the roof to the ground level. This choice was made with regard to the fact that the actions undertaken at this location required significant manual skill, particularly including efficient movement as well as using the full range of body motions and high VR controller operation precision. At the same time, the task was relatively simple in terms of the procedural aspect and its correct performance did not require specialist knowledge outside the scope of standard instruction.

Before proceeding with the test task, each participant underwent theoretical training spanning 7 class periods. Many researchers use traditional teaching methods before immersing the participants in IVR, including Vogel-Walcutt, Fiorella and Malone (2013), or Kim et al. (2020), and it yields positive learning effects. Based on the conclusions of the study presented by Petersen, Klingenberg, Mayer and Makransky (2020), it can be argued that such circumstances may result from the fact that participants who had learnt certain basics beforehand may be able to more easily commit to the role planned for them in the training application later during immersion in IVR.

The presented training encompassed topics such as the applicable legal regulations, rules of conduct and the equipment used when working in contact with asbestos or asbestos containing materials as well as the risks for human health resulting from such work. The participants also learned of the various economic applications of asbestos, its properties and the types of products in which it was used. Individual IVR application elements were also discussed, as well as the mechanics employed during the training course. The lecture was complemented with videos and graphics obtained from the IVR application. All the actions performed before commencing the IVR training were intended to increase the participants' focus on the actual goal of the practical training, by directing their attention towards the most important elements of the conducted work. A similar approach was employed by Vogel-Walcutt (2013) in the publication *Instructional strategies framework for military training systems* as well as by others (da Cruz et al., 2016), (Yiannakopoulou, Nikiteas, Perrea, Tsigris, 2015).

The goal of the instruction was to familiarise the participants with the application and to let them acquire the skill to work in the IVR environment on a level where technical limitations no longer had a negative influence on the manner in which the substance of the training was received. The instruction was conducted in an IVR environment and consisted of two stages.

Starting the first stage, the participants received a standard introductory message, read out by a speaker, and then proceeded to familiarise themselves with the VR controllers and the mechanics implemented in the application, with the help of the training supervisors. The familiarisation process encompassed controller button operation and discussing the use of functions available to the users, which were required for movement, item manipulation, putting on protective clothing, adding tools to the personal inventory, engaging the tools and controlling the available devices. Finishing the first stage of the instruction took about one and a half minutes.

Afterwards, as part of the second stage, the participants, assisted by the training supervisors, moved around the work site and performed their first actions in order to become accustomed to the application, to learn the terrain topography and to master the basic actions available in VR. They could visit all the available rooms, collect tools and test them at the training locations as well as climb the scaffolding and the roof of the main building. The participants were provided support and guidance by the supervisors regarding their actions in the application, while simultaneously retaining the freedom of choice as to the scope of the performed actions and the area in which they moved. Each of the individual skills necessary to perform the test task could be practised during the instruction, but at the same time, none of the other training locations required operating the VR controller at such a high level of precision or working in as diverse, and often uncomfortable, positions. It was due to this aspect that the training location in question proved to be the most difficult for the participants.

The second stage lasted from 30 seconds to about 10 minutes, which corresponded to a total instruction duration ranging from 2 to about 12 minutes. When planning the entire experiment duration, the authors of the study had to remember that human response to an exposure to IVR can vary, and after a time, some individuals may experience certain discomfort, including vertigo and problems with maintaining balance. In their publications, De Back, Tinga, Nguyen and Louwerse (2020), and Kennedy, Lane, Berbaum and Lilienthal (1993) named this aspect as one of the more significant limitations of IVR relative e.g. to PC-based systems or traditional teaching methods.

After the instruction was concluded, the training supervisor requested that a participant perform a test task, during which the task performance time and the number of committed mistakes were measured, and the dust exposure level that the participants were at risk of was recorded.

The test task consisted of a number of actions, the correct performance of which influenced both the time taken and the number of mistakes committed during the conducted work. The first test task stage was to select the individual protective uniform elements and the tools appropriate for the specifics of the conducted work.

Fot. 4. Photos taken during the training – students in the process of asbestos removal

Source: author: J. Grabowski.

Afterwards, the course participants secured the work area and continued to the roof of the building, where they proceeded to dismantle the corrugated asbestos cement sheets. The procedure encompassed the following, in order: moistening the sheet surfaces, removing the nails fixing the sheets to the rafter framing (action requiring high VR controller operation precision), transferring the sheets to the roofing hoist platform, bringing the sheets to the ground level, and laying and securing the sheets on a pallet for hazardous waste transport to a disposal site.

Results & discussion

The performance time of the planned test task and the number of mistakes committed during it were examined. The results depended primarily on the VR controller operation proficiency and the efficient movement in the applied VR environment. All these factors were juxtaposed with the time taken to instruct each person.

The total instruction duration depended on the number of commands and hints that the participants received from supervisors during that time. One of the inspected assumptions was the notion that there is an optimal instruction time which enables the most effective possible time division between the actual training and the instruction.

The test task performance time was the basic measured parameter related to the test task performance. It ranged from 220 to 640 seconds. The total number of committed mistakes ranged from 1 to 10.

Analysing the relationship between the task performance time and instruction duration for all the study participants reveals that once an instruction duration of 300 seconds is exceeded, the task performance time falls under 400 seconds and ranges from 200 to 400 seconds. Further extension of the instruction duration has no significant influence on the task performance time.

Analysing the influence of instruction duration on the number of mistakes committed by the study participants demonstrates that once an instruction duration of 360 seconds is exceeded, the number of mistakes falls under 4 and ranges from 1 to 4 mistakes. Further extension of the instruction duration has a minor influence on the number of committed mistakes.

When analysing the results, it should also be taken into consideration that the differences in the digital competence of individual participants may have a significant influence on the time necessary for IVR environment adaptation and efficient controller operation skill development, which in turn entails other requirements related to the introductory instruction duration in IVR. As demonstrated in the publication *Methodology of Implementing Virtual Reality in Education for Industry 4.0* (Paszkiewicz et al., 2021), describing a training course where one of the elements was to conduct a fire extinguishing action, the participants exhibited a similar action efficiency, expressed in the time taken to perform the task, only by the third attempt.

Comparing the efficiency of individual technologies involving virtual reality was not the subject of this work, but it is nevertheless worth noting that apart from its undeniable advantages, using IVR in education also exhibits disadvantages. As can be observed, for example, in the case of the publication *ImmerTai: Immersive*

Motion Learning in VR Environments (Chen et al., 2018), the use of IVR does not always yield the best results. In certain situations, the CAVE system exhibits a clear advantage over systems utilising HMD, though unfortunately considering the costs related to conducting CAVE-assisted training, doing so at a broader scale currently appears impossible. On the other hand, the lower quality of the motions (Tai Chi figures) performed by the training course participants using HMD sets relative to a PC VR system is very puzzling.

The authors of this publication believe that this may be the result of numerous factors, including for example the insufficient representation of a participant's range of physical motions in VR, the quality of the graphics and avatar motor functions or the manner of adaptation for learning in an IVR environment. It is certainly a very perplexing phenomenon, and it is worth undertaking further research to explain it.

Conclusions

Conducting training assisted by immersive virtual reality technologies leads to a definite improvement in safety during the classes, results in increased student interest in the course subject, and under certain conditions may also result in improved teaching efficiency. However, to fully harness the potential of IVR, it is necessary to first prepare the utilised teaching application, the class organisation form and the time devoted to the training in an appropriate manner.

The study described in this publication was conducted based on a teaching application developed with practical training in mind, targeted at individuals who intend to undertake work that may involve contact with carcinogenic asbestos in the future. Particular focus was devoted to the iterative training of procedures related to the conducted work as well as to the ability to select the appropriate tools and personal protective equipment.

The goal of the study was to attempt to define an optimal time that should be devoted to introductory instructions in IVR for pupils and students taking part in training courses within the scope of the safe dismantling and securing of asbestos containing materials. The influence of the applied duration of the IVR environment adaptation and instruction on the test task performance efficiency was inspected during the study. The efficiency was measured in both the time necessary to carry out the planned work, and in the number and significance of the committed mistakes. The study results were analysed for two groups of training participants, divided on the basis of their experience with IVR application use.

Analysing the obtained results makes it possible to conclude that the optimal time for introductory IVR instruction is 5-7 minutes for the group experienced in IVR use, and 6-8 minutes for the inexperienced group.

The obtained study results may also find application in other training programs, which can contribute to improving the training quality and to optimising the class duration.

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