SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 179

# VR-AIDED TRAINING TO COPE WITH HAZARDS IN COAL MINES

Aneta GRODZICKA[1], Franciszek PLEWA[2], Marcin KRAUSE[3*], Magdalena ROZMUS[4], Kamil SZEWERDA[5], Dariusz MICHALAK[6]

[1] Silesian University of Technology; aneta.grodzicka@polsl.pl, ORCID: 0000-0001-5712-8230
[2] Silesian University of Technology; franciszek.plewa@polsl.pl, ORCID: 0000-0002-6390-6948
[3] Silesian University of Technology; marcin.krause@polsl.pl, ORCID: 0000-0002-9934-1539
[4] KOMAG, Institute of Mining Technology; mrozmus@komag.eu, ORCID: 0000-0003-0381-3237
[5] KOMAG, Institute of Mining Technology; kszewerda@komag.eu, ORCID: 0000-0003-2266-1371
[6] KOMAG, Institute of Mining Technology; dmichalak@komag.eu, ORCID: 0000-0002-7300-4286
* Correspondence author

**Purpose:** Ability to take proper actions and decisions when a hazardous situation occurs is crucial for safety of employees affected by this situation. In a coal mine, this regards both miners and mine rescuers. Providing them with effective training on hazards is a challenge, as these are difficult or impossible to simulate or recreate for training purposes, at real working sites or at training facilities. Application of VR seems to be a solution, as it enables to develop a virtual representation of working environments as well as actions and phenomena happening there. The paper focuses on the use of VR in the training of mine rescuers and concept of such training is proposed. Applicable possibilities, limitations and recommendations are also presented and taken into account in the concept.
**Design/methodology/approach:** Literature studies were carried out: 1) to identify possibilities to VR integration in the training of mine rescuers resulting from legal regulations, 2) to identify applicable methods, recommendations and findings presented in scientific publications. The proposal for use of virtual reality in the training of mine rescuers was described taking into account: the training procedure, observation in the VR-aided training, the training materials.
**Findings:** Researches presented in scientific publications support the idea to VR integration in the training, however – to make it more effective - the trainee should be accompanied by a trainer. Analysis of Polish legal regulations regarding training of mine rescuers reveals that there is no formal barrier for VR integration in the training, however carrying out actions in virtual reality cannot replace the mandatory practical exercises.
**Research limitations/implications:** The concept of VR integration in the training of mine rescuers takes into account possibilities and limitations established by Polish legislation.
**Practical implications:** It is allowed to integrate VR in mandatory training of mine rescues.
**Originality/value:** VR integration in mandatory training of Polish mine rescuers has not been described so far in scientific papers. The paper is addressed to: 1) persons managing mining plants, 2) managers of mining rescue stations, 3) managers of mining supervision authorities.

**Keywords:** training, virtual reality (VR), mining industry, mine rescue, occupational safety and health (OSH).

**Category of the paper:** research paper, general preview.

## 1. Introduction

Application of Virtual Reality (VR) for training purposes becomes more and more common. There are at least two reasons for that: 1) VR gives exceptional opportunities comparing to other ICT solutions, 2) VR hardware and software affordability - and thus popularity of and familiarity with this technology - is growing.

Virtual reality is a computer-generated representation of objects, places and related phenomena and processes. In context of training, this is particularly advantageous when conducting training in real conditions - at real machines, real workplaces, locations etc. is impossible (e.g. you cannot carry out particular activities as a learning task), problematic or accompanied with risks, like e.g. injury of a trainee, causing hazard to persons or objects the trainee interacts with etc. However, the extent to which VR-based materials reflect real working conditions, depends on the type of VR employed.

VR solutions range from non-immersive VR to fully immersive VR (Azarby, Rice, 2022; Mandal, 2013; Martirosov et al., 2022; Pedram et al., 2021). Depending on the type, there are different possibilities as regards sense of presence and immersion (Wilkinson et al., 2021) in the VR world, and taking actions there. Non-immersive VR, called also desktop VR, provides a computer-generated environment, but the user stays aware of and keeps control of their physical environment. High-resolution screens are used for displaying the virtual environment and the user interacts with it with use of input devices likes keyboard, mouse, joystick etc. In semi-immersive VR the user is partially immersed in a virtual environment, where they can move but cannot directly interact with objects there. The user has a sense of being in a different reality – when they focus on the digital image, but they also remain connected to their actual surroundings. A flight simulator is an example. In high immersive VR, a user gets impression of being fully immersed in the virtual world. This is a first-person, multisensory experience comprising a deep ‘sense of presence’. Observers’ perception is that they are inside the virtual world and interact directly with the environment. This is obtained with use of head-mounted displays (HMD) and haptic controllers. Applicability and suitability of particular types of VR for learning purposes depends on a number of factors, like e.g. subject of training, costs, access to hardware and software, possibilities and limitations of trainees.

Application of VR for teaching (including a variety of related aspects), covering all the types of VR mentioned above, is a subject of many research publications (e.g.: Beck et al., 2020; Cail et al., 2021; Omlor et al., 2022; Ogrizović et al., 2021; Zhou et al., 2018). In addition to research activities on the subject - focused among others on development the most appropriate approaches and solutions - the growing interest and appreciation for VR-aided training is also manifested by constantly increasing offer of commercial VR-based training solutions.

The publication concerns the problems of training and virtual reality on the example of the concept of VR integration in the training of mine rescuers. The scope of the work includes: analysis of specialist publications on the use of virtual reality for training purposes and current regulations on the training of mine rescuers (shaping safety with use of VR, legal background regarding training on hazards - in Polish coal mines), proposal to use of virtual reality in the training of mine rescuers (the training procedure, observation in the VR-aided training, the training materials).

## 2. Shaping safety with use of VR

Safety of workers is related with and conditioned among others by: the way in which working activities are carried out; hazards at the working environment (constantly present and these possible ones); taking proper actions and behaviors in emergency situations, e.g. once a hazard occurs or an accident happens; effective rescue action, if it is realized. Training to provide employees as well as rescuers with relevant knowledge and skills is crucial, and use of VR for that purpose becomes more and more common. Dedicated VR-based training materials are created (both as commercial products and as versions for research purposes), and their development as well as their use in training process are a subject of researches. However, it should be underlined that when highly immersive VR is mentioned in scientific papers, typically VR serious games are considered.

Review of publications on application of VR for occupational safety and health training in high-risk engineering industries, published in years 2011-2021, has been done by authors of (Toyoda et al., 2022). Based on selection criteria used for the literature search, there were 45 publications identified as relevant: 25 related with construction, 8 – with manufacturing and assembly, 7 – with chemical process/laboratory, 2 – with mining, 2 – with electric power and electronic and 1 – with agriculture. The findings of the review covered the following issues regarding VR-aided OSH training in the considered industries: topics investigated by researchers; types of VR applied (non-immersive/desktop, semi-immersive, or fully immersive); assessment of the training effectiveness (outcomes measured, techniques used); comparison of training methods applied in terms of improvement of training effectiveness (comparison between particular types of VR and comparison of VR-aided training with other/traditional methods). Extensive elaboration with a thorough and detailed discussion and implications is presented in the paper. Some of the findings are as follows:

- Two main topics learnt within VR-aided OSH training are: 1) risk assessment, 2) machinery or process operation.
- There is a continuous and noticeable increase in use of fully immersive VR for training in OSH in high-risk engineering industries, which is also reflected by the increasing number of studies and publications. The increase is related among others with: 1) continuous improvement of HMD and related software, and – at the same time - decreasing costs of VR integration in the training, 2) benefits provided by the high degree presence and immersion. Application of semi-immersive VR has been least covered by the publications. The main reason for that was that use of this type of VR is related with high costs and efforts both at building stage and operation phase (including maintenance). Another reason is limited access to facilities that actually have integrated semi-immersive VR solutions in their training processes. As regards application of low-immersive VR, its coverage by publications declined during the period covered, however it did not disappear as the semi-immersive. There are two main reasons indicated for that: 1) accessibility due to relative low cost of development and application of the desktop VR, 2) benefits provided comparing to traditional training methods (e.g. in terms of trainee's engagement, considered attractiveness etc.).
- Results of majority of the studies indicate that application of VR for training enables to obtain better learning effects than use of traditional methods, like e.g. video-based training. This applies to all VR types.
- Referring to the 4-level Kirkpatrick's training evaluation model (Kirkpatrick, 2006):
  - in the studies regarding VR-aided training, the focus is mainly on: i) Level 1, i.e. the reaction level, at which opinions of trainees on the training (if it is engaging, relevant etc.) are identified, ii) Level 2, i.e. training level, at which it is verified whether the intended competencies (knowledge, skills, attitudes etc.) have been acquired,
  - Level 3, i.e. application of the competences (acquired/improved at VR-based training) during actual work has been little investigated,
  - no study covered Level 4, i.e. measuring of the training results in terms of its impact on an organization,
  - as regards including Level 3 and Level 4 in the studies – little and non, respectively – it is caused by limited time and funds, insufficient for wider research.

The further discussion will be carried out in context of VR-aided training to prepare workers to cope with hazardous situations in coal mines, addressed for miners or rescuers.

Researches presented in scientific papers provide guidelines and recommendations to be taken into account during: 1) organization and realization of training with use of high immersive VR training materials, and 2) development of this type of materials. The following examples can be mentioned:

- factors that should be taken into account during preparing and carrying out VR-aided training (including development and/or selection of VR materials) discussed in (Liang et al., 2019; Pedram et al., 2020),
- a methodology for creation of VR materials proposed in (Isleyen, Duzgun, 2019),
- an approach to composing of VR materials for training: 1) a 2-stage building of familiarity with carrying out actions in case of hazard occurrence followed by assessment task proposed in (Tan et al., 2015); 2) 2-stage learning within a VR serious game - practical session preceded by instruction session proposed in (Liang et al., 2019),
- organization of VR training site to enable direct (physical) participation of the trainer during VR training session proposed in (Liang et al., 2019).

Examples of high-immersive VR materials are described in (Isleyen, Duzgun, 2019; Liang et al., 2019; Pedram et al., 2020; Tan et al., 2015).

Below, more details regarding the abovementioned papers are presented.

In (Pedram et al., 2020) a study regarding application of immersive VR for training of mine rescuers is presented along with findings as regards factors that directly or indirectly affect this mode of training. In the research, 284 rescuers participated in a VR-aided training session. In the VR scene, the task of the rescue brigade was to carry out rescue action to find a missing miner, in conditions of fire (galleries and roadways contaminated with toxic gases, visibility highly reduced etc.). Before and a month after the training session, the trainees filled in a test, which revealed that 52% of them improved their competencies, and the rest of participants maintained them on the same level. However, the authors underline being aware of shortcomings of this kind of measurement of effectiveness of VR-training of mine rescuers, but at the same time they raise that the nature of rescue actions makes it difficult to verify the learning effect in the real conditions. Additionally, in the paper a research on factors affecting effectiveness of VR-aided training and its consideration by the trainees is presented. A thorough literature review on this subject is followed by the authors' own study carried out with the participants of the VR training sessions mentioned above. The rescuers' opinions and attitudes before and after the training were identified with use of specially prepared questionnaires. There were a number of conclusions drawn from the whole study (i.e. the literature review and own practical study). Some of them are as follows: 1) a trainee should feel comfortable with use of the VR environment, therefore a proper instruction should be provided, 2) the VR material used has to be easy-to-use, 3) the content of the VR material has to be considered as useful and the activities to be carried out in the VR scene must be considered as consistent with real-life working activities, 4) there must be high realism of the VR scene, 5) follow-up discussion with a trainer after the training session, obtaining feedback (comment on the performance in the VR scene, explanations etc.) is essential for the training effectiveness, and expected by the trainees.

VR-based training material addressed for miners to improve their capability to evacuate when coal and gas outburst takes place is a subject of (Tan et al., 2015). The system has been built with use of Virtools – a platform dedicated for development of interactive 3D materials. The authors describe both the very training material and its development process. In the VR training material, there are 3 modules representing 3 stages of the training: 1) building trainees' familiarity with the process of coal and gas outburst – its occurrence and consequences; 2) building trainees' familiarity with carrying out evacuation (the module is a kind of serious game in which a trainee, helped with additional guidance – e.g. prompt windows, arrows displayed on a road etc., carries out an escape task); 3) verification of trainees' knowledge on evacuation (the module is a kind of serious game in which a trainee carries out evacuation task with no additional guidance). The creation of the VR training material conducted by the developers includes: 1) collecting material to properly visualize – in a VR scene – occurrence of coal and gas outburst, damage it causes to roadway(s) and miners; 2) collecting information to define the best evacuation methods and routes; 3) design of the VR scene; 4) development of scenario; 5) development of input materials: 3D models and animations, and other materials, like e.g. sounds, map to be displayed to the trainee etc.; 6) integration of input materials in Virtools scene, taking into account the scene design and scenario.

A methodology to follow to develop VR-based materials for training regarding hazards in underground operations is presented also in (Isleyen, Duzgun, 2019). Identification of potential hazards and taking proper actions to mitigate them was the competence to be acquired or improved. The focus was on hazards occurrence in a tunnel after blasting. The proposed and practically implemented (during the development of the VR training material) methodology includes: 1) development of 3D models of the underground location; 2) development of scenario of the training to be carried out in VR scene; 3) creation of VR material in a dedicated tool – a game engine (adding real-life appearance to the 3D models, defining interactions etc.); 4) implementation of the VR material in a VR system (a dedicated VR space or room); 5) testing by several experts in the given domain (here: mining), including both fresh and experienced VR users. In the VR training material developed, a trainee's tasks included: inspection of the tunnel and identification of potential hazard (one of 3 options is correct); carrying out activities to mitigate the hazards (a trainee is asked to use rock bolts for supporting the tunnel taking into account additional information provided); verifying whether the work has been carried out in a correct way and taking corrective actions if necessary. In the testing stage experts from the domain, with high and with no VR familiarity, took part. Their feedback has been obtained in a follow-up interview. Although some remarks regarding improvement of the material were given, the possibilities to carry out inspections in virtual representations of underground locations as well as to conduct actions to mitigate potential hazards there and observe effects were found highly useful and giving exceptional training opportunities.

In (Liang et al., 2019) development, content and evaluation of a VR serious game for training regarding rock fall hazards in coal mines is presented. A detailed description of the creation process including integration of engineering knowledge on the loose rock and rock fall is provided. As regards the content, the competences intended to be acquired or improved with the VR material are: 1) scaling of loose rock, 2) abilities to identify loose rock and unstable ground. This is reflected by two modules of the VR serious game – one is addressed for novice scalers, to build their familiarity with the scaling process, and the other one is for all other employees carrying out work underground – to build their abilities to recognize hazards related with rock falls. In each module, two phase learning mode is applied. First, there is an instruction session – to obtain relevant knowledge to carry out the task. Then, a practical session in which trainees carry out the actual task (and obtain feedback in case of errors) takes place. In the authors' concept for the game (that was implemented, next) and learning process, particular attention was put to two aspects: 1) support for a trainee – presence of a 'virtual instructor' and a 'real instructor', 2) adapting of difficulty level to a trainee. The virtual instructor operates as a tutor within the game, who provides a trainee with guidelines and information regarding the task. As regards the 'real instructor', according to the authors' concept, both a trainee and a trainer participate in the a VR training session. The trainee who operates in the VR scene with use of HMD and controllers is accompanied by a trainer who – simultaneously - observes view of the VR scene and the trainee's actions on a screen and can give some instructions. Additionally, in the game an algorithm to adapt the content to a particular trainee based on their performance in the game is integrated – to make the training most effective and avoid situations in which a trainee abandons the training due to too high difficulty. The VR serious game underwent evaluation to compare it with video-based training on the same subject. Two testing groups participated: VR-Group and Video-Group. An instruction on use of VR equipment and VR materials was provided as necessary. Each group – after learning with the training material – conducted two tests with use of the serious game - one immediately after the learning sessions and one a week later (to check the long-term effect of the training). The evaluation revealed that use of VR serious game provided better learning effects – in each test the VR-Group obtained higher scores than the Video-Group, and in case of the VR-Group the decrease in scores obtained in the first and in the second test was lower. However – as interviews with participants of VR-Group revealed - time of the VR-aided training session has to be established taking into account dizziness being the side effect. The authors of the paper recommend 15 minutes.

## 3. Legal background regarding training on hazards - in Polish coal mines

Working in coal mines is accompanied by a number of hazards. To avoid them (if possible) or to cope with them once they take place, all the parties involved have to have proper competencies, and these are acquired through – among others – training (Stańczak, Kaniak, 2021). This regards employees from a coal mine (including miners with qualifications of a mine rescuer) and professional mine rescuers from specialized rescue units.

The main legal act, provisions of which set out the rules regarding employee training in Poland is the Labor Code (Ustawa z dnia 26 czerwca 1974 r. …). In particular:

- article 94 states that an employer has to conduct systematic employees' training in occupational safety and health (OSH),
- articles $237^3$ and $237^4$ state that it is forbidden to allow an employee to perform work for which they do not have sufficient knowledge on occupational safety and health, and it is mandatory that an employee undergoes relevant OSH training.

Detailed provisions regarding OSH training are provided in the regulation on training in occupational safety and health (Rozporządzenie Ministra Gospodarki i Pracy z dnia 27 lipca 2004 r. …). The following issues are included in the regulation: training objectives; rules; scope; framework training programs (for different groups of trainees, like e.g.: management staff, workers in blue-collar jobs, employees in engineering and technical positions) and their implementation. The following learning objectives as regards the trained workers are indicated: 1) acquaintance with hazards and risks at work and with appropriate preventive measures and activities; 2) learning the regulations and principles regarding OSH at the trainee's work; 3) acquiring the ability to perform work in a manner that is safe for oneself and others, to deal with emergency situations, and to provide assistance to a person who has suffered an accident.

For some jobs there are separate regulations regarding required qualifications and training. This applies, in particular, to jobs related with high risk as well as jobs in selected services. Examples of the later ones are:

- water rescue: WOPR - Water Volunteer Rescue Service and MOPR - Masurian Voluntary Rescue Service (water rescuers); the applicable regulations are act on the safety of people staying in water areas (Ustawa z dnia 18 sierpnia 2011 r. …) and the regulation on training in water rescue (Rozporządzenie Ministra Spraw Wewnętrznych z dnia 21 czerwca 2012 r. …),
- mountain rescue: GOPR - Mountain Volunteer Rescue Service and TOPR – Tatra Volunteer Rescue Service (mountain rescuers); the applicable regulation is act on safety in the mountains and rescue in the mountains and on organized ski areas (Ustawa z dnia 18 sierpnia 2011 r. …).

Coal mining is an example of high-risk industry. In case of hazards occurrence in a coal mine, mining rescue stations (CSRG – Central Mining Rescue Station, OSRG – Regional Mining Rescue Station, KSRG – Factory Mining Rescue Station) are units involved in rescue actions, if necessary. A legal act that establishes the legal basis for the mining industry, which includes, among others, general regulations on mining and mine rescue qualifications and general regulations on the organization of mine rescue services is the act establishing the Geological and Mining Law (Ustawa z dnia 9 czerwca 2011 r. …), in particular Articles 53-60 and 122-124. Training of all parties involved in rescue actions in mines (not only these excavating coal) is regulated by provisions of the regulation on mine rescue (Rozporządzenie Ministra Energii z dnia 16 marca 2017 r. …). The further discussion will focus on mine rescuers. Undergoing a specialist training and passing the exam is mandatory to become a mine rescuer. Courses for candidates for mine rescuers include a theoretical and a practical part, and are delivered by the relevant rescue unit. The course curricula include the following topics: the organization of mine rescue services; mine rescue regulations; the organization of rescue operations; natural and technical hazards; respiratory protection equipment; rescue equipment; first aid; and the psychology of behavior of mine rescuers and persons in charge of rescue operations. The practical part includes exercises in use and control of self-rescue equipment (breathing apparatus, escape apparatus etc.) and rescue equipment. Depending on the competencies to acquire, practical training includes activities conducted in conditions similar to those occurring during rescue operations, with a simulated hazard, especially in an exercise chamber. There are also exercises conducted under conditions of full smoke and limited visibility. Mine rescuers are obligated to undergo a dedicated periodic course every five years. The scope of the course is provided in the regulation.

Based on the analysis of regulations, the following can be stated in the context of this paper:

- Topics regarding hazards at workplace are a subject of occupational safety and health training. Related regulation defines scope of this training but does not establish mandatory types of training materials and methods. Therefore, there is possibility to integrate VR in this type of training.
- As regards training of coal miners with mine rescuer qualifications and training of professional rescuers, legal acts establish topics to be covered by theoretical training and by practical training. This does not exclude VR integration for learning of knowledge and skills related with hazards in undergrounds of coal mines. However, it cannot replace or reduce the mandatory practical exercises.

## 4. Concept of VR integration in the training of mine rescuers

The prerequisite assumption while development of the concept of VR integration in the training of mine rescuers is that getting familiar with hazards and acquisition of knowledge on relevant behaviors once the hazards occur contributes to safety – both of the rescuers and the rescued miner(s).

Effective training about hazards possible to occur in a coal mine and proper behaviors to take is a challenge. However, use of ICT makes it easier to achieve. Actual occurrence of a hazard, e.g. a fire, can be presented with use of computer-generated animations. This applies also to presenting of taking proper actions in case of a hazard occurrence. Such materials can be complementary to a practical training, and the later one covers some of the activities and situations that take place when a hazard occurs, e.g. rescuing an injured miner in conditions of full smoke and limited visibility. VR-based materials are a solution that combines computer-generated representation with a practical experience of hazards occurrence and taking related actions. They should be considered and used as supplementary (not 'substitute') to the other training materials and activities carried out so far.

### 4.1. The training procedure

A framework plan of the proposed VR-enhanced training aimed for absorption of proper behaviors in case of hazard is presented in the figure below (Figure 1). In the blocks, the parties or items involved in realization of particular activities are provided in the square brackets.

There are three prerequisite conditions for carrying out the training:

- a trainee already obtained a training that provided them with knowledge on hazards and behaviors once they occur,
- a trainee is willing to undergo this type of training, i.e. VR-aided training (no 'forced participation'),
- there are no contraindications or other reasons for excluding a trainee from this type of training; these can be not known at this stage, but should be clear after exercises in VR, carried out before the actual training.

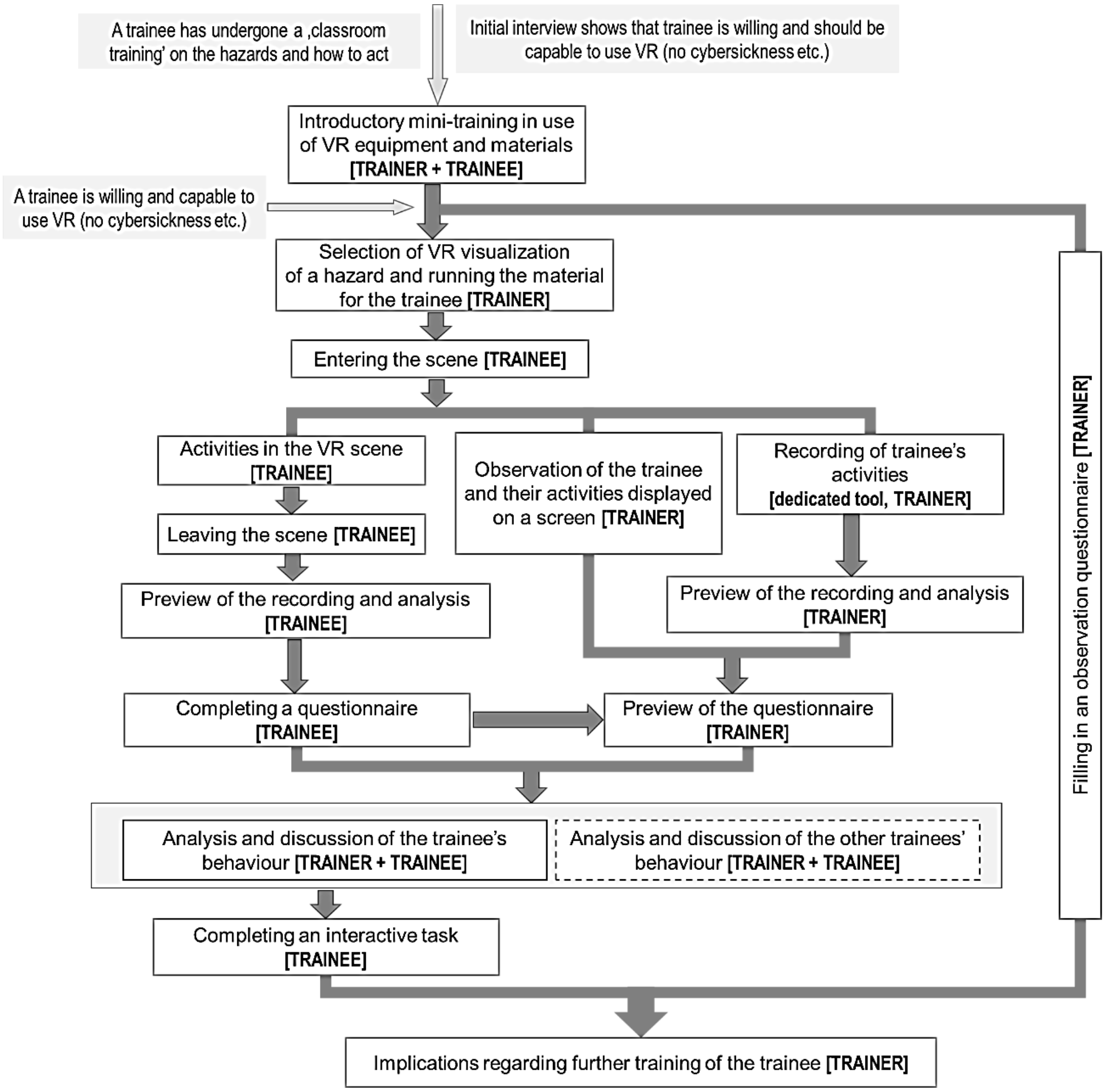


**Figure 1.** VR-enhanced training on behaviors in hazardous situations.

To make VR-based training effective, a trainee has to feel confident in use of the equipment and VR materials. A separate VR material for that purpose should be prepared, and the trainee should be provided with relevant instruction. The VR scene used should include representation of some location in a coal mine undergrounds with typical, ordinary circumstances there (no extraordinary situations, hazards etc.). The exercises should include basic movements and actions (use of controllers). The trainee should be instructed how to operate inside the scene of the VR material they are to enter (e.g. 'you can move around in the location, you can move your head in each direction and…'). The introductory mini-training should be tailored to the trainee's current abilities to use of VR. In case of novice users, the preparatory training should start with basic introductory information and very elementary actions in the VR scene. In case of trainees who already undergone training with this type of materials (e.g. regarding other hazards), this instruction can be relevantly adapted. After this preparatory stage of the VR-enhanced training, it should be clear whether the training can be continued by the trainee.

Once the decision to continue training is made, before running the VR material, the trainee should be also informed about the aim of the training. For the trainee the message conveyed should be that they will have opportunity to experience hazard via immersion in a VR scene where the hazardous situation is simulated, and that the trainee should react as if in real-life. The other reason for this - i.e. observation of the trainee's behavior, its analysis and giving feedback to the trainee - shouldn't be provided to the trainee, not to affect their attitude before and actions after entering the VR scene.

The assumption is that - for the training purposes - there is a repository of VR materials in which occurrence of hazards is simulated. After preparing of a trainee for the VR-aided training, a trainer selects one of the available training materials and the trainee enters the scene and operates there. All the trainee's actions are simultaneously displayed on a dedicated screen and recorded for later use. The trainer – being next to the trainee – observes them as well as the view of their actions displayed on the screen. As regards the observation of the trainee, the aim is twofold:

- to see their behavior and reactions to what is happening in the scene (this is complementary to the view on the screen),
- to stop the training in case of negative impact of the VR material on the user, or accident (e.g. falling over).

After the trainee finishes activities and leaves the VR scene, they are instructed to preview the recording and analyze their behavior (if it was appropriate etc.). This is done by the trainee on their own, and the resulting thoughts are expressed by completing a questionnaire.

Both the recording and the questionnaire are browsed and analyzed by the trainer, who gets view of: i) the trainee's abilities to behave in a correct way when a given type of hazard occurs, and ii) needs to improve these abilities. Then, the trainer starts with the trainee a session, during which they discuss and analyze the trainee's behavior. The objective is to provide the trainee with appropriate explanations and knowledge that should contribute to their proper behavior in the future. Optionally, also recordings from other trainees' VR sessions can be viewed and used for further discussions regarding behaviors during a given type of hazard – to enhance the training effectiveness.

During the whole training, the trainer fills in an observation questionnaire. It should be composed of the following main parts:

- introductory section - identification of a trainee and of a scene used for the VR training session,
- VR session – the main part is a checklist in which possible (both proper and improper) activities are listed. There is also space for additional characteristics; for each VR training material from the repository a separate, adequate checklist is used,
- VR session follow-up – reporting on: 1) the trainee's feedback on their actions in the VR scene expressed in the questionnaire, and 2) discussion with the trainee.

After a week's time, a trainee completes an interactive task to assess their knowledge on behavior when the particular hazard occurs. However, regardless the scores obtained, if the performance of the trainee during the VR-aided training was poor, it is recommended to repeat the training on this particular hazard but with use of other scene, in the future.

### 4.2. Observation in the VR-aided training

In the concept, observation is the method used for gathering information about the trainees' behaviors. Observation is the most elementary method of empirical cognition that is a part of other social research methods, including pedagogical research. Observation is understood, among others, as a purposeful, i.e. directed and intentional and systematic perception of the object, process or phenomenon under study. An object of observation can be e.g.: the conditions in which the observed persons are currently present; the situations in which they participate as active or passive members of them; the reactions (also the psychological ones) of the observed persons to these conditions and situations. In pedagogical research, the following classification criteria and types of observation can be distinguished, among others: the contact of the observer with the observed persons or persons (direct and indirect observation, including participatory observation), the degree of structuring of observation (structured and unstructured observation), the degree of openness of observation (overt – when it is know that observation takes place or covert – when happening of observation is concealed) (Ciesielska et al., 2018; Kumar, 2022; Łobocki, 2000; Sztumski, 2010).

In the VR-aided training, the actions of a trainee in the VR scene - viewed on the screen - are the main object of observation. This observation is carried out two times: 1) during the VR session, 2) after the VR session – via preview of the recording made during the VR session. In the first situation, a direct observation is carried out, and in the second situation – an indirect observation. The observation is overt. The trainer is present in the room where the VR session takes place, and the view from HMD is being displayed on the screen. The observation is also structured. Each VR-based training material has been developed based on a scenario. Additionally the trainer has an observation.

### 4.3. The training materials

Each VR material should be developed taking into account realistic scenarios as regards the hazard (or several hazards) occurrence. But at the same time, the realism and thus affecting on a trainee's senses should be softened because the ultimate goal is not to shock or scare but to make them familiar with particular hazard and thus making them more capable to behave in a correct way when the hazard occurs.

In the figure below (Figure 2), screenshots from VR material regarding fire occurrence are shown. In this scene, first, the trainee is placed in a gallery, where he walks around. After several seconds he hears the sound of sparks and notices them (if he turned towards the sound). Next, smoke appears and starts spreading. Another stage is appearing of open fire and its spreading.

**Figure 2.** Screenshots from VR scene in which fire occurrence take place.

## 5. Conclusions

During occupational safety and health training, there are limited possibilities to encounter hazards - to see and/or experience them, and to react to them by proper decisions, actions, behaviors. This applies in particular to high-risk industries. To some extent, hazards and their effects can be used for training purposes. Exercises of mine rescuers in a training gallery where the task is to evacuate a victim, in dusty conditions and reduced visibility is an example. Application of VR seems to be a good solution to mitigate shortcomings of theoretical and practical training as means to provide employees with knowledge and skills for identification of hazards and taking proper reactions.

VR enables to recreate any work environment and phenomena there, including hazards. However, there are different possibilities as regards learning, depending on the immersion level of VR applied. This mainly regards presence, interactions and taking actions (as in real life workplace etc.) in the VR environment (VR scene). Opportunities offered to learning by fully immersive VR are a subject of growing interest and appreciation, which is followed by growing implementation for training purposes, including OSH training. There is also a growing number of commercial VR solutions (e.g. VR serious games) for training of particular groups of users, information on which is highly disseminated, which contributes to growing awareness on VR as means for training and its popularity This is accompanied by decreasing costs of necessary hardware and software, and growing improvement of software tools to make them appropriate and friendly for ordinary users.

Possibilities and limitations regarding application of VR for training purposes, also as alternative or supplementary to traditional training methods, are a subject of many researches, findings of which are presented in scientific papers. The studies support consideration of VR as technology highly useful and giving exceptional opportunities for training. Recommendations and guidelines on carrying out VR-aided training and development of VR-based training materials are provided as well, in scientific papers. Analysis of legal regulations regarding training of coal mine employees and mine rescuers reveals that there is no formal barrier for VR integration in the training, however – in case of mine rescuers – this cannot replace the mandatory practical exercises.

The concept of VR integration in the training of mine rescuers takes into account possibilities and limitations established by Polish legislation, it is allowed to integrate VR in mandatory training of mine rescues. VR integration in mandatory training of Polish mine rescuers has not been described so far in scientific papers. The paper is addressed to persons managing mining plants as well as to managers of mining rescue stations and managers of mining supervision authorities.

## References


1. Azarby, S., Rice, A. (2022). Understanding the effects of virtual reality system usage on spatial perception: The Potential Impacts of Immersive Virtual Reality on Spatial Design Decisions. *Sustainability, 14(16),* 10326; doi: 10.3390/su141610326.
2. Beck, D., Morgado, L., O'Shea, P.M. (2020). Finding the gaps about uses of immersive learning environments: A survey of surveys. *Journal of Universal Computer Science, 26(8),* 1043-1073; doi: 10.3897/jucs.2020.055.
3. Cai, J.-Y., Wang, R.-F., Wang, C.-Y., Ye, X.-D., Li, X.-Z. (2021). The influence of learners' cognitive style and testing environment supported by virtual reality on English-speaking learning achievement. *Sustainability, 13,* 11751; doi: 10.3390/su132111751.
4. Ciesielska, M., Wolanik Boström, K., Öhlander, M. (2018). Observation methods. In: M. Ciesielska, D. Jemielniak (Eds.), *Qualitative methodologies in organization studies:*

*Volume II: Methods and* possibilities (pp. 33-52). Springer International Publishing; doi: 10.1007/978-3-319-65442-3-2.

5. Isleyen, E., Duzgun, H.S. (2019). Use of virtual reality in underground roof fall hazard assessment and risk mitigation. *International Journal of Mining Science and Technology, 29(4)*, 603-607; doi: 10.1016/j.ijmst.2019.06.003.
6. Kirkpatrick, D.L. (2006). *Evaluating training programs: The four levels*. Berrett-Koehler.
7. Kumar, A. (2022). Observation method. *International Journal of Scientific Research, 13*, 1-14.
8. Liang, Z., Zhou, K., Gao, K. (2019). Development of virtual reality serious game for underground rock-related hazards safety Training. *IEEE Access, 7*, 118639-118649; doi: 10.1109/ACCESS.2019.2934990.
9. Łobocki, M. (2000). *Metody i techniki badań pedagogicznych*. Kraków: Oficyna Wydawnicza Impuls.
10. Mandal, S. (2013). Brief introduction of virtual reality and its challenges. *International Journal of Scientific & Engineering Research, 4(4)*, 304-309.
11. Martirosov, S., Bureš, M., Zítka, T. (2022). Cyber sickness in low-immersive, semi-immersive, and fully immersive virtual reality. *Virtual Reality, 26*, 15-32; doi: 10.1007/s10055-021-00507-4.
12. Ogrizović, D., Perić Hadžić, A., Jardas, M. (2021). Fully immersive virtual reality in logistics modelling and simulation education. *Promet – Traffic&Transportation, 33(6),* 799-806; doi: 10.7307/ptt.v33i6.3941.
13. Omlor, A.J., Schwärzel, L.S., Bewarder, M., Casper, M., Damm, E., Danziger, G., Mahfoud, F., Rentz, K., Sester, U., Bals, R., Lepper, P.M. (2022). Comparison of immersive and non-immersive virtual reality videos as substitute for in-hospital teaching during coronavirus lockdown: A survey with graduate medical students in Germany. *Medical education online, 27(1),* 2101417; doi: 10.1080/10872981.2022.2101417.
14. Pedram, S., Palmisano, S.A., Skarbez, R., Perez, P., Farrelly, M.R. (2020). Investigating the process of mine rescuers' safety training with immersive virtual reality: A structural equation modelling approach. *Computers & Education, 153*, 103891; doi: 10.1016/j.compedu.2020.103891.
15. Pedram, S., Skarbez, R., Palmisano, S., Farrelly, M., Perez, P. (2021). Lessons learned from immersive and desktop VR training of mines rescuers. *Frontiers in Virtual Reality, 2*, 627333; doi: 10.3389/frvir.2021.627333.
16. Rozporządzenie Ministra Energii z dnia 16 marca 2017 r. w sprawie ratownictwa górniczego (2017 z późniejszymi zmianami), tekst jednolity Dz.U. 2022, poz. 1418, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20170001052.
17. Rozporządzenie Ministra Gospodarki i Pracy z dnia 27 lipca 2004 r. w sprawie szkolenia w dziedzinie bezpieczeństwa i higieny pracy (2004 z późniejszymi zmianami), Dz.U. 2004, nr 180, poz. 1860, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20041801860.

18. Rozporządzenie Ministra Spraw Wewnętrznych z dnia 21 czerwca 2012 r. w sprawie szkoleń w ratownictwie wodnym, Dz.U. 2012, poz. 747, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20120000747.
19. Stańczak, L., Kaniak, W. (2021). Occupational health and safety management in hard coal mines in the aspect of dust hazard. *Mining Machines, 39(2)*, 53-62; doi: 10.32056/KOMAG2021.2.6.
20. Sztumski, J. (2010). *Wstęp do metod i technik badań społecznych*. Katowice: Śląsk.
21. Tan, B., Zhang, Z., Qin, X. (2015). Coal and gas outburst accident virtual escape system for miners based on virtools. *The Open Automation and Control Systems Journal, 7*, 379-385; doi: 10.2174/1874444301507010379.
22. Toyoda, R., Russo-Abegão, F., Glassey, J. (2022). VR-based health and safety training in various high-risk engineering industries: A literature review. *International Journal of Educational Technology in Higher Education, 19(1)*; doi: 10.1186/s41239-022-00349-3.
23. Ustawa z dnia 18 sierpnia 2011 r. o bezpieczeństwie osób przebywających na terenach wodnych (2011 z późniejszymi zmianami), tekst jednolity Dz.U. 2023, poz. 714, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20112081240.
24. Ustawa z dnia 18 sierpnia 2011 r. o bezpieczeństwie w górach i ratownictwie w górach i na zorganizowanych terenach narciarskich (2011 z późniejszymi zmianami), tekst jednolity Dz.U. 2023, poz. 1154, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU 20112081241.
25. Ustawa z dnia 26 czerwca 1974 r. Kodeks pracy (1974 z późniejszymi zmianami), tekst jednolity Dz.U. 2023, poz. 1465, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id= WDU19740240141.
26. Ustawa z dnia 9 czerwca 2011 r. – Prawo geologiczne i górnicze (2011 z późniejszymi zmianami), tekst jednolity Dz.U. 2023, poz. 633, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20111630981.
27. Wilkinson, M., Brantley, S., Feng, J. (2021). A mini review of presence and immersion in virtual reality. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 65(1)*, 1099-1103; doi: 10.1177/1071181321651148.
28. Zhou, Y., Ji, S., Xu, T., Wang, Z. (2018). Promoting knowledge construction: A model for using virtual reality interaction to enhance learning. *Procedia computer science, 130*, 239-246; doi: 10.1016/j.procs.2018.04.035.