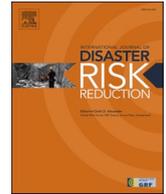




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# Developing serious games for CBRN-e training in mixed reality, virtual reality, and computer-based environments

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## ABSTRACT

In the last decade, chemical, biological, radioactive, nuclear, and explosive (CBRN-e) attacks have become severe risks to countries, prompting connected parties to prioritize CBRN-e training. CBRN-e training is typically performed as physical exercises, and although such training is necessary and beneficial, repeating the same training program can be time-consuming and costly. In this study, newly developed versions of two previous serious games—Hospital and Biogarden—and a new mining serious game were developed for training purposes in Virtual Reality (VR), Mixed Reality (MR), and personal computer (PC) environments. The Hospital and Biogarden games' scenarios were based on the joint activities held in 2018 in France and Belgium as part of the EU H2020 European Network Of CBRN Training Centers (eNOTICE) project, while the mining game was created over a replica of a training mine at a university in Turkey. Sixteen CBRN-e experts from the eNOTICE project, who took part in the physical training programs in France and Belgium, evaluated the games. For evaluation and extensive feedback, presence, system usability scale, technology acceptance model questionnaires, and open-ended questions were conducted. The findings revealed that serious games have a vast potential in CBRN-e training, and the comparisons of different environments provided invaluable testbeds giving hindsight to develop a future training program.

## 1. Introduction

Chemical, biological, radioactive, nuclear, and explosive (CBRN-e) hazards can occur on purpose or by accident; regardless of the cause, they threaten the public's safety while reducing public resources. Thus, emergency management becomes crucial with various emergency scenarios, multiple resources, and training materials. A simple approach to utilizing emergency scenarios to teach emergency management entails giving participants the bare minimum of knowledge about the preparatory circumstances and assigning them one or more roles, tasks, and objectives to achieve. In this most basic form, the scenario refers to a relatively small geographical area, such as a small or medium-sized town, a brief period, a relatively well-defined role, such as emergency coordinator or disaster manager, and a straightforward set of objectives [1].

Although emergency management strategies have gotten more sophisticated and innovative recently, several aspects of emergency

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management still cause inefficient outcomes in a crisis. One of the main problems is not exercising the scenarios thoroughly or adapting them to recent cases. To increase emergency management efficiency and overcome the problems [2], suggests several principles such as making the emergency scenarios living documents instead of a list of instructions, adapting multidisciplinary mechanisms, and increasing the emergency preparedness framework in terms of usability.

Besides the principles mentioned above, adapting the emergency scenarios and emergency management training to the Basel Committee's definition of operational resilience is crucial. By doing so, latent vulnerabilities require enormous care by taking the "unthinkable" into consideration and performing systematic stress-testing. To systematically attack this problem, Pescaroli and Needham-Bennett [3] propose a prototype benchmarking model that aligns complexity with scenario stress testing to improve the operational resilience and preparedness of the vulnerable systems. In another study by Pescaroli and Alexander [4], two massive and overwhelming disruptions of operations scenarios are used to evaluate emergency planning systems and enhance the reaction times to unexpected circumstances. Their findings highlight that such planning decreases the escalation of events (i.e., cascading events) and improves society's resilience.

Emergency management is also crucial for NaTech incidents, where natural disasters such as floods, earthquakes, and lightning cause technological hazards [5]. NaTech incidents can cause damage in chemical and industrial plants, which can cause the release of hazardous materials. To identify these incidents and better understand the dynamics of failure, in a study by Krausmann et al. [5], lessons learned were derived, pipes and storage tanks were identified as the most sensitive equipment to the earthquakes, while flood scenarios and hazardous vapors were also thoroughly analyzed.

The abovementioned emergency management principles and guidelines can also be adapted to the CBRN-e incidents if the common vulnerabilities and hazardous structures can be identified. First responders (FR) are the first to face a threat in a CBRN-e event, and as part of their training, they must cope with unpredictable conditions and occasionally deal with hazardous elements. While CBRN-e is a subject that concerns the safety of civilians in a country, terrorism attacks and wars can also contain CBRN-e related risks. Because of that, governments have focused on training their special forces in this area over the years, and police forces, medical personnel, special security forces, military forces, and scientists are examples of individuals who need to be trained in case of a CBRN-e threat.

Creating a training environment and executing training sessions have enormous economic and time-related costs. Simulating such conditions for training purposes is difficult; nevertheless, virtual reality (VR) and mixed reality (MR) can help by providing unlimited access to various scenarios for repetitive and recurrent training, critical for CBRN-e preparedness. VR immerses users in an immersive environment using computer graphics, body tracking devices, screens, and inputs, while MR integrates holograms to the real world.

VR and MR create presence and allow for learning in a real-world setting and through first-person practices while allowing users to learn by performing the virtual activities several times independently. Besides, in the case of disaster preparedness, VR and MR technologies can reduce time and money and increase the safety of the first responders during training sessions for large groups. These technologies can help staff during training and provide them with the confidence to respond effectively when crises arise. Furthermore, VR training simulations can supplement traditional techniques and concentrate on specific situations with large-scale training scenarios [6].

Several research projects focus on CBRN-e crisis management and adapt to changing needs in the literature. For example, the Austrian Armed Forces developed ABC-IS software [7], and the development, design, and testing methods are explained thoroughly in their study, which demonstrates how software engineering might be helpful in worldwide disasters such as CBRN-e. Individuals trained for CBRN-e events must spot CBRN-e occurrences, understand responder and victim safety, medical and psychological factors, and the essential detection and sample collection procedures [8]. Live agents to teach responders for CBRN-e situations may be part of regular training for CBRN-e cases, which is accomplished by enabling participants to work using hazardous items to add realism and stress to the training. Responders use their equipment to protect themselves when working with hazardous materials and have more confidence in the equipment and the team [9]. Moreover [10], proposes employing a tabletop exercise card concept for CBRN-e training based on numerous scenarios. Their research focuses on developing more generic tools for various crises. Although the developed tool is primarily for healthcare professionals, multidisciplinary participants can also use the tabletop exercise for practice and learning. e-Learning is also employed in CBRN-e emergency training, and it is participant-centered, allowing flexibility in learning in terms of time and location [11].

CBRN-e risks are also valid for high-risk industries such as mining. In general, training in the mining domain focuses on providing practical safety training without risks to trainees and training for high-risk situations. Miners are continually exposed to high-risk hazards, such as geotechnical hazards and toxic gases, which risk their health. In addition to natural hazards, there are hazards related to the equipment used. Such risks can be collisions, entanglement with the equipment, electrical accidents, and underground explosions [12]. Additionally, new mineworkers can lack practical skills related to operational techniques, which may result in accidents [13].

Computer-based, VR, and MR environments can offer training for mineworkers without the limitations of the standard methods, such as lack of time, scenarios, and hands-on practice. They offer the ability to simulate various disaster scenarios without putting the mineworkers at risk and enable immediate reflection on the training progress. VR can be used to provide a safe and controlled environment for training and reduce equipment downtime and the risk of being damaged [14]. In contrast to the usual methods for mining, such as evacuation drills, it could bring the mine product to a stop, which is a disadvantageous training method [15]. Schofield et al. [16] stated that VR simulations could offer opportunities to improve trainee safety, impacting skill degradation and traditional training methods that impose extensive material with limited opportunity for practical implementation for trainees. VR simulations have been implemented in the mining industry for different purposes. Kizil et al. [17] suggest that VR training can reduce injuries and fatalities. Van Wyk and De Villiers [18] indicate that incorporating VR systems with training can be cost-effective, multilingual, customizable for various scenarios, and enable tracking the trainee performance while allowing repetitive training on a scenario

quickly. VR can be used for multiple scenarios such as conveyor belt safety training [19], identifying and recognizing hazards [18], training for drilling in underground mines [20], enhancing decision-making skills concerning failure in mines [21], and generating various scenarios impacting mine safety [22].

VR and MR technologies can also be adapted to simulations and serious games. A serious game has ulterior motives rather than only entertainment [23]. Serious gaming employs game design, game elements, game mechanics, and art to achieve training or education goals by allowing users to study and apply what they have learned. A successful example in the emergency training domain is 3D Wild Land Fire Simulation [24], which allows firefighters to practice on multiple complex scenarios across a network, and is one of the first games for emergency readiness. 3D Wild Land Fire Simulation helps users improve their decision-making abilities under challenging conditions while also allowing users to learn by replicating many events in a controlled and safe environment that is difficult to recreate in real-life situations, such as isolating diseases or disasters [25].

Scenario-based training is also a successful training method [26]. A recent example of scenario-based training is Pangea 2030—a serious game developed by Global Affairs Canada and the Department of National Defense [27]. Pangea 2030 takes place during an infectious disease outbreak and provides crisis management scenarios for teaching purposes. Also, the cooperative aspect of Pangea 2030 allows individuals to practice while facing particular challenges, such as tension among individuals. Pangea 2030 provides global coordination and test suggestions for health professionals and policy-makers while exemplifying the benefits of serious gaming in global crisis management.

In this study, three serious games for CBRN-e training were developed and tested by 16 CBRN-e experts who had participated in the physical training activities of the same exercises in earlier years. During the eNOTICE Middle East Technical University (METU) Joint Activity (JA) 2020, 16 CBRN-e experts tested the Hospital and Biogarden games in Ankara, Turkey, and the Mining game in Eskişehir, Turkey. The games were developed for VR, MR, and PC environments, and their evaluations were performed with System Usability Scale, Technology Acceptance Model, and Presence questionnaires. The results showed that using serious games for CBRN-e training has enormous potential, and a comparative study between different platforms enabled a thorough understanding and analysis.

The following sections will present and discuss the training scenarios of the developed serious games, development criteria, results, and discussion in detail.

## 2. Materials and methods

### 2.1. Joint Activities, our previous study and game development cycle

EU H2020 European Network Of CBRN Training CEnters (eNOTICE) project [28] aims to develop an international network to exchange information, training material, and facilities for CBRN-e preparedness. The consortium hosts “Joint Activities” (JAs), including physical activities, tabletop exercises, simulations, and serious games relevant to the CBRN-e domain. As the authors of this manuscript, we are a part of this project, and we built the serious games developed in the eNOTICE project. In the scope of the project, we conducted surveys [29], constructed a scenario-based game generator [30], and published early VR and PC comparison studies [31]. The scenario-based game generator in our previous work created two basic games (Biogarden and Hospital game) based on the linear scenarios of the eNOTICE Nimes, France JA (2018) and eNOTICE Brussels, Belgium JA (2018), where the user has no control over the plot or ending. Hence, a linear story in a video game is similar to a linear story in any other medium [32].

Based on our earlier studies and user feedback [30,33], this study thoroughly modifies and improves previous game-generator-based games, including non-linear scenarios, animations, new state machines, game mechanics, and user interface. If the player can modify the course of future events and change the plot’s trajectory, the story is non-linear, and branching stories and foldback stories are two of the most common non-linear story forms in video games [32].

Our previous scenario-based game generator developed games that translate linear real-life events into serious games with training goals. Repeated, systematic, and rule-based training, such as CBRN-e training [30], benefit from the scenario-based game generator. In this study, a third-person camera was introduced, as well as additional actions, new environmental settings, updated UI components, non-linear scenario implementation, varied options, animations of actions, characters, and professions, more extended conversations, mechanics, and engaging game aspects to previously developed two games (Biogarden v1.0 and Hospital v1.0). A new VR and MR mining game was also created, and 16 CBRN-e professionals from the eNOTICE project evaluated all three games to provide extensive feedback. While the Biogarden v2.0 and Hospital v2.0 games were based on earlier eNOTICE JAs in France and Belgium, the mining game was replicated based on a training mine at Turkey’s Eskişehir Osmangazi University. In February 2020, the CBRN-e specialists from the eNOTICE project visited Turkey during the eNOTICE METU JA 2020, played the mining game in Eskişehir and interacted with the MR version of the game within the actual training mine.

The development of a serious game begins with defining the requirements of the domain. CBRN-e training is the main topic of this study, so the first step was to answer the question of “*What is the main reason that CBRN-e professionals need a serious game for their training?*” Another question to answer was, “*What are the main phases of CBRN-e training?*”

CBRN-e training sessions are usually based on scenarios that contain specific actions and response phases for the trainees, such as preparation of quarantine zones, decontamination processes, treatment, and evacuation of civilians. These scenarios need to be examined to determine the tasks of each professional, and critical points of the scenario should be given to the development team as an implementable item. The final question to answer before starting the development cycle is, “*Will the final product be a training simulation or a serious game?*”

The main difference between a formal training simulation and a game is the fun factor [34]. Abt [35] invented the phrase serious game to distinguish between the games meant for serious purposes and games intended for fun. The serious game refers to various genres and approaches, including quizzes, interactive stories, sandbox virtual worlds, and simulations. On the other hand, the term

serious game is an oxymoron, a figure of speech that combines two contradictory ideas [36]. Huizinga [37] regards gaming only as a leisure activity in “Homo Ludens”:

“The quintessence of play consists in its voluntariness and openness, the freedom it gives, and having no other objective but to play.”

On the other hand, the play aspect affects learning. Whether pursued or not, playing a game involves emotional and cognitive experiences that influence mental health. Play is commonly considered a natural way to learn [38].

In this study, the developed serious games have fun factors like driving vehicles to create an entertaining experience while training the participants. A balance between fun factors and learning must be provided to create a serious game. The primary purpose of this study was to develop serious games for CBRN-e professionals to train them in the field and take the necessary actions during a crisis. Our game development team included a software engineer responsible for the game logic, implementation, and combining the items from other team members for the project management; a scene designer to create the visuals and level designs of the game and an animator to create the character animations. The games' requirements were based on the eNOTICE JAs, and the presentations of CBRN-e specialists of the eNOTICE project, depicting various places and diverse CBRN-e situations, have also been informative. Certain items were purchased from the Unity Asset Store [39,40]. The teams with multiple software engineers can communicate with description languages such as the Unified Modelling Language (UML) model. In this study, a system description language has not been used; instead, a verbal discussion has been made between team members. Reusability is the key factor of this study. Because of the time and resource-consuming nature of CBRN-e training, serious games are developed in a reusable manner.

Four serious games, including PC and VR versions, were redesigned entirely, developed from scratch, and finalized for eNOTICE participants. Two completely new serious games, including MR and VR versions, were also developed. Participants were from various countries within the eNOTICE project and experts in CBRN-e. A group of CBRN-e professionals (between the ages of 28–56) participated in the eNOTICE METU Joint Activity in Turkey and played the games. To evaluate the success of the games, participants filled the surveys on Presence, System Usability Scale, and Technology Acceptance Model and gave additional feedback. VR and PC versions of the Biogarden and Hospital games and VR and MR versions of the Mining game were compared to see how various platforms, such as VR and MR, can affect players rather than PC platforms. To do so, control, sensory, distraction, and reality items of the presence surveys are used [41]. Users' impact over the environment or engagement with the virtual environment is referred to as control. In terms of presence, more control equals a better user experience. Sensory factors are elements or factors that activate all of the user's senses. All these aspects were analyzed thoroughly for all four games.

## 2.2. Hospital v2.0 game (VR and PC versions)

The Hospital game scenario begins with an airplane arriving from London at a French airport. While more than 250 people wait in the lobby, armed terrorists carry out a terrorist attack. The terrorists are defeated in this scenario, but several civilians are also harmed. While the injured are being transported to the nearest hospital, the attack is classified as CBRN-e due to suspicious packages found in the attack. The entire hospital has been quarantined as a result of this update. The hospital staff checks for adequate water and medical supplies, and the portion up to this point has been depicted in the game with narration, after which the playable section starts.

An ambulance arrives to transport the patients to the hospital after the narration is over. As part of the mini-game phase, players can drive the ambulance. The hospital personnel then completes the necessary preparations (such as handwashing and wearing a mask), doctors and nurses welcome patients, and doctors analyze the patients' condition. The patients in the scenario are in three states: Not Critical, Critical, and Good. If the patient's status is “Good,” she is transported to the waiting area and discharged after completing the relevant controls. If the patient's condition is “Critical,” she is taken to the emergency room, where the doctor performs an emergency procedure. The treatment of these patients is then continued in the same way as the “Not Critical” patients. If the patient's status is “Not Critical,” the patient is sent to the “Decontamination” area, and the decontamination process is performed.

The nurse dresses the patients in new clothes. The nurse dials the secretary's number to see if the hospital has an adequate number of beds. The nurse accompanies the patient to the hospital if there are enough beds; otherwise, the patient will be moved to another hospital. At the hospital, the doctor decides the CBRN-e-related condition the patient has. The patient is sent to RN Ward if she has been exposed to a radioactive substance, Chem Ward if she has been exposed to a chemical substance, and Bio Ward if she has been exposed to a biological substance. The nurse will accompany the patient to the Wards, and if the patient needs to be quarantined, the staff will change the patient's clothes if their condition is contagious.

The doctor and nurse welcome new patients, and the procedure repeats itself until all of the patients have arrived. With its non-linear parts, the hospital scenario was incorporated into the game. Each patient has a different decision pattern due to the player's actions or the randomized patient state. A small camera on the left side of the screen allows players to glimpse the state of the other key characters. This function is triggered when players wait for a process to be completed, such as the decontamination process. The decontamination sequence has also been added to the latest version of the game. Patients who are non-player characters (NPCs) finish their decontamination animation in the decontamination area's shower cabinet. The nurse waits for the process to be finished, and after that, the action of giving clean clothes to the patient starts.

## 2.3. Biogarden v2.0 game (VR and PC versions)

Two alternative events occur in the Biogarden game scenario on the Champions League final day. The first event involves a pizza purchased from the BioPizza restaurant near the stadium poisons a person, and the second involves the discovery of a secret laboratory known as Clandestine Lab. Due to the possibility that both incidences are linked to CBRN-e, two separate teams have been assigned to investigate the incidents. These teams are in charge of the investigation at the same time. This section has been described as a narrative

in the game, and the rest has been developed as a playable section. The Restaurant Investigation Team enters the restaurant where the poisoning occurred and collects the appropriate samples. The player receives food samples from the restaurant by hitting the interaction button E in Fig. 1. Other NPCs, decontamination members in special suits, can also be observed simultaneously. A drone transports samples to the B-Life Lab mobile laboratory for analysis. In the game, the player (PC Only) controls the drone.

The B-Life Lab Team collects drone samples, analyzes them, and transmits the test results to the Restaurant Investigation Team. There are two possible outcomes: The results in case 1 are precise, and BioPizza is a simple poisoning case, while the results in case 2 show that BioPizza is a CBRN-e related biological weapon, and it is immediately forwarded to the center. The player can also play as a B-Life Lab employee. In Fig. 2, the drone mini-game can be seen.

The B-Life Lab is the game's central sequence, and the player can choose between playing as the Restaurant Investigation Team or the Local Investigation Team. The Local Investigation Team version enters to the underground laboratory, collects samples of the compounds they discover, and sends them to B-Life Lab via drone. This section is identical to the part on the B-Life Lab Team. There are two possible outcomes in this case as well. According to the precise results, the laboratory was built up to prepare for a CBRN-e attack. The team is brought to the "Decontamination" area in this case. Teams in charge of decontamination dress appropriately and complete their preparations. The team chooses the appropriate detectors to detect the types of contaminants in the laboratory, trains the Local Investigation Team in the decontamination procedure, and refers them to the appropriate department. The outcomes of the processes are communicated to the center whenever they are completed. When the player discovers the Clandestine Lab's secret section, they can play as a member of the Local Investigation Team. As in our previous work [30], there are broken chemical tubes and smashed glasses in the game scene. The Biogarden game has been updated with new laboratory basements, lockers, microscopes, floors, and faucets.

A larger game world was designed in the Biogarden game than the Hospital game. The crisis management tent is located across the game environment and includes the cafeteria, clandestine labs, and numerous mobile labs. In addition, a stadium where the Champions League final will be played was added to the stage visually. On the graphical user interface (GUI), scenario-based objectives are displayed. The player is prompted to touch an interaction button that appears in the interface when the character enters the task area. The locations of the quests are indicated by colored circles that are distinctive to the chosen character. The character is on an interaction trigger in Fig. 3, and the game is waiting for the player to hit E to continue. Animations, conversations, and quizzes are triggered when players press the interaction button. The Hospital game uses similar game mechanics to determine the total number of patients and available beds.

#### 2.4. Mining game (VR and MR versions)

The VR version of the Mining game (Fig. 4) was developed using the Unity game engine, C# programming language, HTC Vive VR headset, and Steam VR SDK. Unlike the PC version, the teleport mechanism is used to navigate the stage. It is possible to reach pre-determined points on the map using HTC Vive controllers. An exemplary training mine model was used in Eskişehir, Turkey as a stage model. Due to the limitations in VR game development, the user interface (UI) elements in the game are placed on the stage as game objects. The questions are answered by bringing the controllers in line with the correct answer and pressing the trigger button with a mechanism like a point and click.

There are information and question screens in the VR version of the game and directions covering essential information about underground mining and some risk situations that are potentially more frequently experienced. The sections where colliders interact with these screens are marked with a blue circular visual to guide the users within the scenes.

There are information screens to help the users navigate the training mine. The information screens aim to inform the player about specific areas or equipment in underground coal mines. An example is the information screen on the chain conveyor used to transport the coal produced, the mine entrance, the personal protective equipment (PPE), and different support systems required to prevent any collapse that has been represented in the game. Guidelines are used to draw the user's attention to various potentially dangerous



Fig. 1. A screenshot from the Biogarden v2.0 game where the player is part of a restaurant investigation team.



Fig. 2. Biogarden v2.0 game, the player is controlling a drone during a mini-game.



Fig. 3. Biogarden v2.0 game, the player collects samples from the floor.



Fig. 4. A screenshot from the VR version of the mining game, with a replica of the Eskişehir Osmangazi University's training mine.

situations in the game (Fig. 5 and Fig. 6). The user is informed on the screens shown and expected to provide feedback. For example, it is emphasized that the mine worker should use the PPE placed on the table, and the player is expected to notice this situation. Similarly, while the green indicator on the lifeline should show the exit direction, the red color shows the exit direction in the game, and the user is expected to change the direction of these colors. The unsuitable state of the lifeline and its proper state after the user changes is indicated with different colors. Water barriers are placed at certain sections against the risk of dust explosion in coal mines. The water barriers are damaged and dripping, leading the user to detect this situation and follow the necessary steps. As a result, this malfunction is fixed, and the required precautions are taken in the game.

Multiple-choice questions are also asked in the game. For example, in the question of an object with a risk of falling, the question is asked what measure should be taken against this risk. In case of the correct answer, this hazardous object disappears.

The MR implementation of the underground mine was developed using the Microsoft HoloLens. It was aimed to insert digital content in a real-world setting of a training mine with an overlay of digital content in real-time for training purposes. Two different settings were developed on each end of the training mine. The main scenario is based on the player entering the mine and getting instructed to stay at the marked location to wear the MR headset. Players are exposed to various digital elements overlaid in the real world that can be interacted with to display relevant information about the progress in the training. Mining-related safety events are represented in the MR implementation to train users who interact with the digital elements to mitigate risks. Microsoft HoloLens displayed digital content in real-world scenarios while Unity3D and Autodesk Maya were used for content development.

The MR version of the mining game was developed using the Unity game engine, C# programming language, Microsoft HoloLens MR, and HoloToolkit SDK. This version enables physical interaction with the training mine modeled, including various signs and objects. A starting point was pre-determined so that the game was calibrated for participants to see the holograms in the correct positions, and the holograms were placed in the correct coordinates during the development by taking this point as a reference. Developers had to work inside the mine to position the holograms. Using the Holographic Emulation feature of the Unity game engine, the coordinates of the objects and holograms in the game space were determined simultaneously. A gesture system was used to enable users to interact with objects. Specific animations were triggered to display animations and information screens thanks to the colliders added on the objects and the pinch gesture.

In the MR version of the mining game (Fig. 7), a mine car is modeled as an earlier method of material transportation, and when interacted with the material, the flow starts. Compressors provide compressed air for pneumatic equipment used in underground mines and are represented in the game with an interaction related to repairing such equipment. Once the bolt or nut is selected correctly, the compressor is fixed. In the exit location, the main models and their objectives are as follows (Fig. 8): 1) Mannequin: Helmet: Protects against falling objects, 2) Headlamp: Provides illumination, 3) Oxygen self-rescuer: Portable oxygen source, 4) Protective gloves: Protects against vibration, impact, 5) Knee protector: Protective gear against impacts, 6) Safety shoes: Protects against falling objects or compression, and 7) Safety suit: Protective clothing. The arrows indicate the escape direction with the lifeline (Fig. 9). Roof support items are modeled as being damaged, and, once interacted, a message to change the support is displayed, then the new timber support should be replaced with the broken one, and the material flow from the roof is stopped. Another roof support member is modeled as a metal plate, and a message to stop the loose material flow is displayed, leading the user to move the plate to its location, and the material flow from the roof is stopped.

## 2.5. Standard Questionnaire items and the assessment of the developed games

CBRN-e experts who had participated in the JAs in France and Belgium in 2018 played and evaluated the suggested games during the eNOTICE METU JA 2020 in Turkey. The 2018 JAs were used to create the Hospital and Biogarden games, which were completely



Fig. 5. Screenshot from the Mining VR game.

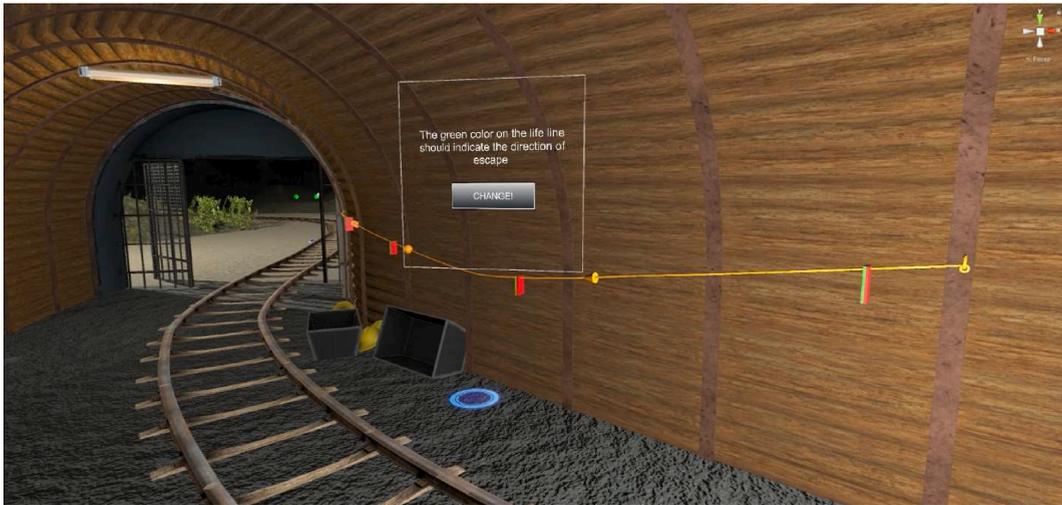


Fig. 6. The screenshot of the lifeline from the Mining VR game.



Fig. 7. Screenshot from the Mining MR game displays the material flow.

redesigned with non-linear settings, new game mechanics, animations, and mini-games. A new mining game for VR and MR settings was also built—a recreation of a university mine in Eskişehir, Turkey. Inside the mine in Eskişehir, Turkey, the participants played the MR versions of the game. The evaluation is based on the gold standard in evaluating similar interactive experiments from the literature: presence, system usability, and technological acceptability surveys. Numerous studies have extended them to fit different technologies, contexts, and users [42].

Presence [41] refers to a person's experience of being in one place while in another. Virtual environments have been re-defined as a person's perception of being in a virtual, computer-generated world while in the real world. Davis [43] developed a new metric called the Technology Acceptability Model (TAM), which is now frequently used to assess user acceptance of technology. TAM was finished by Vanketash and Davis [44], and it focuses on perceived utility and ease of use. The evaluation of usability is another important aspect of virtual environment research. The System Usability Scale (SUS) was created by Brooke [45], a questionnaire approach that has been widely used to evaluate usability on websites, apps, and virtual environments. Control, sensory, distraction, and reality questions are included in presence questionnaires, according to Witmer and Singer [41]. Sensory factors are elements or factors that activate the senses of consumers. The distraction element is another important aspect of surveys. When designing a virtual reality experience, users' ability to focus on the virtual environment and isolation from the physical surroundings are key considerations. Virtual reality

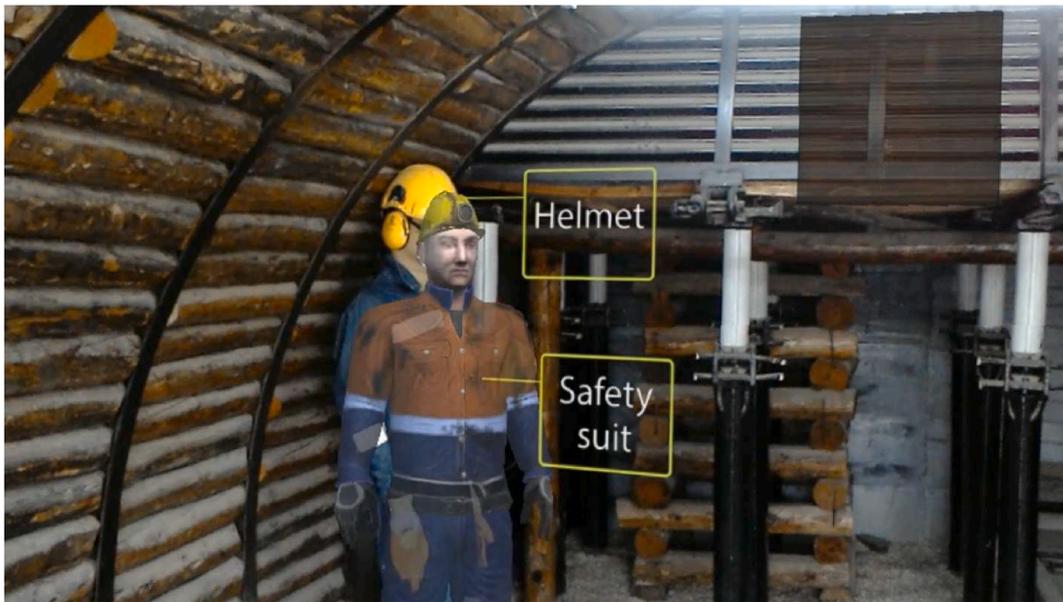


Fig. 8. Screenshot from the Mining MR game, where the information on the mannequin is displayed.



Fig. 9. Screenshot from the Mining MR game, where the arrows indicate the exit direction.

head-mounted displays were created to separate the user from his or her surroundings. Users' lack of focus and distraction induced by other ambient components such as noise and touch are examples of distraction causes. Some questions about distraction are good in the questionnaires, while others are unfavorable. For example, a positive question is "How attentive were you of events occurring in the real world around you?" and a negative question is "How distracting was the control mechanism?" Distraction has three positive and two negative questions. The final part of the presence questionnaires is the realism factor.

Presence questionnaire measures the sense of immersion in the games. There are 28 questions in the questionnaire with a 7-point scale (1–7 from negative to positive). The first 14 questions are about Control, eight questions are about Sensory, five questions are about Distraction, and one is about Realism factors. The second part of the questionnaire system usability scale (SUS) determines game user experience. There are ten questions in the questionnaire with a 5-point scale (1–5 from negative to positive). However, the SUS questions are grouped into positive (odd) and negative (even) questions, based on the content of the standard questionnaire item, e.g., "I thought the system was easy to use" is a positive statement while the "I found the system very cumbersome to use" is a negative one.

The score calculation for SUS can be calculated by the formula below [46,47].

$$\begin{aligned} A &= \text{Sum of the points for all odd numbered questions} - 5 \\ B &= 25 - \text{Sum of the points for all even numbered questions} \\ \text{SUS Score} &= 2.5*(A + B) \end{aligned}$$

The third part of the questionnaire is related to the Technology Acceptance Model (TAM), which contains questions about the games' acceptance in terms of technology [43,44]. TAM questionnaire has 16 questions on a 10-point scale (0–10 from negative to positive). The reliability of a TAM test can be determined by Cronbach's alpha ( $\alpha$ ) value which should be greater than 0.7 as a threshold.

### 3. Results

#### 3.1. Results of biogarden v2.0 game

Primary statistical evaluation results show that in Table 1 and Table 2, VR versions of both Biogarden v2.0 and Hospital v2.0 games have slightly higher scores than the PC versions. Table 1 is about the evaluation of presence in Biogarden game between PC and VR versions. In terms of control, the Biogarden VR version has a mean score of 63.33, while the Biogarden PC version has a mean score of 62.75. Although the scores are very close to each other, it can be said that the VR version provides users with better control in the virtual environment. On the sensory side, Biogarden VR has a mean score of 35.83, and the Biogarden PC version has a 32.25 mean score. Using the opportunity of new user experience provided by the HTC Vive platform, the VR version has slightly higher scores than the PC version. As mentioned above, distraction questions have both positive and negative questions. Biogarden VR got 22.33 while Biogarden PC 21.91, nearly identical with a 0.42 difference. Finally, realism scores are 4.25 on the VR side and 4.16 on the PC side, nearly identical. The reason was that both versions were developed with the same textures, assets, sounds, and gameplay. With a total mean score of 125.50, the Biogarden VR version provided a better experience on presence than the Biogarden PC version, which got a 121.08 score.

To determine whether the difference between the mean values of PC and VR versions are statistically zero considering the responses, independent samples *t*-test was conducted. The null hypothesis (H0) defined in this study is "the difference of the mean values from responses of PC and VR versions of the game is equal" (H0:  $\mu_{PC} - \mu_{VR} = 0$ ). The alternative hypothesis (H1) is two-tailed because it assumes that the difference is not equal to zero (H1:  $\mu_{PC} - \mu_{VR} \neq 0$ ). The results are summarized in Table 2.

The null hypothesis is accepted based on the statistical data in Table 2. The reason for this acceptance is that Sig. (two-tailed) value (0.71) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Biogarden Game in terms of presence.

Table 3 is the basic statistical evaluation of the System Usability Scale answers. The Biogarden VR version has a 66.00 mean SUS score, while the Biogarden PC version has a 65.75 mean SUS score. These values are almost the same, with only a 0.25 difference. Also, similar standard deviation with 14.58 for Biogarden VR and 16.45 for Biogarden PC, a standard error mean of 4.61 for Biogarden VR, and 5.20 for Biogarden PC. Score evaluation results show that (Table 3) PC version of Biogarden Game has slightly lower scores than VR Version. Scores 65–66 mean "OK" in the SUS score scale means that participants found the games pleasing but needed improvement in System Usability. To determine whether the difference between the mean values of PC and VR versions are statistically zero considering the responses, independent samples *t*-test was conducted. The results are summarized in Table 4.

The null hypothesis is accepted based on the statistical data in Table 4. The reason for this acceptance is that Sig. (two-tailed) value (0.45) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Biogarden Game in terms of System Usability.

As for the Technology Acceptance Model questionnaire results,  $\alpha(\text{Biogarden}) = 0.79$ , indicating that tests are reliable. Table 5 is the basic statistical evaluation of the answers. VR version of the Biogarden Game has a slightly higher score than the PC version in TAM. Table 6 summarizes the comparison results.

Table 5 shows that the Biogarden VR game had a 116.66 mean score while the Biogarden PC game had a 109.25 mean, meaning that the VR version got a slightly higher score in terms of technology acceptance.

The null hypothesis is accepted based on the statistical data in Table 6. The reason for this acceptance is that Sig. (two-tailed) value (0.29) is higher than 0.05, meaning that participants did not feel any significant difference between PC and VR versions of the

**Table 1**  
Basic statistical evaluation of the answers about presence in Biogarden Game.

Presence	Group	Mean	Std. Deviation	Std. Error Mean
Control	Biogarden VR	63.33	17.89	5.16
	Biogarden PC	62.75	7.73	2.23
Sensory	Biogarden VR	35.83	12.86	3.71
	Biogarden PC	32.25	7.95	2.29
Distraction	Biogarden VR	22.33	7.77	2.24
	Biogarden PC	21.91	3.65	1.05
Realism	Biogarden VR	4.25	1.65	0.47
	Biogarden PC	4.16	0.93	0.27
Sum of all variables	Biogarden VR	125.50	38.27	11.04
	Biogarden PC	121.08	16.57	4.78

**Table 2**  
Two-sample *t*-test scores Biogarden Game for Presence.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
0.36	0.71	4.41	12.04	-20.55	29.38

**Table 3**  
Score evaluation of SUS in Biogarden Game.

SUS	Group	Mean	Std. Deviation	Std. Error Mean
Score	Biogarden VR	66.00	14.58	4.61
	Biogarden PC	65.75	16.45	5.20

**Table 4**  
Two-sample *t*-test scores of Biogarden Game for SUS.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
0.76	0.45	1.70	2.21	-2.94	6.34

**Table 5**  
Basic statistical evaluation of the answers about TAM in Biogarden Game.

TAM	Group	Mean	Std. Deviation	Std. Error Mean
Sum of all answers	Biogarden VR	116.66	15.29	4.41
	Biogarden PC	109.25	18.66	5.38

**Table 6**  
Two-sample *t*-test scores of Biogarden Game for TAM.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
1.06	0.29	7.41	6.96	-7.02	21.86

Biogarden game regarding technology acceptance.

### 3.2. Results of hospital v2.0 game

**Table 7** shows the results of presence in Hospital PC and Hospital VR games. Hospital VR had a 67.35 mean score in control, while Hospital PC had 61.92. Like the Biogarden game, the VR version of the Hospital game had higher scores on control. Again, the Hospital VR version exceeded the Hospital PC version with a 6.29 difference by 39.35 mean scores for VR and 33.07 mean scores for PC. On the distraction side, Hospital VR got 23.64 while Hospital PC got 21.42. The difference is much higher on the realism scores than the Biogarden game, with Hospital VR 4.42 mean score while Hospital PC 3.92. To sum up, with a 134.28 score, Hospital VR presented a better user experience than Hospital PC, with a 120.21 mean score.

To determine whether the difference between the mean values of PC and VR versions are statistically zero, independent samples *t*-

**Table 7**  
Basic statistical evaluation of the answers about presence in Hospital Game.

Presence	Group	Mean	Std. Deviation	Std. Error Mean
Control	Hospital VR	67.35	8.55	2.28
	Hospital PC	61.92	7.92	2.11
Sensory	Hospital VR	39.35	8.69	2.32
	Hospital PC	33.07	7.61	2.03
Distraction	Hospital VR	23.64	3.75	1.00
	Hospital PC	21.42	3.58	0.95
Realism	Hospital VR	4.42	1.15	0.30
	Hospital PC	3.92	1.07	0.28
Sum of all variables	Hospital VR	134.28	18.64	4.98
	Hospital PC	120.21	16.02	4.28

test was conducted. The null hypothesis ( $H_0$ ) defined in this study is “the difference of the mean values from responses of PC and VR versions of the game is equal” ( $H_0: \mu_{PC} - \mu_{VR} = 0$ ). The alternative hypothesis ( $H_1$ ) is two-tailed because it assumes that the difference is not equal to zero ( $H_1: \mu_{PC} - \mu_{VR} \neq 0$ ). The results are summarized in [Table 8](#).

The null hypothesis is rejected based on the statistical data in [Table 8](#). The reason for this rejection is that Sig. (two-tailed) value (0.04) is lower than 0.05. This means that participants had a significantly different feeling of presence between PC and VR versions of Hospital Game.

[Fig. 10](#) shows the box plot of the presence questionnaire results of all games. The box plot shows that the VR version has higher scores than the PC version. Also, Hospital VR and Biogarden VR scores are similar. Hospital and Biogarden PC versions are slightly lower than the VR versions, and both games are similar to the scores of the PC versions.

[Fig. 11](#) is the individual value plot of presence questionnaire results from Hospital VR, Hospital PC, Biogarden VR, and Biogarden PC versions. As seen in the plot, scores are intensified on a 4–5 scale on both games and versions. However, VR versions have higher scores on the 5–7 scale, but PC versions do not have mean scores higher than 6. For the System Usability Scale results, as seen in [Table 9](#), the Hospital game also had similar scores on both PC and VR versions with 66.78 mean SUS score for Hospital VR, and 66.25 mean SUS score for Hospital PC. Also, similar standard deviation with 16.47 for Hospital VR and 17.77 for Biogarden PC, standard error mean 4.40 for Hospital VR and 4.75 for Biogarden PC.

The null hypothesis is accepted based on the statistical data in [Table 10](#). The reason for this acceptance is that Sig. (two-tailed) value (0.43) is higher than 0.05, meaning that participants did not feel any significant difference between PC and VR versions of Hospital Game in terms of system usability.

[Fig. 12](#) shows the box plot for the results of the system usability scale questionnaires of Hospital and Biogarden games in VR and PC versions. In [Fig. 13](#), individual value plots of SUS questionnaire results can be seen.

The Technology Acceptance Model results for the Biogarden and Hospital games can be seen in [Table 11](#), and the Hospital VR game had a 117.28 mean TAM score while the Hospital PC game had a 110.92 mean TAM score means that the VR version got a slightly higher score in terms of technology acceptance.

The null hypothesis is accepted based on the statistical data in [Table 12](#). The reason for this acceptance is that Sig. (two-tailed) value (0.40) is higher than 0.05, meaning that participants did not feel any significant difference between PC and VR versions of Hospital Game regarding technology acceptance.

In [Fig. 14](#), the box plot of Hospital VR, Hospital PC, Biogarden VR, and Biogarden PC games in terms of technology acceptance questionnaire can be seen. In [Fig. 15](#), the individual value plot of technology acceptance model questionnaire results is represented as individual mean scores. The plot shows that Hospital VR and Hospital PC versions had higher scores than their Biogarden game counterparts with 9–10 scale mean scores (see [Fig. 17](#)) (see [Fig. 16](#)).

### 3.3. Results of the mining game

The answers given to the presence questionnaire are about the sense of immersion in the games. The first 14 questions are about Control, eight questions are about Sensory, five questions are about Distraction, and one is about Realism factors. Primary statistical evaluation results show that ([Table 13](#)) the VR version has slightly higher scores than the MR version of the Mining game.

To determine whether the difference between the mean values of VR and MR versions are statistically zero, independent samples  $t$ -test was conducted. The null hypothesis ( $H_0$ ) defined in this study is “the difference of the mean values from responses of VR and MR versions of the game is equal” ( $H_0: \mu_{VR} - \mu_{MR} = 0$ ). The alternative hypothesis ( $H_1$ ) is two-tailed because it assumes that the difference is not equal to zero ( $H_1: \mu_{VR} - \mu_{MR} \neq 0$ ). The results are summarized in [Table 14](#).

The null hypothesis is accepted based on the statistical data in [Table 13](#). The reason for this acceptance is that Sig. (two-tailed) value (0.57) is higher than 0.05, meaning that participants did not feel any significant difference between VR and MR versions of Mining Game in terms of presence.

Score evaluation results ([Table 15](#)) show that the VR version of Mining Game has a slightly higher score than the MR version of the mining game. Scores 69–77 mean “Good” in the SUS score scale means that participants found the games acceptable but needed improvement in system usability. To determine whether the difference between the mean values of VR and MR versions are statistically zero considering the responses, independent samples  $t$ -test was conducted. The results are summarized in [Table 16](#) (see [Table 18](#)) (see [Table 17](#)).

The null hypothesis is accepted based on the statistical data in [Table 16](#). The reason for this acceptance is that Sig. (two-tailed) value (0.12) is higher than 0.05, meaning that participants did not feel any significant difference between VR and MR versions of Mining Game in terms of system usability. [Fig. 18](#) shows the box plot of SUS questionnaires, and [Fig. 19](#) shows the individual value plot of SUS questionnaires for Mining VR and Mining MR games.

The null hypotheses are accepted in terms of technology acceptance. The reason for this acceptance is that Sig. (two-tailed) value (0.06) is higher than 0.05. [Fig. 20](#) shows the box plot of TAM questionnaires, and [Fig. 21](#) shows the individual value plot of TAM questionnaires for Mining VR and Mining MR games.

## 4. Discussion

This section discusses the results and feedback obtained from the eNOTICE METU Joint Activity 2020 in detail. The questionnaires show that Hospital and Biogarden serious games were found satisfactory in presence, system usability scale, and technology acceptance model for both PC and VR versions, while the VR and MR versions of the Mining game were also found satisfactory on these three aspects.

**Table 8**  
Two-sample t-test scores Hospital Game for Presence.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
2.14	0.04	14.07	6.57	0.56	27.57

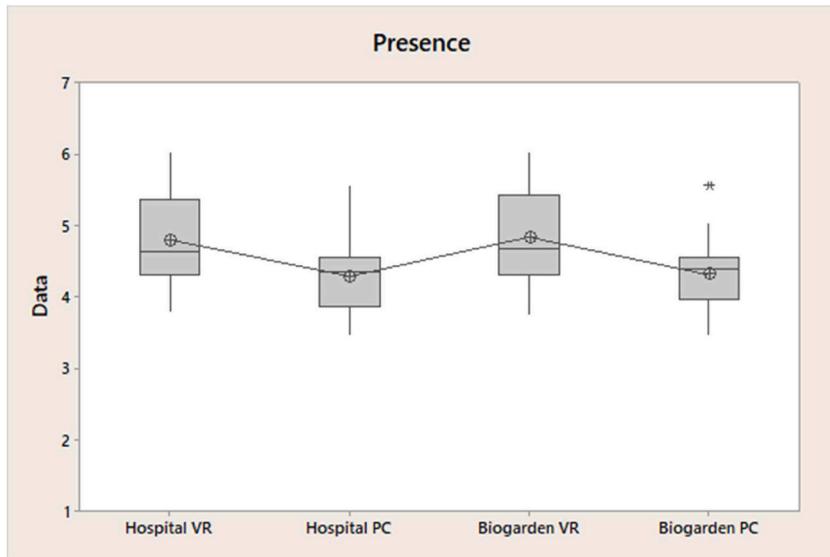


Fig. 10. Box Plot of Presence Questionnaires (Biogarden v2.0 game and Hospital v2.0 game).

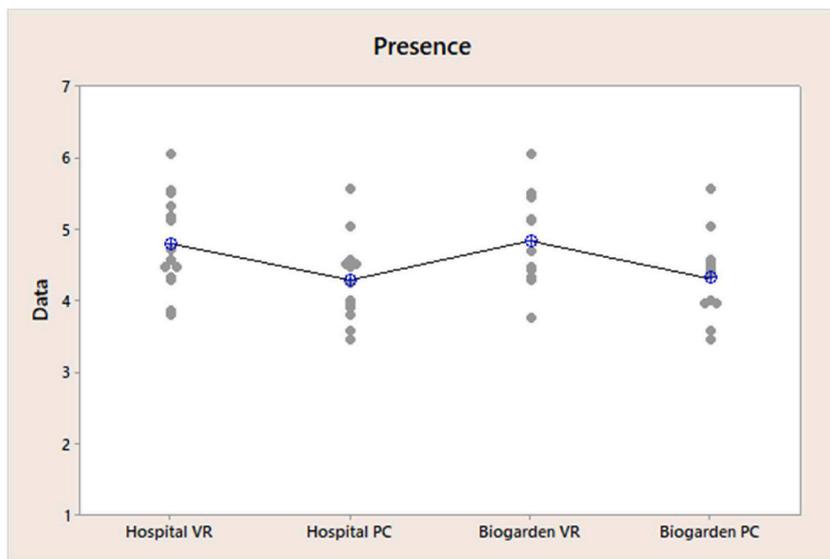


Fig. 11. Individual value plot of Presence Questionnaires (Biogarden v2.0 game and Hospital v2.0 game).

**Table 9**  
Score evaluation of SUS in Hospital Game.

SUS	Group	Mean	Std. Deviation	Std. Error Mean
Score	Hospital VR	66.78	16.47	4.40
	Hospital PC	66.25	17.77	4.75

**Table 10**  
Two-sample t-test scores of Hospital Game for SUS.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
0.78	0.43	1.85	2.36	-3.00	6.71

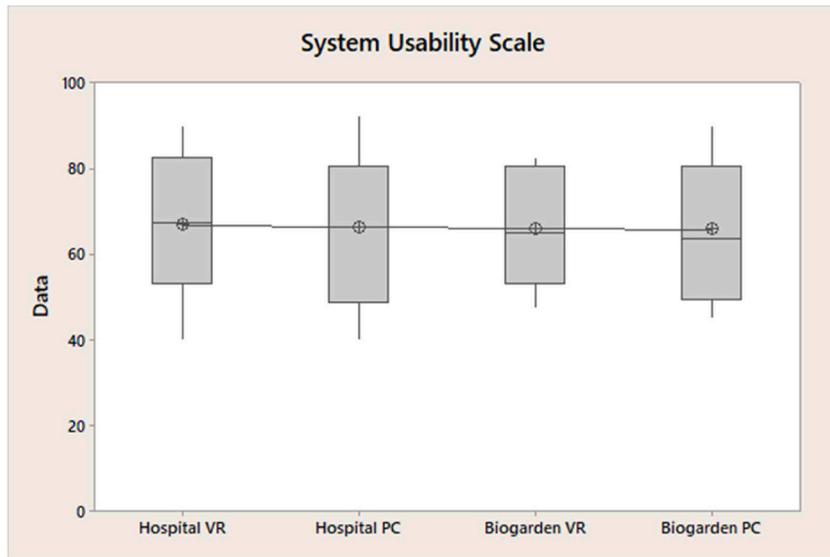


Fig. 12. Box Plot of SUS Questionnaires (Biogarden v2.0 game and Hospital v2.0 game).

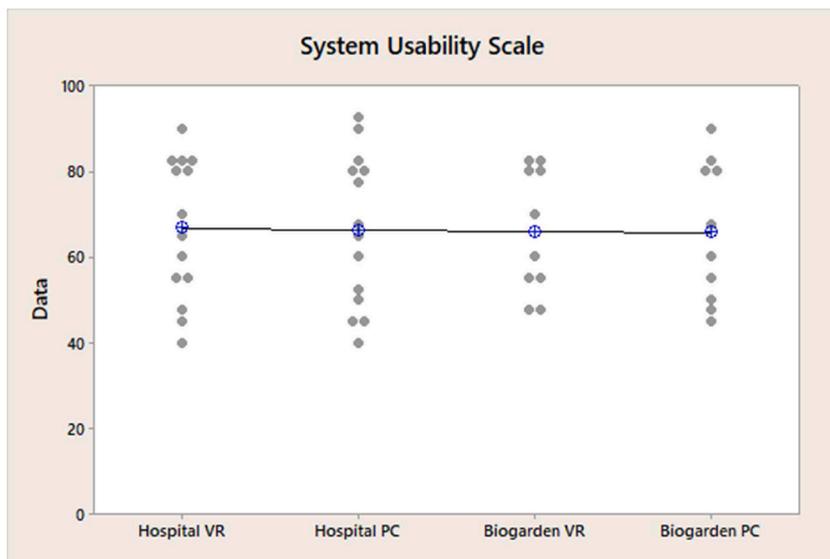


Fig. 13. Individual value plot of SUS Questionnaires (Biogarden v2.0 game and Hospital v2.0 game).

**Table 11**  
Basic statistical evaluation of the answers about TAM in Hospital Game.

TAM	Group	Mean	Std. Deviation	Std. Error Mean
Sum of all answers	Hospital VR	117.28	18.40	4.91
	Hospital PC	110.92	21.43	5.72

**Table 12**  
Two-sample *t*-test scores of Hospital Game for TAM.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
0.84	0.40	6.35	7.55	-9.16	21.87

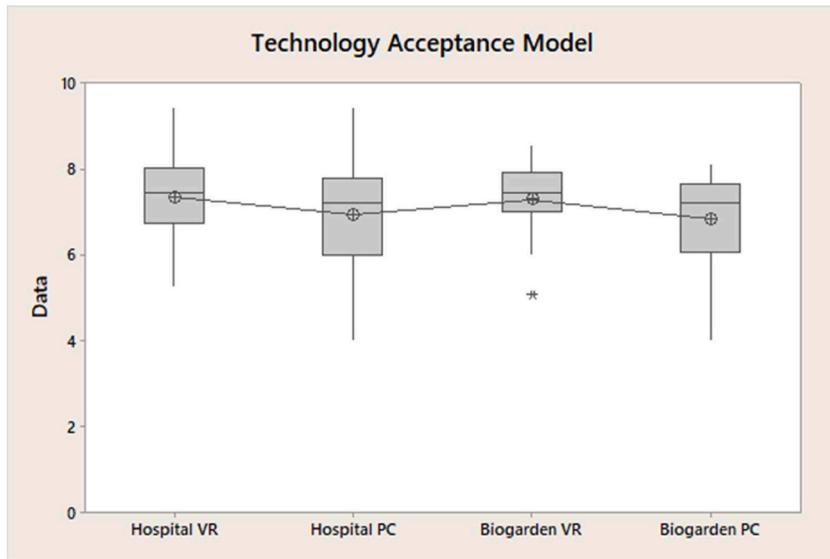


Fig. 14. Box plot of TAM Questionnaires (Biogarden v2.0 game and Hospital v2.0 game).

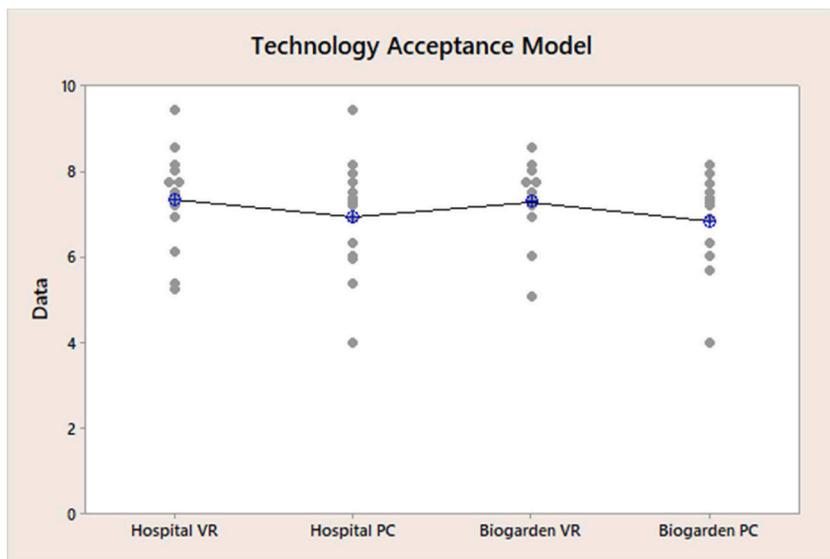


Fig. 15. Individual value plot of TAM Questionnaires (Biogarden v2.0 game and Hospital v2.0 game).

PC and VR versions of the Hospital game’s *t*-test results are different in terms of presence. Results show that the VR version is considered a slightly better experience than the PC version. In terms of presence, *t*-test results on the answers show no difference between PC and VR versions of the Biogarden game. Although VR environments enhance presence, VR can still be considered a premature technology and has flaws such as pixel quality, vertigo, screen-door effect, and poor cable management, especially for pre-2019 VR headsets. Furthermore, the PC versions’ strong points, such as mini-games and GUI elements for navigation, were lacking in the VR versions because of the constraints in the VR game development. Different approaches could be used to overcome these

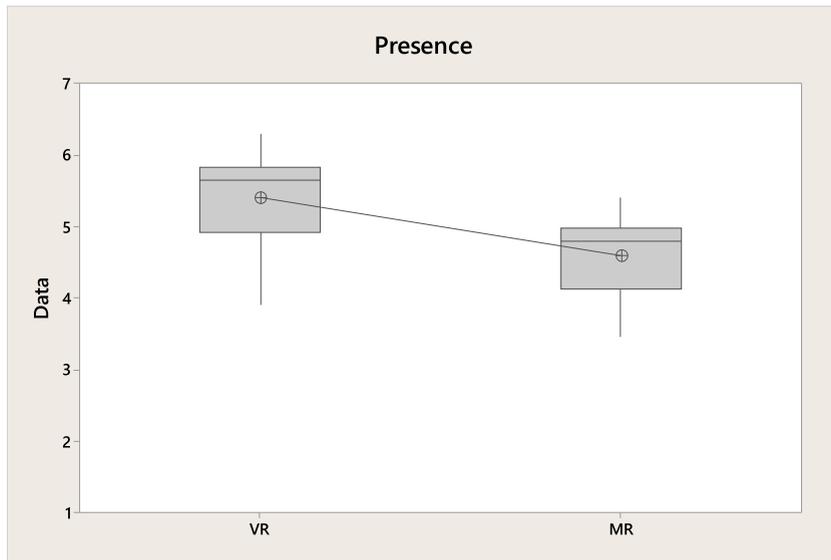


Fig. 16. Box Plot of Presence Questionnaires (Mining VR game and Mining MR game).

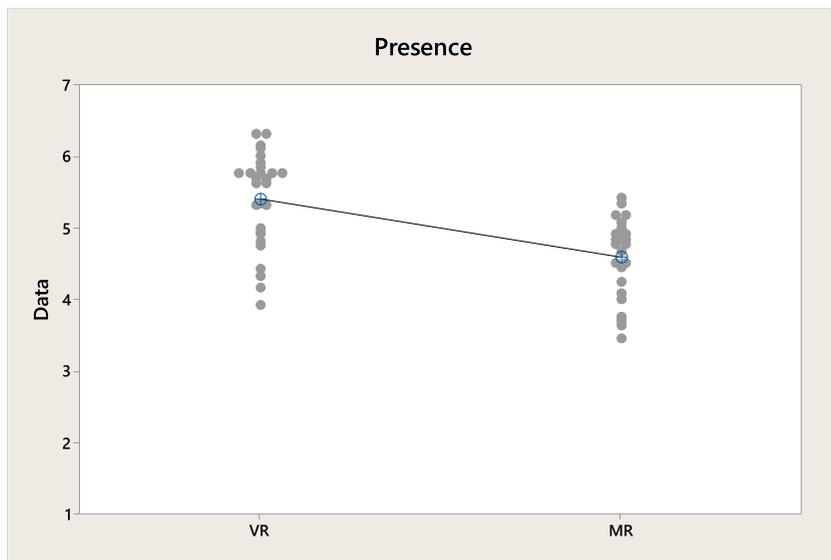


Fig. 17. Individual value plot of Presence Questionnaires (Mining VR game and Mining MR game).

**Table 13**  
Basic statistical evaluation of the answers about presence in Mining Game.

Group Statistics				
Presence	Group	Mean	Std. Deviation	Std. Error Mean
Control	VR	73.92	12.36	3.42
	MR	64.30	12.55	3.48
Sensory	VR	44.00	7.63	2.11
	MR	36.30	7.94	2.20
Distraction	VR	23.53	6.50	1.80
	MR	22.15	5.55	1.53
Realism	VR	5.69	1.03	0.28
	MR	5.00	1.35	0.37
Sum of all variables	VR	145.46	24.05	6.67
	MR	126.46	35.70	6.79

**Table 14**  
Two-sample t-test scores of Mining Game for Presence.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
1.996	0.57	19.00	9.52	-0.64	38.64

**Table 15**  
Score evaluation of SUS in Mining Game.

SUS	Group	Mean	Std. Deviation	Std. Error Mean
Score	VR	77.50	14.58	4.61
	MR	69.82	16.45	5.20

**Table 16**  
Two-sample t-test scores of VR and MR version of Mining Game for SUS.

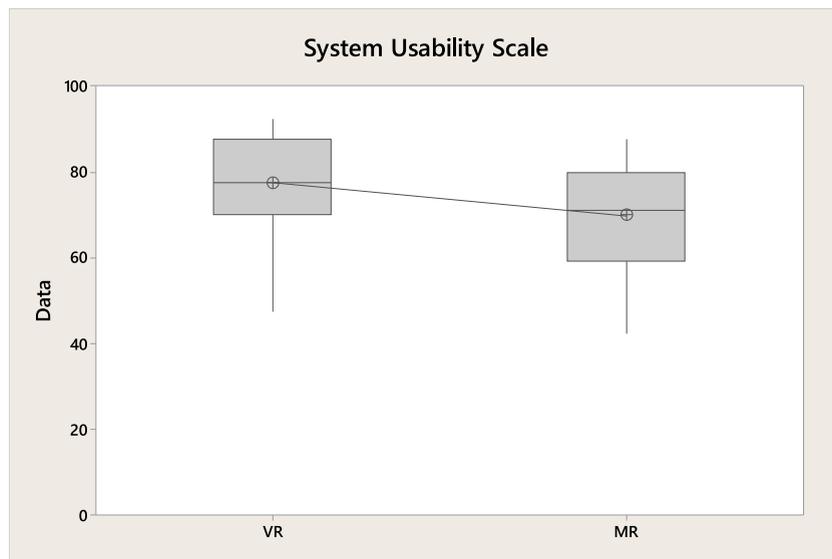
t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
1.60	0.12	1.70	1.99	-0.90	7.29

**Table 17**  
Basic statistical evaluation of the answers about TAM in Mining Game.

TAM	Group	Mean	Std. Deviation	Std. Error Mean
Sum of all answers	VR	127.84	15.01	4.16
	MR	112.61	23.39	6.48

**Table 18**  
Two-sample t-test scores of VR and MR version of Mining Game for TAM.

t	Sig. (two-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
				Lower	Upper
1.976	0.060	15.23	7.70	-0.67	31.14



**Fig. 18.** Box Plot of SUS Questionnaires (Mining VR game and Mining MR game).

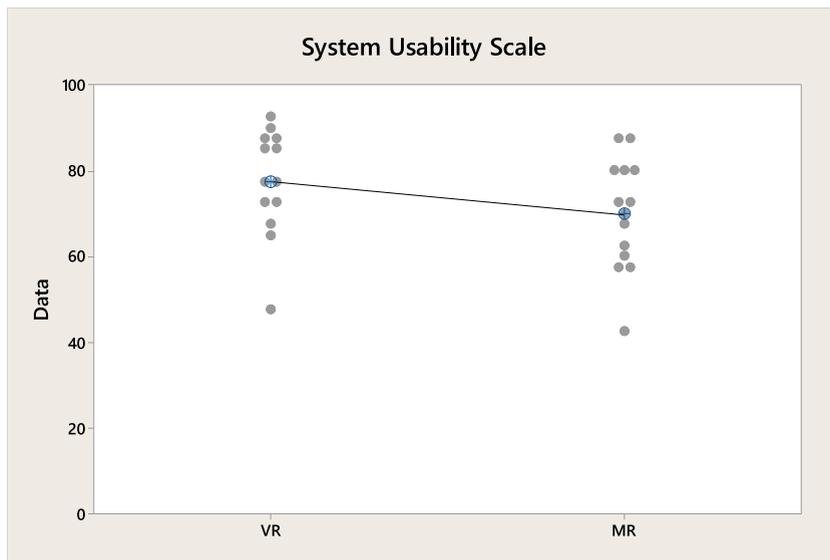


Fig. 19. Individual value plot of SUS Questionnaires (Mining VR game and Mining MR game).

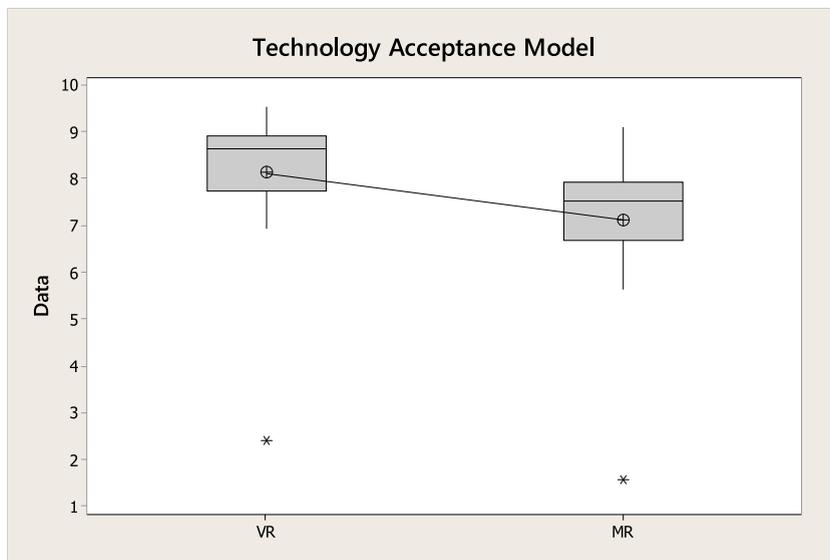


Fig. 20. Box plot of TAM Questionnaires (Mining VR game and Mining MR game).

constraints, but these approaches could make the VR version very different from the PC version, making the comparison of the two versions uncomparable with each other. Even though most participants considered VR a unique experience, the abovementioned disadvantages could be why VR versions do not provide a better experience than the PC version in terms of presence.

SUS scores and *t*-test results show no significant difference between PC and VR versions of the Hospital and Biogarden games regarding system usability. The advantages and disadvantages of both versions are considered equal in terms of the system usability scale. Overall scores are 66, which means acceptable. Technology acceptance model results show that both games' PC and VR versions are equal. To sum up, despite its disadvantages as a new technology, the VR platform is considered a good gaming experience and competes with the PC platform. Apart from the objective of this study, both platforms should be considered separately, and teams should focus on improving the weak points of each when developing a serious game.

Participants (experts in the CBRN-e domain) gave detailed feedback using open-ended questions. Responses to the open-ended questions show that the VR version gave the participants a better experience in terms of presence and felt more realistic. However, according to the survey results, there is a more evident difference between Hospital VR and Hospital PC, while there is no significant difference between Biogarden VR and Biogarden PC versions. In terms of System Usability and Technology Acceptance, it is concluded that there is no difference between PC and VR versions. There could be many reasons for this result. First, the number of participants

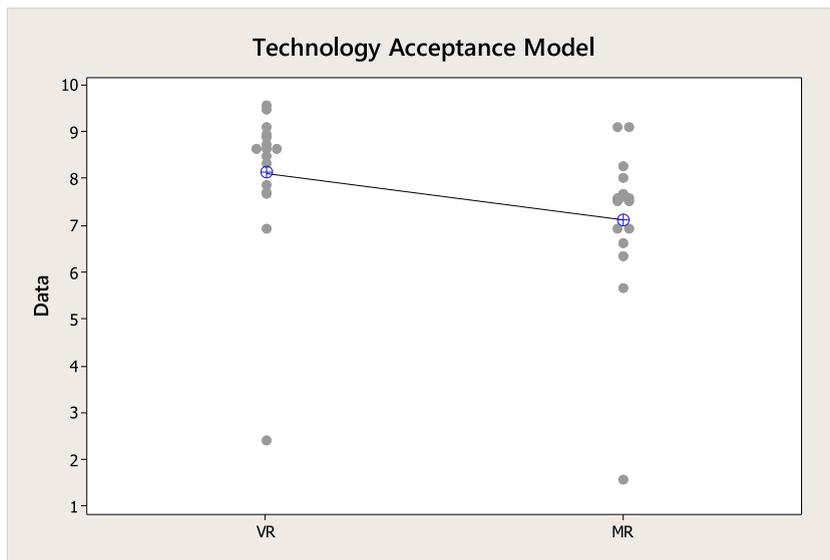


Fig. 21. Individual value plot of TAM Questionnaires (Mining VR game and Mining MR game).

makes it difficult to get a precise survey result. In the eNOTICE METU Joint Activity, only 11 of the 16 participants who answered the questionnaires played all the games. Of the remaining five people, three did not only play the Hospital games and the Biogarden games, while the remaining two were excluded from the comparisons because they only played the Biogarden VR version. Although the VR versions create a different and enjoyable experience, due to some limitations of VR game development, we could not use the features such as duty distance indicator, drone and ambulance use, news bulletin, and entry sequences in PC versions the VR version. This situation limited the experience in VR versions. In VR versions, the “First Person” camera was used to increase reality, but since the character animations are prepared according to the “Third Person” when the animations are triggered, the camera switches to “Third Person,” and we see our character in this way. This situation significantly reduces the sense of realism and presence.

After the presence, system usability, and technology acceptance questions, participants were asked to answer open-ended questions about suggestions and feedback on the Hospital, Biogarden, and Mining games. Participants will be referred with numbers in the following section. The first question was ‘What are your suggestions to improve the Hospital, Biogarden, and Mining games?’. Participant #1 said that games need different actions. This can be achieved with different scenarios, and the possibilities are limitless. Participant #2 thinks that interaction with the objects and menu must be increased. Participant #3 asked to add information about symptoms. To do so, more information from health professionals is needed. According to Participant #4, getting familiar with the environment before performing tasks is essential in a real-life situation. With the introduction of the environment, a tutorial mode can be given to the players before the training starts. Participant #5 mentioned that medical objects and instructions were unclear. As being said, more information from health professionals is needed for the Hospital Game. Participant #6 said that answers were too obvious, and players should not walk through walls and objects. Participant #7 suggested that the procedures, lab procedures, and hospital procedures should be improved. Details for the protocols and procedures can be added. Other participants commented similar to strengths and weaknesses sections. To sum it up, Table 19 shows the project’s strengths and suggestions for improvement. Some of the keywords for the strengths are; immersion (especially for VR versions), new experience (again, most of the participants think the VR as a whole new experience), scenario, virtualization of the scenes, interactions, and using a drone.

Participants gave valuable information, strong points, and suggestions about the project, as shown in Table 19. Some of the keywords for the suggestions are; different actions, procedures, making complex decisions, first-person camera view, difficulty or difficulty adjustment, specific data for scenarios, using a mini-map, and variation of elements in games. In terms of the feedback given

Table 19

The list of the system’s strengths and suggestions for improvement based on the participants’ answers to the open-ended questions.

Strengths of the System	Suggestions for Improvement
<ul style="list-style-type: none"> <li>• Immersion</li> <li>• Scenario</li> <li>• Drone</li> <li>• New Experience</li> <li>• Interactions</li> <li>• Learning Tool</li> <li>• Virtualization</li> </ul>	<ul style="list-style-type: none"> <li>• Improving Procedures</li> <li>• Providing Different Actions</li> <li>• Varying the Difficulty</li> <li>• Providing Specific Data</li> <li>• Enabling First Person View</li> <li>• Providing Complex Decisions</li> <li>• Providing a Mini Map</li> <li>• Increasing the Variation</li> </ul>

to the open-ended questions by the participants, the strengths of the study are being able to play with different characters, using drones and ambulances, stage designs, being updatable and adaptable to other scenarios, with different versions (VR-PC, Biogarden-Hospital; VR-MR, Mining), and multiple-choice options.

Participants provided valuable feedback regarding the comparison of the proposed system with the traditional CBRN-e exercises. They found the proposed system to be practical and flexible in making the users aware of difficult situations, multi attacks, scenarios, difficulties with communication management, and decision-making. They suggested that this training environment could be used for operational debriefings and learning. Accessibility for everyone was mentioned as another valuable aspect of the system, highlighting the importance of providing a real setting with different characters in a low-cost setup. Immersion, realism, and blending real-life with virtuality were listed as the strengths of the proposed system.

Collaboration and interaction are essential aspects of VR-based systems. In our study, collaboration was only possible with a think-aloud setting, while the participants could ask for feedback while their game environment was projected to another screen for the others participants to see. In a recent study by Huang et al. [48], the field system usefulness of two 3D modeling learning approaches was tested. The findings can help educators better grasp learning usability issues and learning effectiveness to apply new design technology tools in practical design learning. A three-person design collaboration approach improves the efficacy of 3D VR modeling learning, conveyed to the proposed study. Given that interaction and collaboration are helpful in training and learning, a multi-user and collaborative setting can help trainees learn more effectively.

In the literature, there have been several studies on VR training in emergency management, such as training for Ebola deployment [49] and emergency management experiences from two case studies [50]. Ebola deployment study analyzed the results in terms of learning aspects while the emergency management experiences discussed the observational and qualitative feedback. Although these studies have not analyzed the provided systems in terms of presence, usability, and technology acceptance, the results of our study and provided feedback support the potential of VR and MR training.

The results of our previous study on providing a game generator, tested with CBRN-e training, are in line with the proposed study. Although the participants' profiles are very different in these studies —students vs. CBRN-e experts— the average scores of system usability and technology acceptance of both studies and their reliability scores are similar. Besides, positive feedback on realism, immersion, and scenarios highlights the substantial aspects of VR training in the CBRN-e domain.

Although there have been several recent studies on the use of VR in training and risk mitigation in mining, these studies have not been assessed in terms of usability and presence, making it difficult to provide a comparison. To the best of the authors' knowledge, this has been the first VR and MR study in mining with a CBRN-e focus, providing usability, presence, and technology acceptance. The provided results of the mining support the results provided with both the previous study and current proposed study on CBRN-e training, depicting the potential of using VR and MR in mining.

## 5. Conclusion

In this study, three CBRN-e training-based serious games are developed on PC and VR platforms (Biogarden v2.0 game and Hospital v2.0 game) and VR and MR platforms (Mining game). Scene designs, animations, sounds, scripts, physics were designed following the pre-defined scenarios of the eNOTICE projects' joint activities, performed in 2018 in Nimes, France, and Brussels, Belgium. The mining game is designed and developed for the eNOTICE METU Joint Activity 2020. The Hospital game is for the CBRN-e crisis training of hospital professionals, as doctors and nurses, while the Biogarden game is for the training of security personnel to collect and analyze the samples to detect CBRN-e related attacks. In the eNOTICE METU Joint Activity 2020, which took place in Turkey, 16 CBRN-e experts from the eNOTICE project, who participated in the physical training in 2018, tested all three games and gave detailed feedback. The results were analyzed regarding the presence, system usability, and technology acceptance. Besides, open-ended questions enabled the participants to propose suggestions for future developments. The results show that using serious games in the CBRN-e training and different platforms such as PC, VR, and MR has enormous potential to provide reusable, low-cost, and repeatable CBRN-e training.

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## Conflicts of interest/Competing interests

The authors declare that they have no conflict of interest.

## Availability of data and material

(data transparency) Not applicable.

## Code availability

(software application or custom code) Not applicable.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### APPENDIX



Fig. A1. Screenshot of the player measuring radioactivity as part of the decontamination activities. .

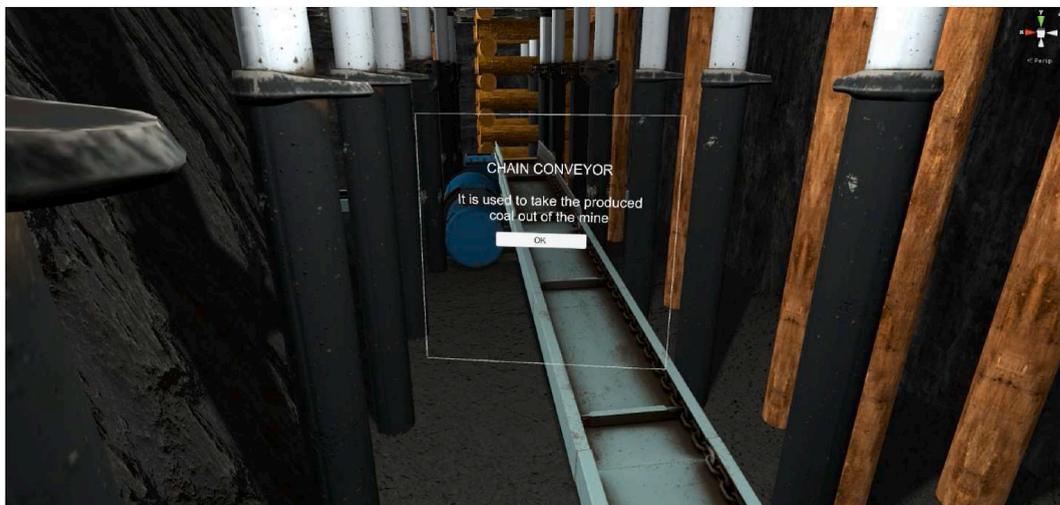


Fig. A2. Screenshot from the Mining VR game, highlighting the information screen on the chain conveyor.



Fig. A3. Screenshot from the Mining VR game, highlighting the information screen on the additional supports of the underground mines.



Fig. A4. Screenshot from the Mining VR game, demonstrating the mannequin and the interior details of the underground mine.

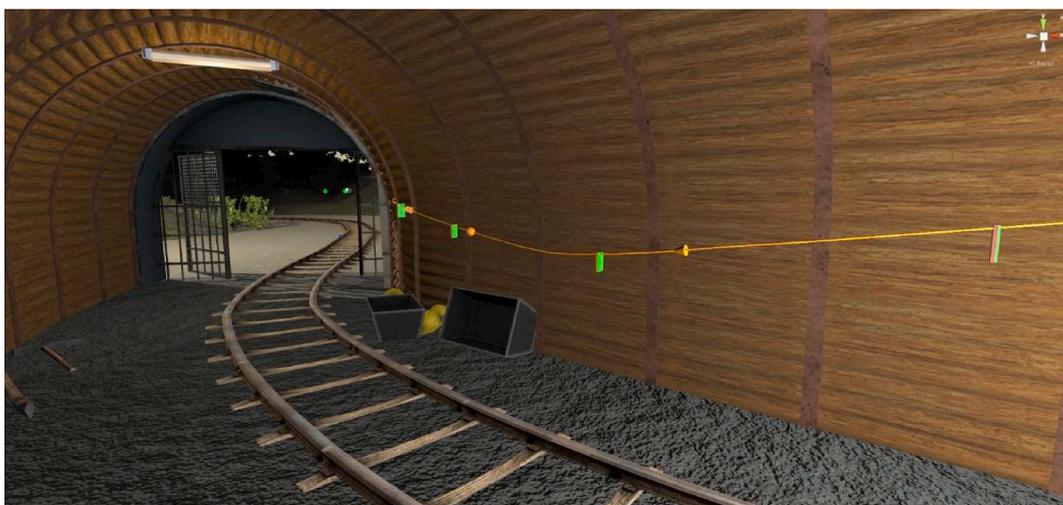


Fig. A5. Screenshot from the Mining VR game, demonstrating the lifeline from the underground mine.

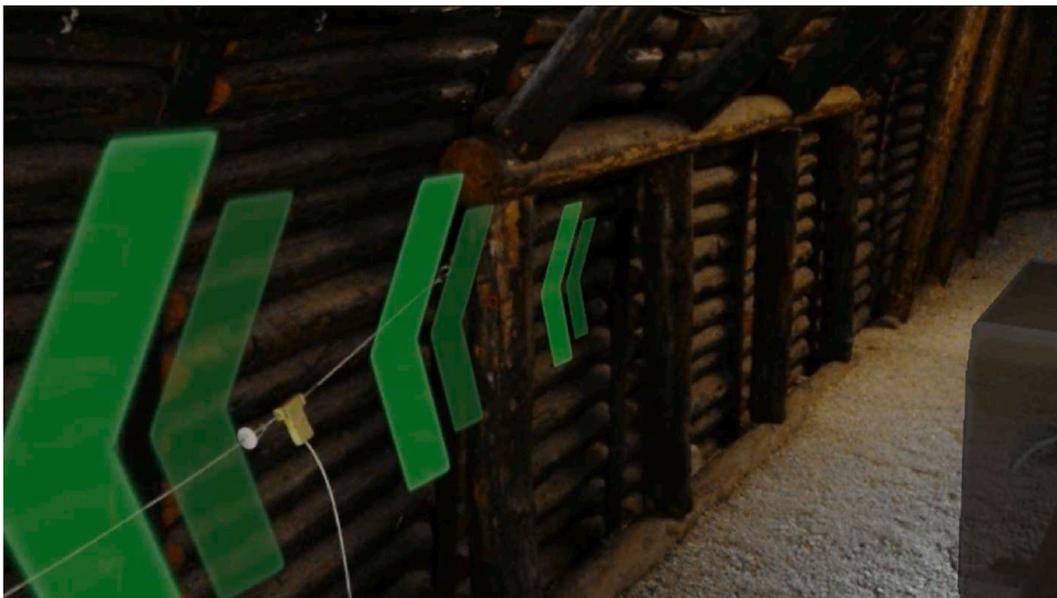


Fig. A6. Screenshot from the Mining MR game where the hologram highlights the Exit direction.

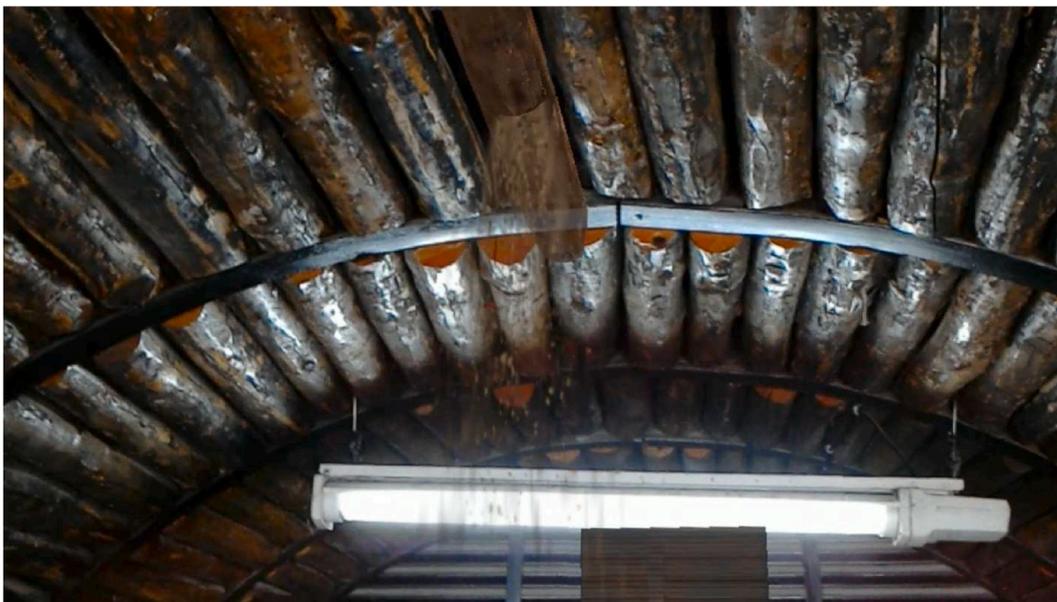


Fig. A22. Screenshot from the Mining MR game, where the material flow is displayed.

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