DEVELOPMENT OF A VIRTUAL REALITY-BASED SERIOUS GAME FOR OCCUPATIONAL HEALTH AND SAFETY TRAINING IN UNDERGROUND MINING

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submitted by **SERVET GÜRER** in partial fulfillment of the requirements for the degree of **Master of Science** in **Mining Engineering, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ______________

Prof. Dr. Naci Emre Altun
Head of the Department, **Mining Engineering** ______________

Assist. Prof. Dr. Mustafa Erkayaoğlu
Supervisor, **Mining Engineering, METU** ______________

Assist. Prof. Dr. Elif Sürer
Co-Supervisor, **Modeling and Simulation, METU** ______________

Examining Committee Members:

Prof. Dr. Nuray Demirel
Mining Engineering, METU ______________

Assist. Prof. Dr. Mustafa Erkayaoğlu
Mining Engineering, METU ______________

Assist. Prof. Dr. Muhammet Mustafa Kahraman
Mining Engineering, Gümüşhane University ______________

Date: 15.02.2021

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Servet Gürer

Signature:

ABSTRACT

DEVELOPMENT OF A VIRTUAL REALITY-BASED SERIOUS GAME FOR OCCUPATIONAL HEALTH AND SAFETY TRAINING IN UNDERGROUND MINING

Gürer, Servet
Master of Science, Mining Engineering
Supervisor : Assist. Prof. Dr. Mustafa Erkayaoğlu
Co-Supervisor: Assist. Prof. Dr. Elif Sürer

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Mining is a hazardous multi-disciplinary sector for workers and the working environment. It can be said that one of the most important methods to combat these risks is training. These pieces of training are usually given with traditional methods, but thanks to today's technological developments, new training methods are also emerging, and simulations and serious games have become widely used tools in training. In this study, MINING-VIRTUAL, which is a very detailed and realistic serious game, is introduced. The game has been developed using the Unity3d game engine to include both computer and virtual reality versions. The game allows users to freely navigate for educational purposes within the underground coal mine simulation. Users' ability to identify existing risks and their knowledge on critical issues are measured with interactive tools in the game. The MINING-VIRTUAL game was tested by a group of 30 participants, consisting of mining engineers and game developers, and the technology acceptance and usability aspects of the game were evaluated with questionnaires. As a result, when the system usability scores and technology acceptance levels in the questionnaires were evaluated, it was seen that both groups were positively affected by the game. With the paired t-test, the effects of using game technologies and the frequency of playing games on technology acceptance were evaluated. The evaluations revealed that the MINING-VIRTUAL game could be an essential training tool in occupational health and safety training related to mining.

Keywords: Virtual Reality, Underground Mining, Serious Gaming, Safety Training

ÖZ

YERALTI MADENCİLİĞİNDE İŞ SAĞLIĞI VE GÜVENLİĞİ EĞİTİMİ İÇİN SANAL GERÇEKLİK TABANLI CİDDİ OYUN GELİŞTİRİLMESİ

Gürer, Servet
Yüksek Lisans, Maden Mühendisliği
Tez Yöneticisi: Dr. Öğretim Üyesi Mustafa Erkayaoğlu
Ortak Tez Yöneticisi: Dr. Öğretim Üyesi Elif Sürer

Şubat 2021, 91 sayfa

Madencilik, işçiler ve çalışma ortamı açısından oldukça riskli çok disiplinli bir sektördür. Bu risklerle mücadele etmek için en önemli yöntemlerden birinin eğitim olduğu söylenebilir. Bu eğitimler genellikle geleneksel yöntemlerle verilmektedir, ancak günümüz teknolojik gelişmeleri sayesinde yeni eğitim yöntemleri de ortaya çıkmaktadır ve simülasyonlar ve ciddi oyunlar eğitimde yaygın olarak kullanılan araçlar haline gelmiştir. Bu çalışmada oldukça detaylı ve gerçekçi bir ciddi oyun olan MINING-VIRTUAL tanıtılmaktadır. Oyun, Unity3d oyun motoru kullanılarak hem bilgisayar hem de sanal gerçeklik versiyonlarını içerecek şekilde geliştirilmiştir. Geliştirilen bu oyun, kullanıcıların yeraltı kömür maden ocağı simülasyonu içerisinde özgürce eğitim amaçlı gezinti yapmalarına imkân vermektedir. Kullanıcıların mevcut riskleri tespit edebilme becerileri ve bazı kritik konulardaki bilgileri, oyun içerisindeki interaktif araçlar ile ölçülmektedir. Maden mühendisleri ve oyun geliştiricilerinden oluşan otuz kişilik bir katılımcı gruba MINING-VIRTUAL oyunu test ettirilmiş, teknoloji kabulü ve kullanılabilirlik yönleri yapılan anketlerle değerlendirilmiştir. Sonuç olarak, yapılan anketlerdeki sistem kullanılabilirlik puanları ve teknoloji kabul seviyeleri değerlendirildiğinde, her iki grubun da oyundan olumlu yönde oldukça etkilendikleri görülmüştür. Yapılan eşleştirilmiş t-test ile, oyun teknolojilerinin kullanılmasının etkileri ve oyun oynama sıklığının teknoloji kabulü üzerindeki etkileri değerlendirilmiştir. Yapılan değerlendirmeler, MINING-VIRTUAL oyununun, madencilikle ilgili iş sağlığı ve güvenliği eğitimlerinde önemli eğitim aracı olabileceğini ortaya çıkarmıştır.

Anahtar Kelimeler: Sanal Gerçeklik, Yeraltı Madenciliği, Ciddi Oyun, İş Sağlığı ve Güvenliği Eğitimleri

To my family

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ABBREVIATIONS	
3D	Three Dimensional
HMD	Head Mounted Display
IT	Information Technologies
MR	Mixed Reality
OSR	Oxygen Self Rescuer
SUS	System Usability Scale
TAM	Technology Acceptance Model
VR	Virtual Reality
VE	Virtual Environment

CHAPTER 1

INTRODUCTION

1.1 Background

Mining activities utilize various equipment and technologies mainly operated by people that originated from different disciplines. The known risks related to most mining unit operations are one of the main reasons the industry is considered dangerous. The unit production processes of mines that involve exploration, drilling and blasting, excavation, transportation, ventilation, and others are considerably complex. Because of this complex and hazardous nature, mining is commonly classified as a high hazard industry. The unfortunate event resulting in injuries and deaths still occur both at surface and underground mining operations worldwide. All people working at mining operations can be continuously exposed to various risks due to their workplaces' working conditions, and serious accidents might occur due to poor occupational health and safety (OHS) measures and practices.

The incident, occurrence, and accident rates in the mining industry are at a considerable level, although the OHS standards are aimed to be continuously improved. This causes society's common perception about mining being a high-risk industry (Mining Sector, 2020). Occupational accidents are frequent due to difficult working conditions and complex production methods in mining. Therefore, one of the essential tools for creating safe working conditions in already difficult conditions is safety training (Wang et al., 2018). The establishment of a safety culture to prevent accidents and training of everyone related to the mining industry has been suggested by different industry stakeholders. Previous experiences showed that one of the highest risks is associated with underground coal mining in the industry, where workers' limited safety training and lack of risk assessment are primary issues.

This thesis study focused on a serious game for underground coal mining, enabling users to experience a virtual mine mainly developed in Autodesk 3DsMax and Unity3D game engine. Unit operations of underground coal mining are modeled to represent potential risks that are part of users' training about hazardous situations. The game has two versions, personal computer (PC) and virtual reality (VR)-based, tested by 30 users that were selected among mining engineering and game developers. The users' responses were assessed by the System Usability Scale (SUS) and Technology Acceptance Model (TAM) questionnaires to improve the game that provides a safe environment to simulate hazardous situations.

1.2 Problem Statement

Practical training is compulsory for the miners in developed countries such as the U.S.A. and Australia, but there is no such obligation in Turkey yet. Training tools that are considered as essential for creating a safety culture for miners are missing in Turkey due to the absence of a legally binding commitment. Today, it is known that VR-based training tools are used to increase the effectiveness of training in many fields, such as aviation, military and others.

In this study; the applicability of VR technology in training for the mining industry, its potential benefits compared to conventional training methods regarding hazard recognition of employees, and improvements that can be achieved with VR-based training compared to traditional training methods were determined as research questions.

1.3 Research Objectives

This study aims to develop an underground coal mine simulation that enables learners to navigate, observe, and identify underground mining-related hazards. It is believed that this underground coal mine simulation can be widely used in the mining industry.

The MINING-VIRTUAL game aims to improve underground mine working conditions by improving hazards recognition and identification, safety training and education, safety instruction, and inspection within the scope of this study.

1.4 Research Methodology

The methodology of this study consists of the following steps:

- Gathering information about health and safety-related Turkish legislations and underground coal mines hazards,
- Determination of the underground coal mine to be modeled,
- Determination of the hazardous situations that will be included in virtual environment,
- Determination of the questions to ask users,
- 3D modeling of the underground mine and adding interactions,
- VR implementation,
- Implementation of evaluation method,
- Analysis of the questionairres results

After determining the underground coal mine and the hazardous situations to be modeled, the virtual environment was developed using the following software.

- 3DSmax
- Unity3d
- Substance Painter, 3DCoat, Adobe Photoshop
- Adobe After Effects
- Audacity
- C#

1.5 Thesis Outline

This thesis study consists of 6 chapters and two appendices. Chapter 1 provides general information about the thesis covering the problem statement, objectives of the study, and methodology of the study. Literature survey of the thesis study is provided in Chapter 2. Chapter 3 explains the methodology followed during the MINING-VIRTUAL game development and gives information about VR technology. Development studies of the game are given in Chapter 4. Chapter 5 includes evaluation, results, and discussion topics, and finally, the conclusion and recommendations are provided in Chapter 6.

Appendix A provides scripts developed for the interactions in the game. In Appendix B, the questionnaire template can be seen.

CHAPTER 2

LITERATURE REVIEW

Training plays an essential role in improving health and safety conditions and increasing productivity in mining workplaces. Still, it is challenging to train workers in real working environments due to mines' difficult conditions (Kizil et al., 2004).

As in other high-risk industries, one of the main problems in underground mining workplaces is how to provide quality and efficient safety-related training to miners. Today, it is known that in many mining workplaces, training is given by classical methods. However, since current traditional training materials are mostly lecture-based and are weak in physical practice, they are losing their relevance. The increasing number of occupational accidents and diseases highlight the need for new and additional innovative approaches to safety training.

The existing training method mainly includes the traditional teaching method, practical method, seminar method, the newly introduced virtual reality training, and augmented reality training.

Practical training is one of the most effective learning methods, especially for adults. However, it has some difficulties in the case of the mining industry. There is no standard training material explicitly prepared for underground mines in Turkey. Besides, providing training in a real underground mine would be very risky for most workers, especially inexperienced ones. Therefore, it should be preferred to provide more efficient training to miners without exposing them to any risk, rather than giving them risky training in real underground conditions. Thanks to VR technology, all kinds of high-risk scenarios can be applied without any risk to miners. In addition to providing safer educational environments, VR technology is less expensive and offers repeatable content.

Providing training to workers under real-life conditions is undoubtedly very efficient, but various software technologies are also used in multiple high-risk sectors in order to reduce the existing risk, increase the efficiency of education and save time spent on training. The VR technology, which has recently been used widely, can be shown as an example of these technologies. VR technology allows users to interact with virtual objects in developed virtual training environments. VR technology can increase the efficiency of the mining industry's training and other areas where it is widely used (Kizil and Joy, 2001).

Virtual environments developed using VR technology are very close to reality and do not contain any risks for workers. VR technology also enables the development of scenarios that cannot be experienced in real life and training the workers in these environments without exposing them to real-life risks. VR technology allows researchers to explore high-risk training scenarios that cannot be re-developed in real life (Nickel et al., 2019).

In addition to not containing real-life risks, VR does not have any harmful effects on machines and equipment in the training environment as in real life. Controlled operator training can be given to newly recruited operators in training provided in a VR environment. Although it does not replace the training given in real life, a training experience close to real-life can be developed thanks to VR technology. Thus, production losses will be prevented and training costs will be significantly reduced. (Kizil et al., 2004).

Due to the unique difficulties of the working environments in mines, it is necessary to take necessary physical measures and make improvements for the human factor. In mining workplaces where serious accidents constantly occur due to difficult conditions, the safety perceptions of workers should also be improved. The most effective way to do this is to give them the training they need. Employees' familiarity with the technical details of their work and the occupational health and safety risks they will encounter are important factors for dealing with occupational accidents. Considering the mines’ high-risk working environments, it can be said that training the workers in real mines can be quite risky. It can be said that the best way to train miners is to train them in natural working environments. However, this has some disadvantages. In an actual underground mine, it is challenging to organize training, it disrupts production, and most importantly, it poses a high risk to miners. On the other hand, underground mine visits are time-consuming and less effective (Fei and Anbi, 2011). Several training mines have been created in Turkey to eliminate this risk, but these mines cannot reflect the working conditions of the real-world mines. As a matter of fact, none of these training mines are widely used today.

Due to frequent serious occupational accidents in the mining industry and insufficient safety training available, VR technology emerges as an important tool for effective training (Squelch, 2001). In some countries, various simulations have been developed and used in training miners. The games developed mainly include navigating the mine, risk identification, and emergency scenarios.

In general, VR training also includes serious games that have additional motivation rather than only entertainment so that the training program becomes more immersive, motivating, and fun. Serious games are widely used in healthcare (Tobler-Ammann et al., 2017), the defense industry (Brandãoet al., 2012), and education (Zhonggen, 2019).

Developing VR technology is used in education in high-risk industries and creates a chance to overcome traditional training methods’ limitations (Kizil and Joy, 2000). Virtual reality simulations make it possible for users to receive training by interacting with virtual objects in virtual environments that are created to be realistic.

VR has been applied in many sectors where safety is a key issue. This includes the aviation industry, the nuclear industry, and the military applications, as can be seen in Figure 2.1.

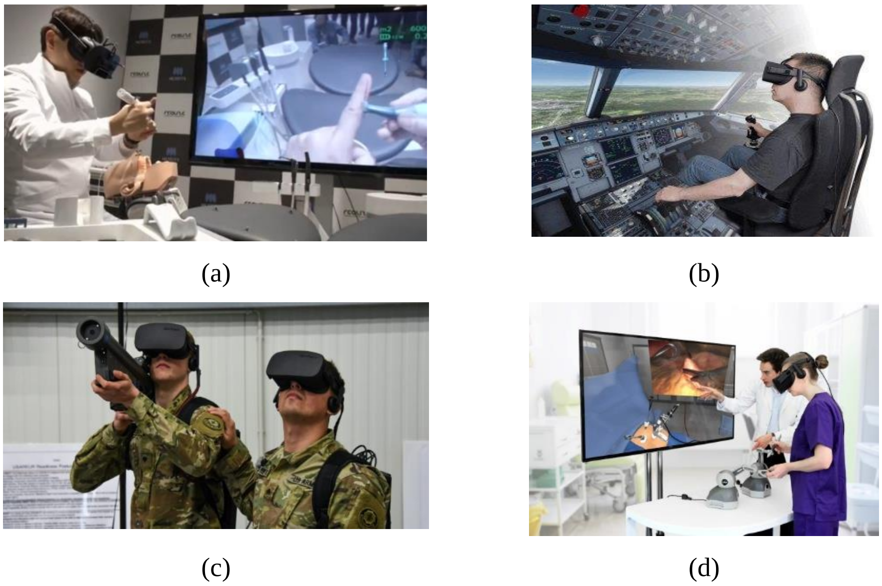


Figure 2.1. VR training examples in various fields. (a) surgery (Bionest, 2020); (b) aviation (Morozova, 2020); (c) military (Helfstein, 2020); (d) medicine (Rashid, 2020).

Even though serious games are widely used in education and training for industrial purposes, there are no serious games addressing the mines in the VR setup. Thus, to overcome this lack in the domain, this study merges the benefits of VR training with the use of serious games.

Various studies have been carried out, and various applications have been developed in the fields of mining and occupational health and safety in the world. A literature survey about these studies is given below.

Fei and Anbi (2011) developed a virtual mine programming tool allowing students to obverse mining procedures and mine accidents, navigate in the mine, and interact with the virtual mine environment. In addition, a module in the training platform allows students to know the positive and negative consequences of their behavior. The developed teaching platform is aimed to enhance the efficiency of mine safety education. Natural objects (terrain, trees, flowers, rivers, lakes, valleys, cliffs, rock, ore, and faults) and important buildings (air compression room, transformer substation, elevating rooms, tunnel, stope, chamber, etc.) within the mining area are created. Mining environment, machines, processes, and mine accidents are simulated, and navigation in the mine is controlled by mouse, keyboard, and data gloves. In the evaluation section, different score counting weights are granted to all risky cases on the platform, and after passing the virtual operation, the certificate of operation was issued. It was also stated that the developed platform would help develop more realistic environments for miners' training in the future (Fei and Anbi, 2011).

A similar safety training framework was developed by Wang, Sun, Wang, & Liu (2018) based on AR and Cloud Computing (CC) platform. This platform has several modules. The modules are designed to contain basic knowledge on mines, equipment cognitive module, intelligent maintenance module, standardized operation module, remote help module, collaborative work module, capability assessment module and several other modules. The framework also functions as user registration and login, role management, safety knowledge production training, practical training, and periodic assessment functions based on augmented reality. It has been stated that with the augmented reality technology, theoretical and practical mining training can be developed, and such activity will be advantageous due to its low environmental requirements. The modules of the framework achieve functions such as behavioral standardization and theoretical knowledge learning. It has been demonstrated that this training tool, which enables practical training, is cheaper, less risky, and contributes to the creation of a safety culture in workers. It is stated that it can be applied not only in mining but also in other areas where it is needed (Wang et al., 2018).

Another remote virtual reality operating system was introduced by Xie et al. (2018) for a mechanized coal mining face, aiming to eliminate specific problems in existing educational tools used. It focuses on the existing issues such as training on a single PC, lack of interactions, insufficient immersion, and degree of reality. An interactive environment was developed by modeling machines on mechanized coal face within the scope of the study. In this environment, operators can work by interacting with control panels similar to real life. In this way, it aims to improve the operators' skills and eliminate the risks existing in underground mines. It has been noted that this training simulation significantly enhances the existing VR technologies offered for mining training. All the experiments conducted within the study's scope have improved the workers' training and have shown that occupational accidents are reduced (Xie et al., 2018).

Onsel et al. (2018) demonstrated that VR/MR techniques could be used to improve all stages of a rock engineering investigation and at a wide variety of scales. It is revealed that VR and MR systems can be used in all phases of rock engineering research, and thus, these researches can be developed. Using a laser scanner, point clouds of the underground and ground scenes to be model were scanned. Then, low poly models were made with two different software because of the difficulties in playing high poly scenes in Hololens. As a result of the study, it is stated that MR/VR has significant future potential in rock engineering in the areas of rock mass characterization, ground monitoring, and geomechanical modeling. Compared to previous methods, Microsoft Hololens has revealed a more realistic and immersive 3D experience (Onsel et al., 2018).

The immersive concepts used in the mining industry were also studied by Tomasz et al. (2010) for prospective applications. Visualization was handled by the Unity3D software and an iPhone-based touchpad device. Data gloves were also used in the study. Interaction was made possible through selection techniques and gesture recognition. The user was located at the focal point of a dome, and a virtual mining environment surrounded her at that point. There were two scenarios developed within the study, namely (3D) mine engineering e-book and teleoperated surface mine. The main goal of the experiment presented in this paper was to employ the apparatus and methods described above to create a realistic and intuitive experience within immersive virtual reality scenarios. The users' interaction with the virtual environment objects reveals an efficient learning system (Tomasz P. et al., 2010).

In another study, the training given over PowerPoint presentations were compared with the security training provided over virtual reality. Comparison of these training methods was made under the titles of risk perception, learning, and risky choices. As a result of the study, the authors found an effect of the training method on the change in risk perception regarding probability judgment and risky decisions but not on learning (Leder et al., 2019).

There are often some obstacles to performing emergency drills at workplaces. Because of these obstacles, emergency drills can often be postponed or even not performed at workplaces. In the exercises that can be done despite these difficulties, only major issues can be addressed, and minor problems can be ignored. Failure to conduct drills can cause workplaces not to be ready for possible emergencies and emergency teams' functionality to become dull. A hazard simulation has been developed using VR technologies. With the emergency scenarios developed in this simulation it is aimed to carry out emergency drills that may be more expensive and dangerous in real life. With this simulation, emergency drills at workplaces can be done thanks to virtual scenarios created in a virtual environment. It was also stated that the training made by this method is more effective, cheaper, safe, and flexible. The basic idea of the method is to bring real-life and very risky emergency drills to the virtual environment. If this happens, one of the most critical obstacles for workplaces to perform emergency drills will be eliminated, and there will be no need to create a practice environment by deploying workers, machinery, and equipment. Laboratory studies were conducted with 60 university students, and as a result of the study, it was observed that this method had significant effects on risk management practice (Kwok et al., 2019).

Another virtual reality training system, the Miner Simulator system (MinerSIM), was created for the training of miners. The simulator is composed of text, three-dimensional images, animations, and videos to introduce trainees to basic principles of ground control and rock bolting using a jackleg drill. It also has a virtual reality simulation. The computer simulation allows users to install rock bolts in a virtual mine environment. Users are also exposed to real-life risks in the simulation. The first part of the simulation is in multimedia format, and the virtual environment is designed on Half Life game codes. With these codes, the underground coal mine virtual environment was developed. The second part is the augmented reality system. In this section, users can check the ground conditions, manipulate various rock bolt process parameters, select suitable rock bolts, drill holes, and install rock bolts. Users can safely do these exercises under the supervision of a trainer. In addition, a real jackleg drill was used in training. Using a real jackleg drill during the simulation increased the sense of reality with the weight, sound, and vibration of the machine (Nutakor, 2008).

VR Mine is developed by the National Institute for Occupational Safety and Health researchers. VR Mine has some effective features like mine generation, simulated networks, proximity detection systems, and the integration and visualization of real-time ventilation models. Applications built from VR Mine can be run in single-player or multi-player and as participants or observers. The mine production module covers the development of mine geometry, design of ventilation systems, infrastructures within the mine, and the addition of machinery and equipment. Various underground mines can be created using simulation. There are room-and-pillar underground coal mine sections that can be added to each other in the simulation and as a result of adding these parts to each other, the underground mine in the desired scale can be created. Then, infrastructures and machines in the program can be placed in the mine created by simulation. Ventilation design, one of the most important topics in terms of occupational health and safety in underground coal mines, was also developed in simulation. In the ventilation simulation developed in real-time, it can be analyzed whether the system installed for ventilation of the mine is sufficient. In addition to the ventilation, smoke, and gas propagation are also simulated (Bellanca et al., 2019).

With another simulation developed, it was aimed to increase the efficiency of education and to transfer the safety culture effectively. The simulation developed has two modes. These modes have been created to be used for different purposes.

One is designed for relatively novice workers, and the other is designed for rock-related risks. The simulation was developed using Unity3D and HTC Vive was used in its implementation. In the game, guiding training is given to the user first and then the user practices himself. As a result of the evaluations made about the training’s effectiveness, it was observed that the training given by simulation was more effective than the training given with classical methods. In addition, with the training provided with simulation, miners can better perceive existing risks, and the information they acquire with this training can be longer-lasting (Liang et al., 2019).

A VR training system evaluation method with the analytic hierarchy process and the fuzzy logic technology was developed by Zhang et al. (2019). Within the scope of the evaluation, firstly, the elements of the VR system were analyzed, and the effects of the system elements were determined. With the determined evaluation method, an already existing VR training system was evaluated, and as a result, it was determined that the main disadvantage of the VR training system is that it is not realistic enough. Other disadvantages are that there is no user information record, and the VR scene is limited. As a result, it was emphasized that this study revealed an effective method for the scientific evaluation of VR training systems. It will also contribute to the development of training systems developed according to the evaluation results (Zhang et al., 2019).

In a drilling training simulation developed, the user has been provided to perform the drilling process using the joystick. The use of head-mounted displays during drilling and the use of the user's own hands is intended to increase the sense of reality in training. In the study, ten users used both the VR education system and the screen-based methods for drilling operation in order to compare the efficiency of the training. The evaluations made showed that the VR training system is easy to use and offers a better user experience. It has been concluded that more emphasis is given to the user, tasks, software, and database among the developed VR training elements (Hui, 2017).

Another study is based on a series of developed training simulations. Mining method teaching simulations, drill rig, rock testing simulations, and ventilation simulation of the University of Queensland Experimental Mine (UQEM) are the main ones.

Mining method teaching simulations cover block caving, open pit mining, strip mining, longwall mining, sublevel stoping, and cut and fill mining methods, and development, production, and ventilation issues are covered in detail within each method. This study aimed to overcome the difficulties of imagining environments such as underground mines with 2D pictures. A VR mining model from virtual mining methods simulation is shown in Figure 2.2.

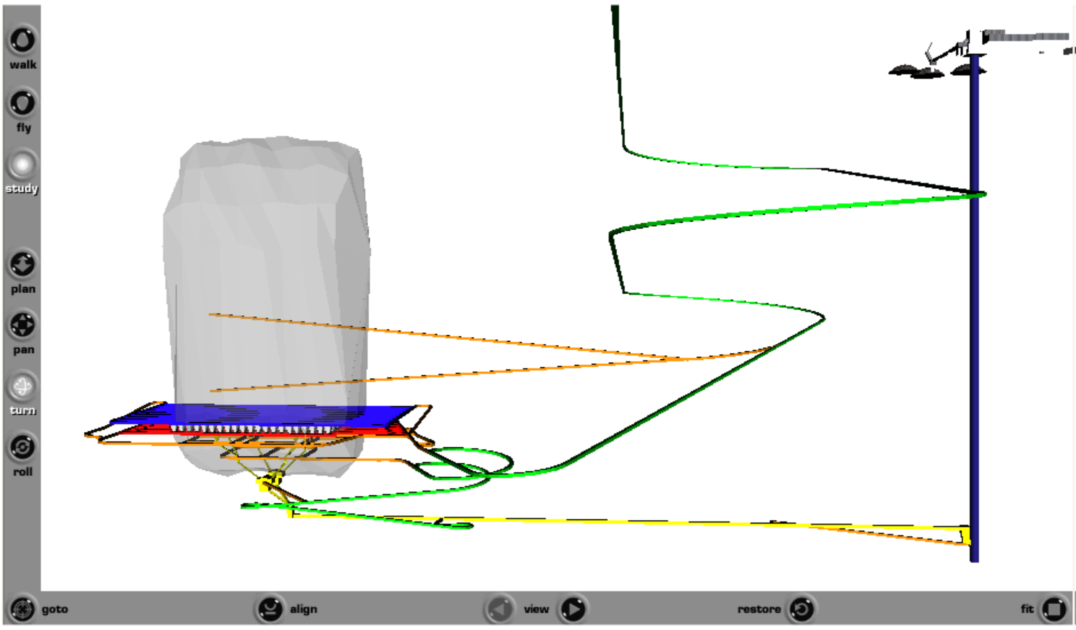


Figure 2.2. An interactive 3-dimensional VR mine model (Kizil et al., 2004).

UQEM 3D ventilation simulation aims to train students on data visualization and mine ventilation. In the ventilation simulation, users can change the parameters related to the ventilation elements, interact with the ventilation doors or regulators, and instantly see the results of their changes and their effects on the mine ventilation system. The program also allows the user to navigate the mine.

Figure 2.3. View of underground mine from simulation and use of vane anemometer (Kizil et al., 2004).

The developed program can evaluate the effect of the changes made in the ventilation system on the mine air and show the amount, and the velocity of air in each gallery in the mine as a result of the values entered into the system.

CRC Mining Drill Rig Training Simulation has been developed with a drill rig modeled to be quite similar to a real drilling machine. Within the simulation, there is a functional control system to operate the drill rig. Realistic sound effects have been added to make the environment realistic. The simulation consists of two basic modules. The first of these is equipment inspection, and the other is operator training.

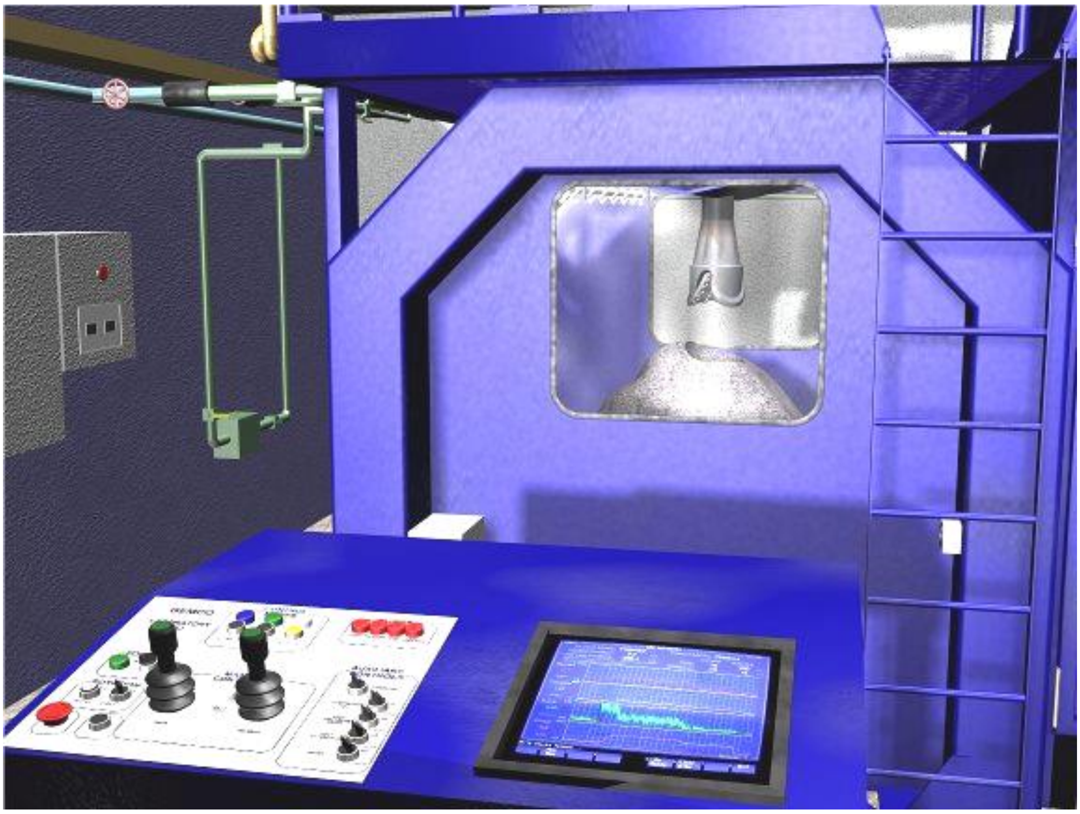


Figure 2.4. Drill rig training simulation (Kizil et al., 2004).

At the University of Queensland, Instron UCS Testing Simulation has been developed that allows UCS testing using an Instron rock testing machine. The aim of this simulation is to enable many experiments to be carried out in more comfortable environments. The simulation allows students to individually operate the machine and thus perform various tests (Kizil et al., 2004).

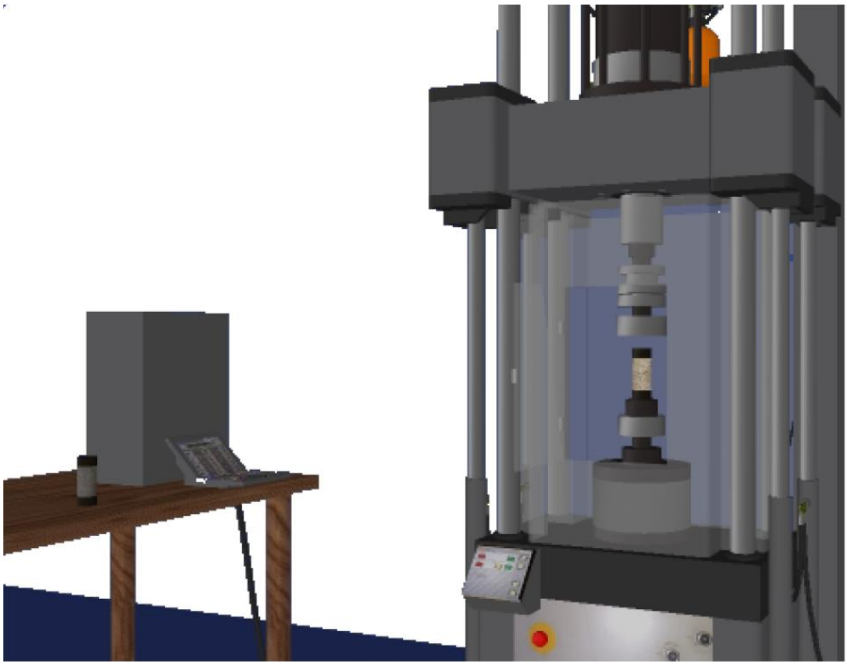


Figure 2.5. InstronVR (Kizil et al., 2004).

A simulation introduced by Isleyen and Duzgun (2019) was developed to evaluate roof fall hazards in underground mines and to take necessary precautions for these hazards. The simulation includes scenarios created for decision-making tasks. Within these scenarios, the user can work on creating a safer working environment. Users are first asked to identify hazardous situations that occur in a post-blast tunnel. If they are successful in the hazard identification stage, they are then asked to make the necessary support systems. Users are asked first to determine the rock bolt patterns and then install the necessary rock bolts. Finally, users are asked to evaluate the hazard levels before and after the rock bolts they make by observing displacements around the opening. After using the simulation, interviews were done with the participants. Their opinions and suggestions were received. As a result, it was determined that simulations could be effective training tools for tunnel studies (Isleyen and Duzgun, 2019).

Simulations were also utilized by Grabowski and Jankowski (2015) to evaluate the experience of 21 users. Two different motion capture systems were used in 2 different simulations, and all participants used both two simulations. These motion capture systems are Razer Hydra and vision-based systems. At the same time, Head-Mounted Displays with two different viewing angles (45 degrees and 110 degrees) were also compared. As a result of the evaluation, users found this application useful, and as a result of the comparison, high immersive VR along with the large field of view was rated as the best solution for education (Grabowski and Jankowski, 2015).

The terrain, development and transportation system, orebody occurrence condition, and underground mining process were modeled by Zhou and Guo (2010) in a virtual reality simulation. A simulation consisting of 5 different modules has been developed. The modules are the display modes module, special effect module, roaming module, mining process simulation module, and stereoscopic display module. There are two kinds of roaming way in the virtual reality simulation: Manual roaming and automatic roaming. By the roaming module, the user can freely navigate within the simulation. The user can also interact with the virtual environment and objects using the mouse in the simulation. In the simulation, users can freely navigate and experience the sense of reality. In addition, user interaction with the machine, equipment, and objects in the simulation is possible. As a result of the study's evaluation, it was seen that the method was reasonable and feasible (Zhou and Guo, 2010).

A study was conducted at Virginia Tech to evaluate VR training practice's efficiency for workers working on conveyor belts in the surface mining industry. The simulation includes instructional modules and task-based modules. The instructional module provides users with information about conveyor belts, conveyor belt components, and hazardous situations. The user's problem-solving and hazard elimination capabilities are measured with the task-based module. Two different evaluation methods were applied for each module. The first evaluation method was made informally through 2-3 safety officers by asking users' feedback.

The other evaluation was that one group received standard safety training and another group received training with the instructional method mentioned in this study. After the instructional module was completed, the task-based module was applied, and the performance of the users was measured. As a result, it has been stated that those who receive VR-based education are more successful than those who receive training with standard methods, and the VR education method provides more effective learning (Lucas et al., 2007).

In a study, an occupational accident in an open pit mine was reconstructed using virtual reality technology. The effectiveness of accident reconstruction as a training method was discussed by Schafrik, Karmis, and Agioutantis (2004). A high training impact occupational accident was selected and reconstructed in VR format. While selecting the accident, care has been taken to ensure that it is an accident that has occurred as a result of unsafe work practice, is difficult to reconstruct in real life, and can be prevented by procedure changes. A VR training accident recreation has been prepared for truck drivers, as the majority of occupational accidents in open pit mines are haulage related. The training simulation’s main purpose is to ensure the use of seat belts and proper pre-shift controls. The main purpose of the study and recreation of a fatal accident is to promote safe equipment use at all times, even in emergencies, and also to encourage rigorous pre-shift checks (Schafrik et al., 2004).

Kızıl and Joy (2001) emphasized that accident reconstruction using simulations is an effective tool in increasing employees’ safety performance. With accident reconstruction, workers can understand how and why accidents occur, how they can be prevented, and how deaths and injuries can be avoided. Virtual reality technology offers the best tools for accident reconstruction. The users experience a real-life experience with practical training and hazard identification training in developed virtual environments (Kizil and Joy, 2001).

A simulation called MERITS, used for emergencies in the mining field, has been developed. The simulation allows the skills of the personnel in leadership positions to be tested. People working in the mining field can practice in emergency scenarios created similar to real life. Training can be given in groups or individually. With the use of simulation, people can see the results of their mistakes without being exposed to the fatal real-life consequences of their errors. Possible emergency scenarios have been created in underground and surface mines within MERITS. The user's decisions shape the results of the scenarios created in the simulation. The simulation's main purposes to improve the skills of command center personnel during emergency situations and increase their decision-making potential (Brnich et al., 2002).

MERITS users are exposed to negative situations such as lack of information or lack of communication during the simulation, and they are expected to make correct and fast decisions in these situations. As a result of the tests conducted with mine workers after the use of simulation, it has been concluded that MERITS is a beneficial experience for those who need to manage emergencies in mines. The commands to be given to the miners in the MERITS in emergency situations are shown in Figure 2.6.

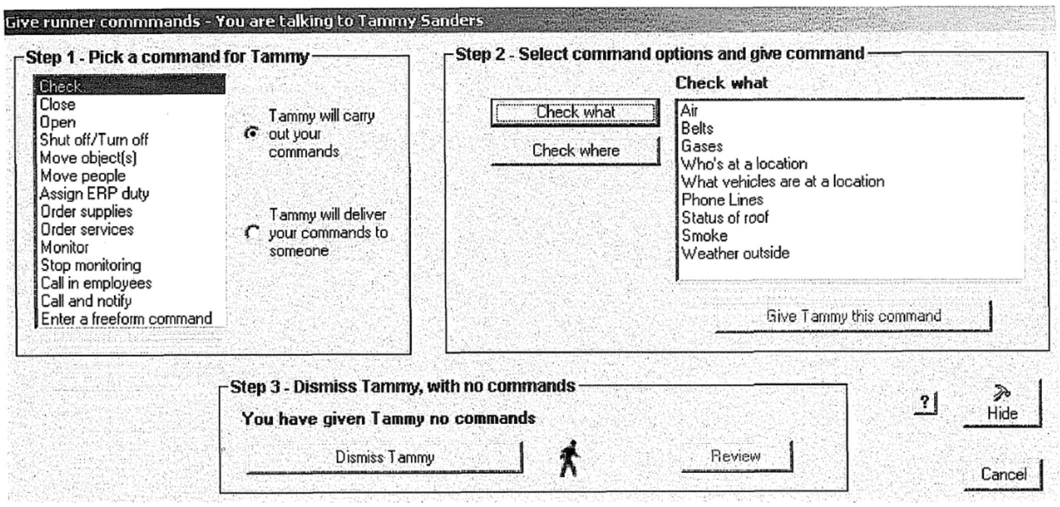


Figure 2.6. Screen for issuing a command to a runner (Brnich et al., 2002).

FERDENO is an avatar-based simulation. It has been developed in order to increase the efficiency of the training provided in the mining field. It was developed by Health and Safety innovator NORCAT in conjunction with Ontario Mine Rescue. In an area surrounded by high-resolution monitors, users have inspected scenarios such as fire, first aid, and more developed for emergencies in mines. It was developed to be used by mining industry professionals to improve their skills for emergency situations (Peters et al., 2010). The scenario for taking the injured miner out of the mine in the FERDENO simulation is given in Figure 2.7.

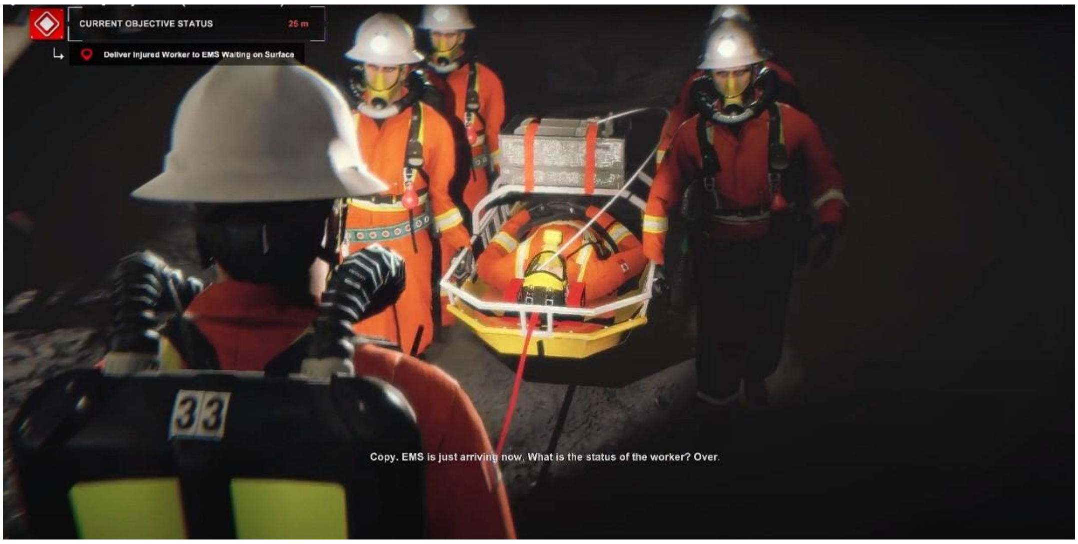


Figure 2.7. Image from FERDENO game (Norcat, 2016).

Another simulation used in the mining industry and developed within the scope of technological developments is the MineSafe platform. It has four basic modules. These are an interaction framework, a story-telling framework, a game state manager, and a creation toolkit. Two serious games Interactive Fatalgram Simulator and San Xavier Challenge, have also been designed for specific purposes for the purpose of occupational safety training in mines (Brown, 2015). Mine Safety and Health Administration (MSHA) creates fatalgrams related to serious accidents in the mining area in the USA (MSHA, 2019). The main purpose is to investigate the causes of accidents in detail and to prevent similar accidents from happening again. It is aimed to guide the way of preventing similar accidents by analyzing the occurrence of the accidents, the factors causing the accident, the impact area of the accident, the results of the accident, and adding photographs of the accident site. For these purposes, fatal accidents that occur can be reconstructed in 3D virtual environments, and users can have an idea about the way the accident occurs from different angles. Fatalgram reconstructions related to a haulage accident in an open pit mine, a haulage accident in an underground mine, and a fall of material from the roof in an underground metal mine accident are shown in Figure 2.8. The figures on the left represent the real images of the accidents, the ones on the right represent the images in the simulation.

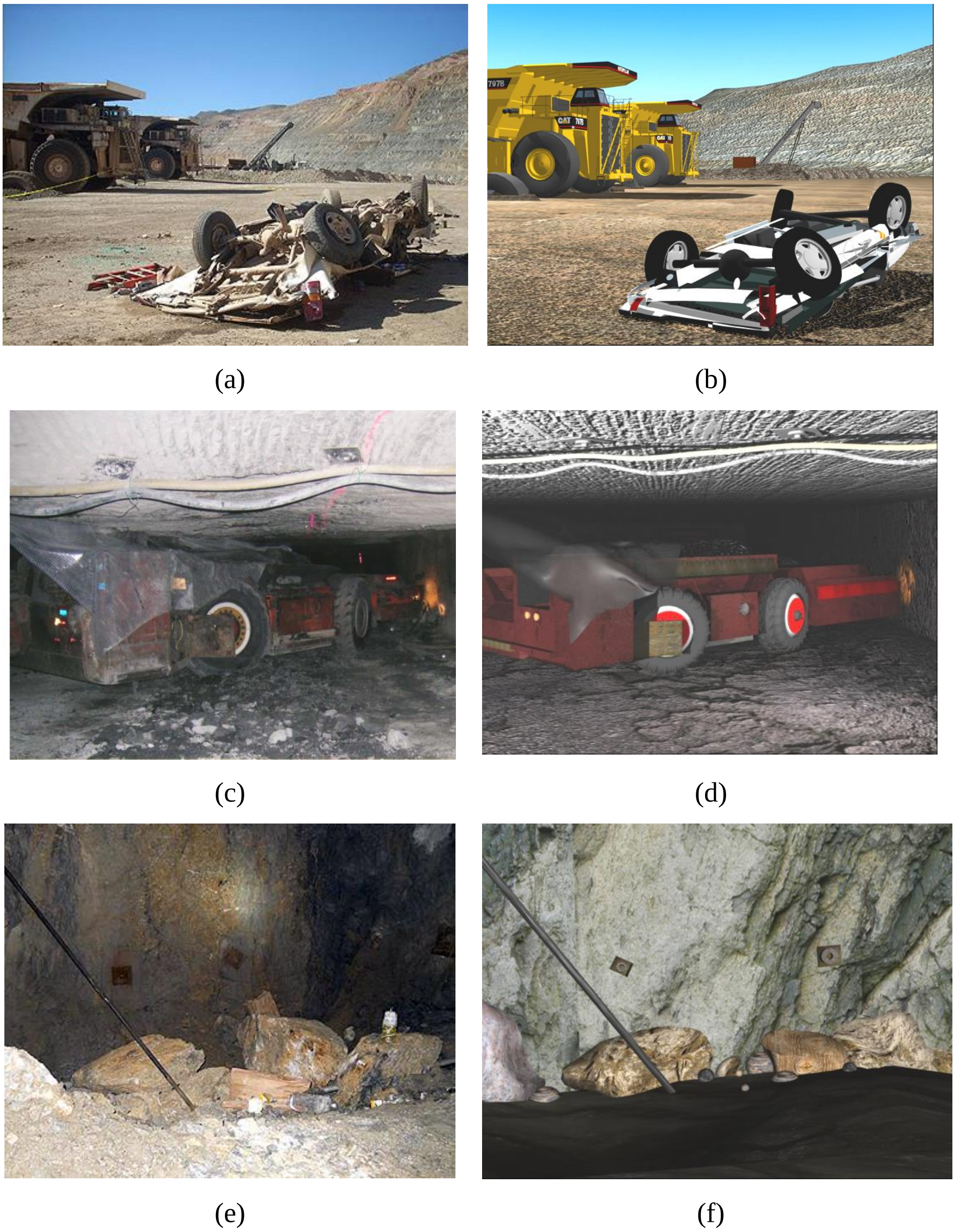


Figure 2.8. Fatalgram reconstruction for serious games. (a,b) Haulage accident in surface metal mine; (c,d) Haulage accident in underground coal mine; (e,f) Fall of material accident in underground metal mine (Brown, 2015).

The San Xavier Challenge application is mainly aimed at improving the map reading skills of users and recognizing the dangers that exist around them while navigating the mine. There are secondary missions, in addition to map reading and navigating the mine. Map reading, spatial awareness, workplace navigation, technical terminology, task-specific expertise, equipment usage, and self-rescue are important training topics within the San Xavier Challenge. Users are told that they will be ranked according to their efficiency in the simulation as in real life. At the same time, their jobs are intended to be stressful. Users are expected to identify the risks they encounter while performing their tasks. The simulation risks are those that are randomly derived from the risks introduced into the simulation (Brown, 2015).

Harry’s Hard Choices simulation has been developed about how the character named Harry can best survive as a result of a fire in an underground coal mine. The character Harry faces a range of options in the simulation and is expected to increase their chances of survival as a result of the choices he makes. While creating the scenario, it was partially inspired by real life. The simulation’s target audience is new miners, experienced miners, trainers, command center personnel, equipment manufacturers, responsible persons, and other mining industry employees. When this simulation is complete, it is aimed that the participants learn the escape routes in the mine, gather as much information as possible, learn the proper use of self-contained self-rescuers, understand the importance of the multi-gas detector in emergency situations, and learn when and under what conditions they should enter the refuge alternatives. A fire scenario that takes place in the game is shown in Figure 2.9.

Figure 2.9. A fire scenario developed in the game (Brown, 2015).

Underground mine maps are generally modeled in 3D, but they are available at workplaces printed on paper. This makes it difficult to understand, so the workers must have map reading skills. The National Institute for Occupational Safety and Health (NIOSH) published a computer-based exercise for map reading and navigation training. The application has two modules, “Map Reading Basics” and “Mine Navigation Challenge.” This exercise’s main objectives are to improve the ability of users to read underground coal mine maps, allowing them to navigate the underground coal mine modeled in 3D and familiarize them with underground coal mining terminology and symbols (Brown, 2015).

Xiaoqiang, An and Jianzhong (2011) introduced a virtual reality system developed in the mechanized mining face of the underground coal mine. There are modules for navigating in a virtual underground mine and interacting with the environment. The main reason for the simulation to be developed in a mechanized mining face is that the coal production is mainly made from these parts and these areas have low visibility. In addition, underground coal mine accidents occur significantly in these sections. The 3D model of the underground coal mine was created by modeling ventilation ways, haulage ways, and mining face. Then, underground equipment such as shearer, hydraulic supports, belt conveyors, chain conveyors was modeled, and their animations were added to the virtual scene. The simulation has five different modules. These are data input module, visual simulation module, technology simulation module, scene roaming module, interaction control module. While using these modules, users can navigate the virtual environment using keyboard and mouse, interact with longwall equipment, and observe animations in the scene like conveyor movement, shearer mining, and hydraulic support advancement (Xiaoqiang et al., 2011).

Akkoyun and Careddu (2015) presented a simulation for which a real magnesite mine has been selected. A computer simulation has been developed to teach the subjects related to the mining industry using an interactive education method. The main purpose of choosing a real mine is to get the required data from a real mine. Inspired by this mine, a drilling and blasting simulation was developed. The simulation developed allows the participants to change almost all parameters as they wish during the drilling and blasting process. With this training, users can simulate their own mines by changing various parameters. It has been stated that computer-based training methods can be used by students in universities and other mining industry employees in subjects such as drilling and blasting, excavation, haulage, size reduction, magnetic separation, and can provide participants with a basic and effective education (Akkoyun and Careddu, 2015).

McMahan et al. (2010) investigated strategies for reducing fatalities from haulage equipment in the mining industry through improved training using virtual reality technologies. A virtual reality simulation was developed to increase the efficiency of the training given to the miners. The research has focused on two different issues. These are haulage trucks and conveyor systems. The effectiveness of the simulation has been experimentally evaluated. As a result, it has been observed that virtual reality training systems are effective on haulage trucks and conveyor systems workers. The study's main purpose is to increase the efficiency of the training given to the workers and reduce occupational accidents in workplaces related to haulage equipment. Issues such as providing effective training to workers, evaluating the training's effectiveness, and reinforcing the importance of training are primarily aimed. An image from the developed simulation is given in Figure 2.10.

Figure 2.10. Example hydraulic hose inspection point and associated information window (McMahan et al., 2010).

In the first part of the training, the necessary information for a pre-shift inspection of a haul truck is explained to the user. In the second part, it is evaluated whether the information given in the first part is understood by the user. In the third part, the user is asked to inspect the truck. In the event of a malfunction that misses the user, accident simulations are shown to show what the consequences of the malfunction could be. Thus, it was aimed to emphasize the importance of pre-shift inspection of haul trucks. Another virtual environment was developed in a similar way for conveyor systems training, and an informative module on conveyor systems was added to this simulation. With this module, it is planned to inform the user and emphasize the importance of training. With the evaluations made on the users before and after the training, it was concluded that the virtual reality simulation developed within the scope of this study improved the safety perceptions of haul trucks and conveyor system workers (McMahan et al., 2010).

VR-based applications in the minerals industry have been studied by various researchers with different contribitions to the literature in this field. One of the main drawbacks of existing appliations is that the user experience and evaluation of decision-making are not the primary focus. This study highlights the realistic details of the virtual environment that has been based on actual underground mines in Turkey and provides a suitable environment for evaluation of situation awareness. The novelty of this study is the accurate representation of underground coal mining activities of Turkey including equipment used and the level of mechanization.

CHAPTER 3

METHODOLOGY

Virtual reality technology has started to be used in training given to miners in the field of mining as in many different fields. As summarized in the literature review section of the thesis, this technology was used in training given under various specific titles. Virtual reality technology, which was previously used only for entertainment purposes, has now become an effective tool in the field of training.

Within the scope of this study, it was aimed to develop a realistic underground coal mine virtual environment for use in miners' training. Various stages have been followed in the development of the underground mining virtual environment. The steps of the development of the MINING-VIRTUAL game are summarized in Figure 3.1.

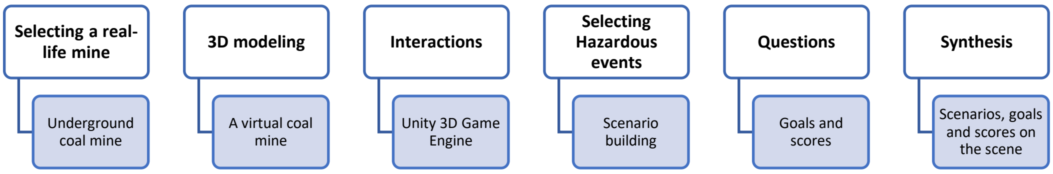


Figure 3.1. Steps of the MINING-VIRTUAL Serious Game.

Virtual reality is a technology used to create immersive environments that allow users to have experiences as close to real-life as possible. Virtual environments can be designed similar to real life, or they can be designed as completely imaginary. Thanks to the developing innovative technologies, virtual environments that are very close to real-life can be produced today.

Some important advantages of using VR in mining training are listed below.

- A variety of potentially hazardous situations can be created.

- It allows replication and modification.
- It is safe for participants and the working environment. Participants can be trained without exposure to actual risks and without damaging any equipment.
- It instantly shows the results of the choices the user has made.
- It can contain several modes in the same instance. The system can highlight hazards and ask hazard related questions in training mode. In the testing mode, the trainee must carry out an inspection of the workplace, and the logging of the inspection allows assessment.
- VR training materials are available to all employees of a company at any time.
- Trainees can walk through the mine or virtually view the mine from different angles as in real life.

It can be said that virtual reality may have some disadvantages besides its advantages.

One of the disadvantages of this technology is that virtual reality systems and components are quite expensive, and this may be one of the reasons it is not very common in Turkey.

Another major disadvantage is that no matter how close to reality it is developed, users always know that they are in a virtual environment, and therefore they may react differently from real-life reactions, and as a result, it is not clear whether users will behave in the simulation as in real life.

Prolonged exposure to VR may cause symptoms of nausea and vertigo (Patterson et al., 2006). VR headsets can also cause some eye strain among users. They strain their eyes to focus on a pixelated screen or on a specific object and focusing on a specific object may become uncomfortable after some time.

Virtual reality systems have two basic elements; headsets and controllers. Most head-mounted displays (HMDs) are mounted in a helmet or goggles set, as shown in Figure 3.2. HMDs are designed in such a way that no matter where the user looks, there is always an image that stays in front of him. The use of these devices increases the sense of reality. As seen in Figure 3.2., HMDs usually have monitors for each eye.

Figure 3.2. HTC VIVE VR headset (Htc Vive, 2020).

As seen in Figure 13, controllers are used for real-time detection of user reactions and make it possible for users to interact with the virtual environment or virtual objects within the game.

Figure 3.3. HTC VIVE VR interaction devices (Htc Vive, 2020).

CHAPTER 4

DEVELOPMENT OF THE MINING-VIRTUAL GAME

During the development of the MINING-VIRTUAL game, some preparatory steps were followed first. The dimensions of the underground coal mine, which parts of the mine, and occupational health and safety issues will be covered are decided. The mine sections that the user can navigate during the virtual tour are determined.

After the preliminary stage was completed, work was done on the 3D modeling of the designated mine, adding lighting and sound effects, developing animations, and finally adding interactions to the game.

4.1 Simulation Development Studies

The methodology of this study consists of the following steps:

- Gathering information about health and safety related Turkish legislations and underground coal mines hazards,
- Determination of the underground coal mine to be modeled,
- Determination of the hazard that will be included in the scene,
- Determination of the questions to ask users,
- 3D modeling of the underground mine and adding interactions,
- VR implementation,
- Implementation of the evaluation method.

The following software packages were used in the development of the project:

- 3DSmax (3D modeling)
- Unity3d (Game engine)
- Adobe Photoshop, 3dcoat, substance painter (Texturing)

- Adobe After Effects (Creating videos)
- Audacity (Sound effects)
- C# (Scripting)

4.1.1 Determination of Underground Coal Mine to Be Modeled

4.1.1.1 The Scale of the Underground Coal Mine

Mining companies determine their production methods according to specific parameters in the field of operation after studies. Coal can be extracted from underground by various production methods. Therefore, within the scope of this study, a large underground mine was modeled in order to include various production methods and operating modes.

Attention has been paid to modeling both the dynamic work areas where coal production and development works are carried out and other galleries where production works are not carried out but are very important in mine safety.

The top and perspective views of the 3D underground coal mine modeled within the scope of the study are given in Figure 4.1. and 4.2.

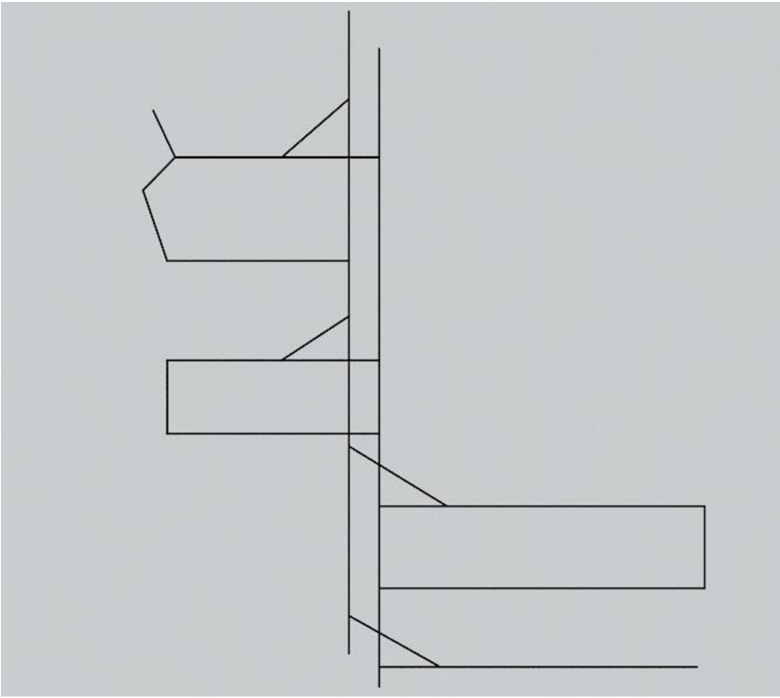


Figure 4.1. Top view of 3D underground mine model.

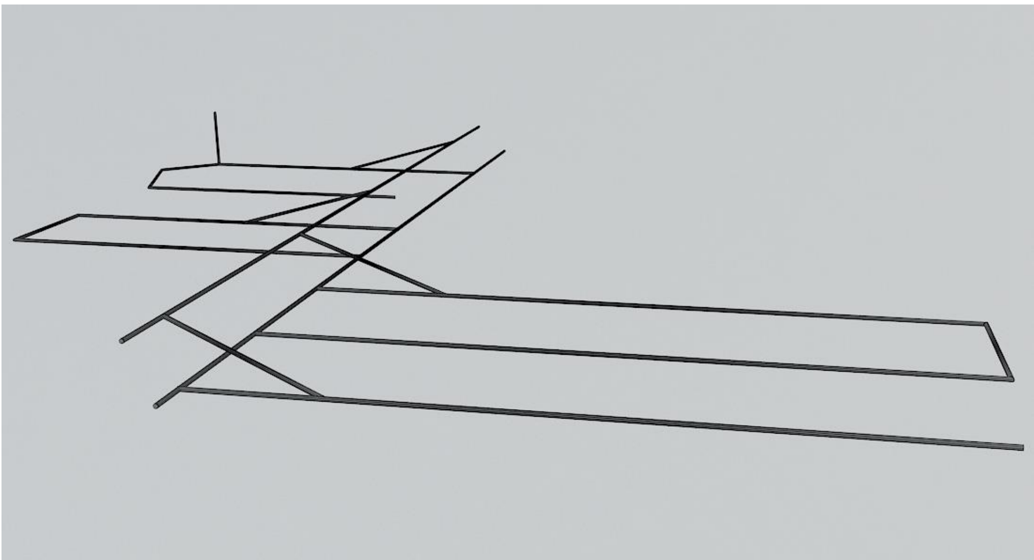


Figure 4.2. Perspective view of 3D underground mine model.

As seen in Figure 9, while determining the underground coal mine to be modeled, it was tried to be as inclusive as possible. Therefore, it was decided to model a large-scale mine as much as possible. It is aimed that the developed game includes different working methods and support systems as much as possible. Different support systems commonly used in Turkey are modeled, and some of them are shown in Figure 4.3.

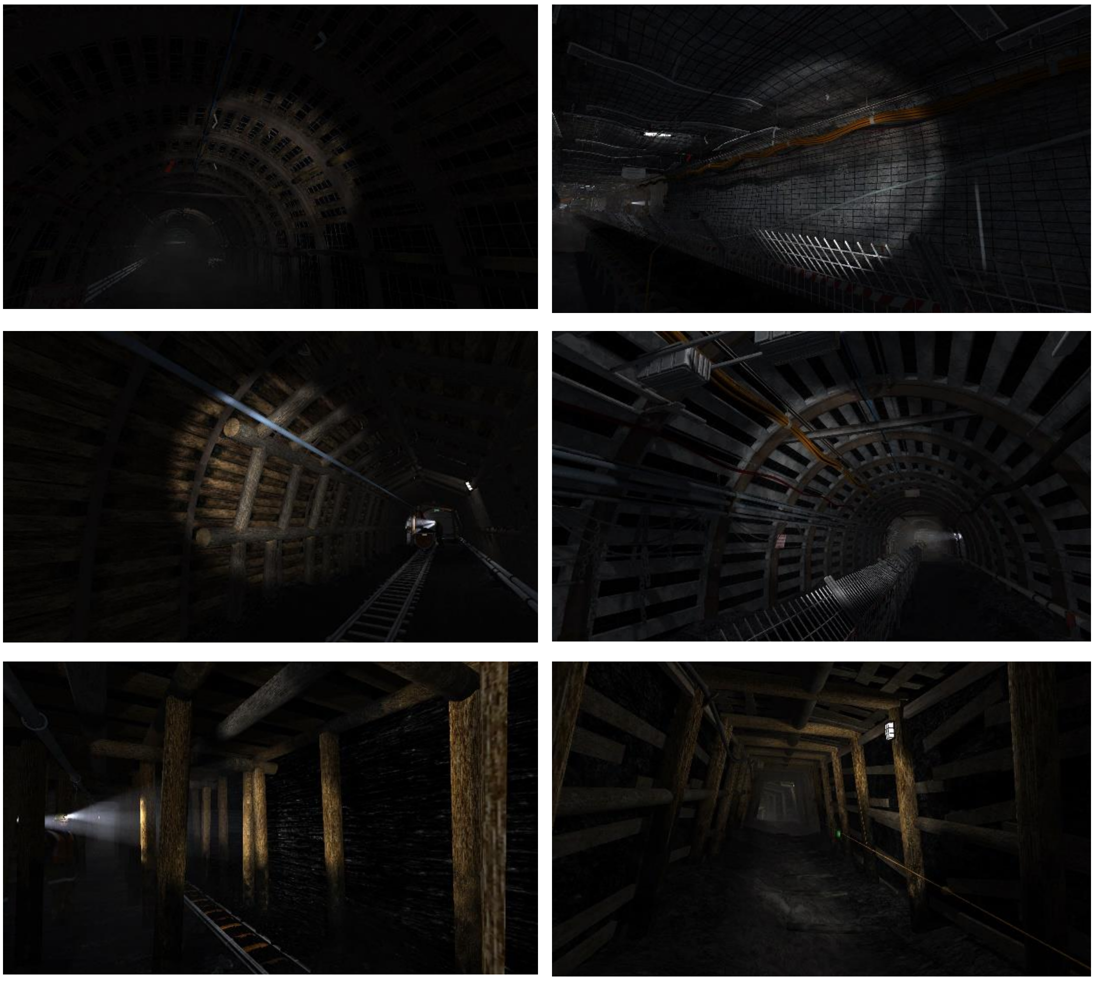


Figure 4.3. Underground support systems included in the game.

The entire mine is shown in Figures 4.1. and 4.2. has been modeled, but the interactions, animations, and sounds are concentrated in the production and development sections of the mine, which are relatively more dynamic and are constantly undergoing work and therefore have the highest health and safety risks.

The modeled underground mine includes a mechanized longwall face, a development gallery, a production panel created with classical wooden supports, which is very common in our country, and a production area for an inclined coal seam.

4.1.1.2 Common Health and Safety Issues

Different working methods and the health and safety risks that occur during production activities in underground coal mines were considered as much as possible to select the suitable mine for modeling purposes.

In underground coal mines, risks realted to ventilation, hazardous gases, support systems, electricity, coal fires, materials, transportation ways and dust are the most common risks, and these risks have the potential to cause serious accidents.

Therefore, it was decided to develop scenarios, especially for the risks related to these areas. Since these risks are mostly encountered in galleries where production and development works are carried out in the mine, these hazardous situations are placed in production and development sections in the simulation. Other sections of the mine were also modeled in the virtual environment, especially for the users to be able to navigate freely in the mine and to get a sense of reality.

In the scenario developed in the simulation, legal care to be shown in compliance with regulations in force in Turkey. For example, the issue of the necessity to establish lifelines, which came into force later, was covered in the game. The lifelines modeled in the underground coal mine in accordance with the legislation are shown in Figure 4.4.

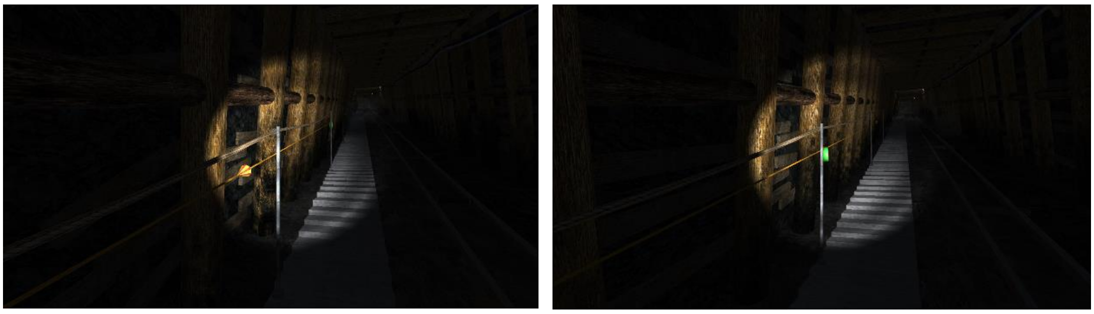


Figure 4.4. Life line developed in the game.

4.1.2 Free Navigation

Those who cannot see a real mine cannot imagine what an underground coal mine is like during their education due to various constraints; in general, they can navigate the underground coal mine and become familiar with underground coal mines by navigating within the mine. For this reason, not only the very risky parts of the mine but also the relatively less risky parts of the mine in terms of integrity are modeled. It is aimed for the user to navigate the entire mine easily.

4.2 Development of The Game

4.2.1 3D Modeling and Creating Textures

The most tiring and longest-taking part of the virtual environment development phase has been the 3D modeling of the underground coal mine.

The determined underground coal mine was modeled using Autodesk 3DsMax software. While modeling the objects on the scene, attention was paid to modeling as detailed as possible, but with VR technology, care was taken to keep the polygon numbers at an optimum level, considering that various problems occur during the game in scenes with very high detail and high polygon number.

It was ensured that that the dimensions are consistent within themselves during modeling and it is aimed that the user does not lose the sense of reality while navigating through the mine.

Objects modeled with 3DsMax were exported one by one in .obj format, and their textures were created with 3DCoat software. The objects' textures are intended to be as close as possible to that of a real underground coal mine. For example, while creating the texture of any equipment, care has been taken to ensure that it is dirty, worn, and rusted as if it were used in a mine, rather than being very clean. In the modeled underground coal mine, some objects with created textures are shown in Figures 4.5. and 4.6.

Figure 4.5. Modeled mechanized coal mine face with textures.

Figure 4.6. Modeled coal production area with wooden support systems with textures.

The textures, created using 3DCoat and Adobe Photoshop software, were transferred to Unity3D game engine, one of the most popular game engines, together with models prepared with 3DsMax. In the Unity3D game engine, using the textures of each object, the materials of the objects were created, and the materials were assigned to the relevant objects.

At this stage, the model of the underground coal mine was created, but considering that a real underground coal mine is a dynamic environment that is constantly changing, studies were carried out to prepare lights, sounds, and various animations in order to make the developed simulation more realistic.

As in the 3D modeling phase, while adding lights, sounds, and animations, it is aimed to make the scene as close to real-life as possible. In addition, attention has been paid to developing a dusty environment. The dusty environment in the game is given in Figure 4.7.

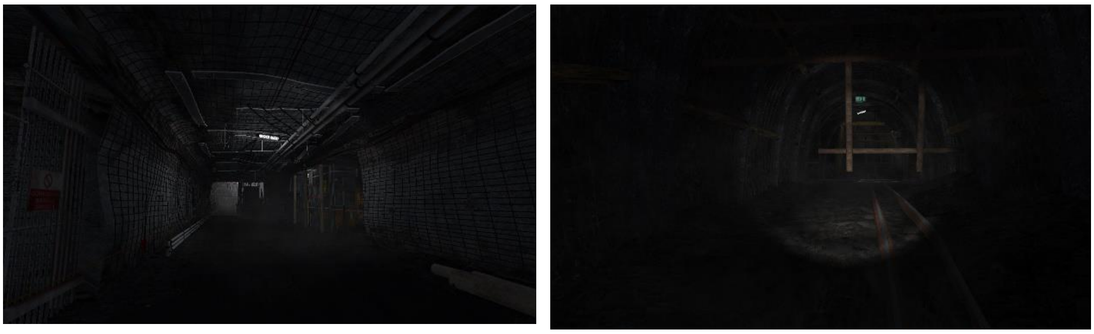


Figure 4.7. Dusty underground coal mine environments from the game.

4.2.2 Lights

Considering a real underground coal mine, we can say that certain places that need light are illuminated, but generally, the inside of the mine is dark, and lighting is provided with miner’s headlamps. For this reason, in the simulation developed, the mine was tried to be as dark as possible. However, a general global illumination value has been assigned inside the mine in order not to completely isolate the user from the environment.

In addition, additional lighting was provided in the mine, especially in the sections where transportation, development, and production works are carried out, by placing lighting lamps on the walls of the galleries.

It was decided to use the miner’s head lamp as the main lighting tool in the mine, and by adding a spotlight to the camera of the first-person character, it was ensured that the path was illuminated at a certain angle in the direction of the user's travel during navigation, close to the real life. At the same time, real-time shading is used in order not to lose the sense of reality.

All of the lighting objects were modeled with 3DsMax, and textures were created with 3DCoat and imported into Unity3D game engine, lights were added in Unity3D. There are three main lights in Unity3D named directional light, spotlight, and pointlight.

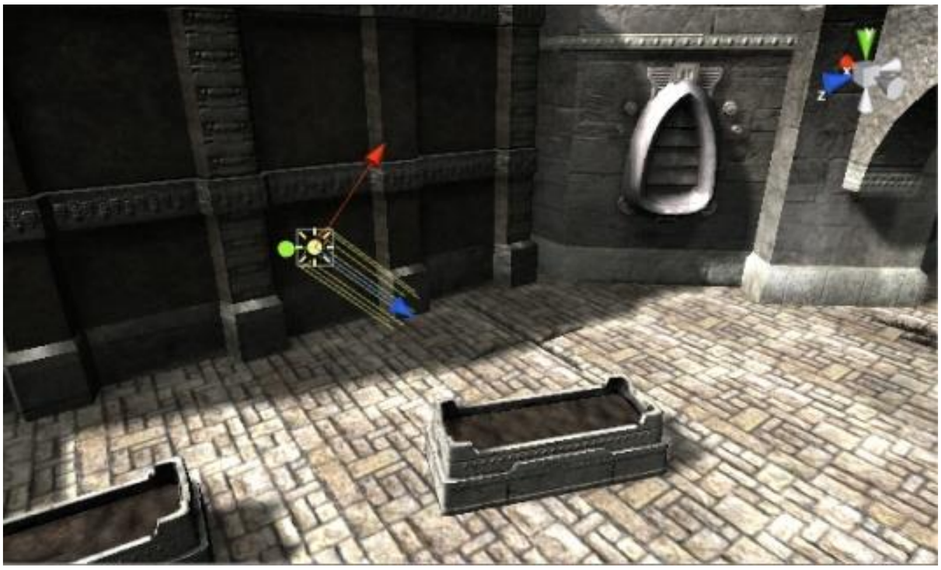


Figure 4.8. Directional light (Unity Manual, 2020).

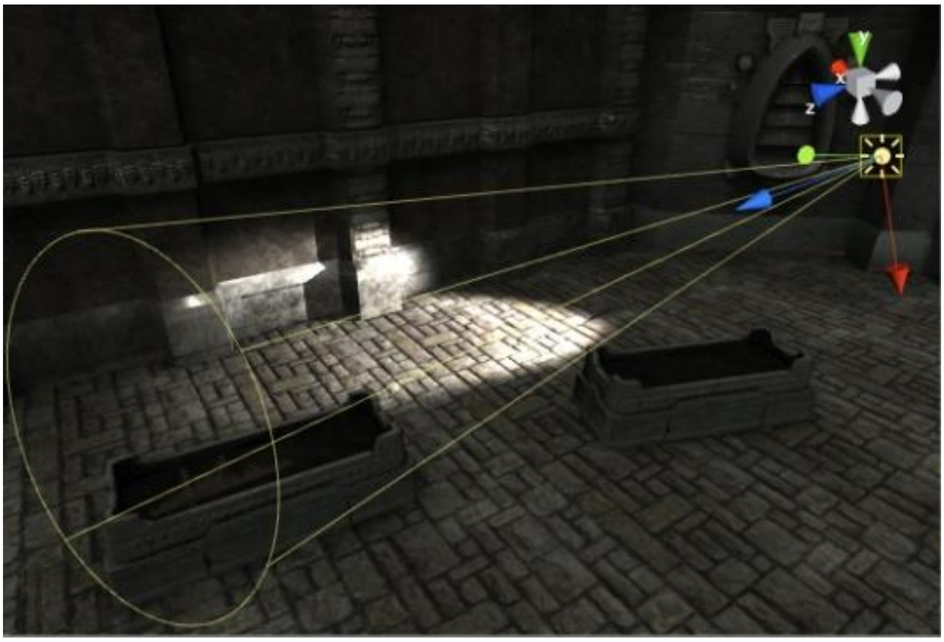


Figure 4.9. Spotlight (Unity Manual, 2020).

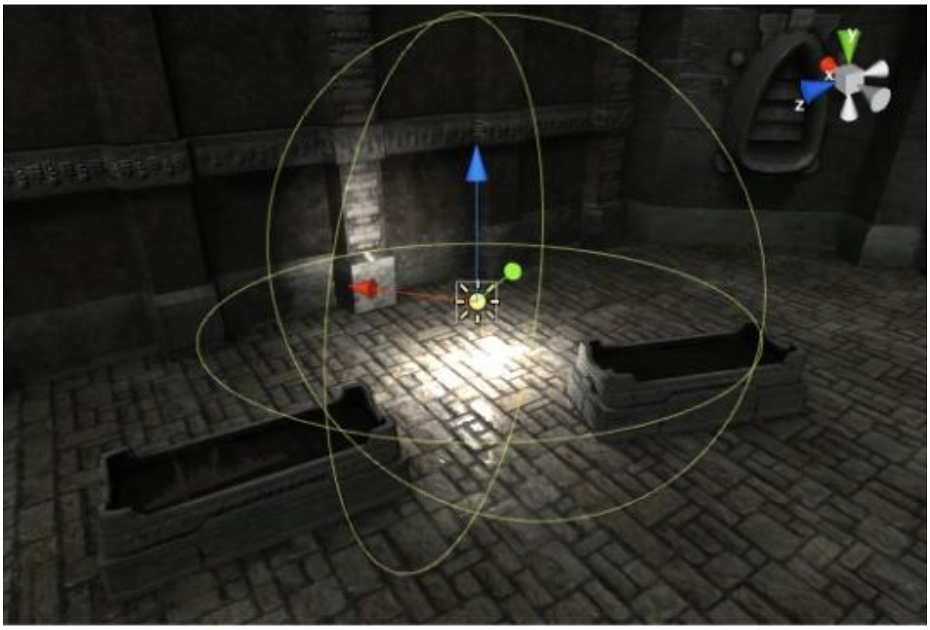


Figure 4.10. Point light (Unity Manual, 2020).

As seen in the figures, while directional light affects the whole scene, the spotlight and point light illuminate certain areas. Unlike point light, the spotlight illuminates a certain area at a certain angle.

In the simulation, directional light was used to provide a global illumination in order to prevent it from being completely dark in the mine to prevent navigation. Spotlights are used in the headlamps of the user and other workers in the mine. Point lights were used for the lighting on the gallery walls.

Figure 4.11. Point light usage example.

Figure 4.11. shows the use of a point light in Unity3D. The point lights are located at a point in a virtual environment and it illuminates in all directions where it is located..

Figure 4.12. Spot light usage example.

Figure 4.12. shows the use of a spotlight inside the mine. A spot light is constrained to an angle, resulting in a cone-shaped region of illumination.

In the figures, it is also seen that the parts of the mine that are not illuminated are not completely dark. This is due to the use of directional light.

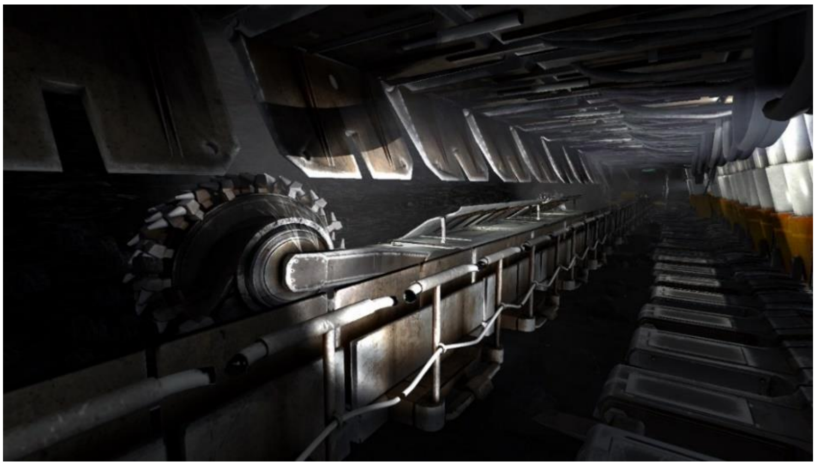
4.2.3 Audio

There is no complete silence in any working mine. Even in a gallery where intensive works are not carried out, the sounds of working ventilation systems are heard because of continuous ventilation. The sections where production and development works are carried out are quite noisy when the sounds of the machines and equipment used in these sections are added in addition to the sounds of the ventilation systems.

For this reason, ventilation noise was added to the main galleries in the simulation, to the sections where the work is concentrated, the belt conveyors, chain conveyors, ventilation doors, shields and shearer, water spray systems, electrical panels, moving wagon, water drops, and the user’s footsteps sounds were added. Sound effects were prepared using the Audacity software and added to the Unity3D Game Engine.

Some parts with sound effects added to develop a realistic underground coal mine environment are given in Figures 4.13 (a, b, c).

(a)



(b)

(c)

Figure 4.13. Some parts of the mine with sound effects added. (a) Belt conveyor, (b) mechanized longwall, (c) chain conveyor.

4.2.4 Animations

Underground coal mines are dynamic and continuously operating workplaces. Therefore, in the simulation developed, necessary animations have been added to create a dynamic working environment like a real underground coal mine. When the animations made are combined with the sound effects added to these sections, it has been observed that the sense of reality increased considerably.

The main animations added to the virtual environment are given in Table 4.1.

Table 4.1. *Animations created in the game.*

Objects	**Animations**
Ventilation doors	- Opening
	- Closing
Chain conveyors	- Moving with coal on it
Belt conveyors	- Moving with coal on it
Chains, ropes, cables, etc. hanging from the roof	- Swinging
Shields	- Lowering
	- Advancing
	- Rising
Shearer	- Rotating
	- Rising
	- Lowering
	- Advancing
Dust particles suspended in the air	- Rotating
	- Moving
Water drops	- Dripping
	- Water spraying
Workers	- Standing/Idle
	- Walking

Table 4.1. (Cont'd)

	- Observing
	- Machine using
Mine wagon	- Wheel rotating
	- Wagon advancing

All of the animations used in the scene were created in 3DsMax, transferred into Unity3D, and assigned to the objects. Since most of the animations in the mine are continuous, the continuity of the animations is ensured by enabling them to loop in Unity3D.

There are also non-continuous animations played on the scene due to the triggering of a collider. An example of this is the opening and closing of ventilation doors during the passage of the workers. The animation of the ventilation doors is exemplified in Figure 4.14.

Figure 4.14. A ventilation door is closed and opened after interactions.

The 3D worker modeled with the lowest polygon and basic personal protective equipment used in the mine, rigged using the Mixamo application (Mixamo, 2020)**,** thanks to the application of animations created in 3DsMax to the worker model in Unity3D, they are provided to be mobile.

4.2.4.1 Interactions, Scripts, Colliders, Navigation

In addition to making it possible to navigate the underground coal mine with the simulation developed, it is also aimed for the user to interact with various objects in various situations.

For this reason, information screens, detailed information screens, and questions in line with the legal regulations were added to the simulation by using the Unity3D-UI system, taking into account the OHS risks frequently encountered in previous accidents in underground coal mines. The user is intended to receive the information she/he needs in certain places while navigating the mine and is expected to answer the questions posed to her/him about hazardous situations.

Collider components have been added to the 3D models created in 3DsMax in the Unity3D Game Engine. Interaction with these objects is made possible with collider components. At the same time, thanks to the scripts written, it is ensured that the predicted results are produced when interacting with any object. For example, when interacting with the ventilation door, with the script component of the door object, the animation on the door is played, and as a result, the ventilation door is opened and closed. At the same time, when interacting with objects, various information screens and question screens are shown to the user through scripts. The scripts are written in Microsoft C # using Microsoft Visual Studio (Unity Manual, 2020).

Scripts are used to create visual effects and develop output that will occur as a result of the interactions of the player in the game (Unity Manual, 2020).

Scripts in the game are used for playing animations as a result of interaction with objects and showing the user the information screens on technical and safety issues in the underground coal mine and the multiple-choice questions about the hazardous situations.

4.2.4.2 Information Screens

These screens give information about what the objects in front of the user are and what they do, on the screen, in technical and safety-related titles specific to the mines, during the tour in the underground coal mine.

In the game, information screens such as ventilation doors, air tank, self-contained self-rescuers exchange station, fire dams, dust barriers, water barriers, dirty air outlet, ventilation fan, gas sensors, water well, water discharge pump have been developed. When the user looks at the object, she/he is curious about the tour through the mine, and she/he can get information about this section or object with the information screens. The screen turns off automatically when the user moves away from this section or turns to the other side. Information screen about gas monitoring system is shown in Figure 4.15., information screen about fire dam is shown in Figure 4.16., information screen about ventilation door is shown in Figure 4.17., information screen about water well is shown in Figure 4.18., information screen about water barriers is shown in Figure 4.19., information screen about dust barriers is shown in Figure 4.20.

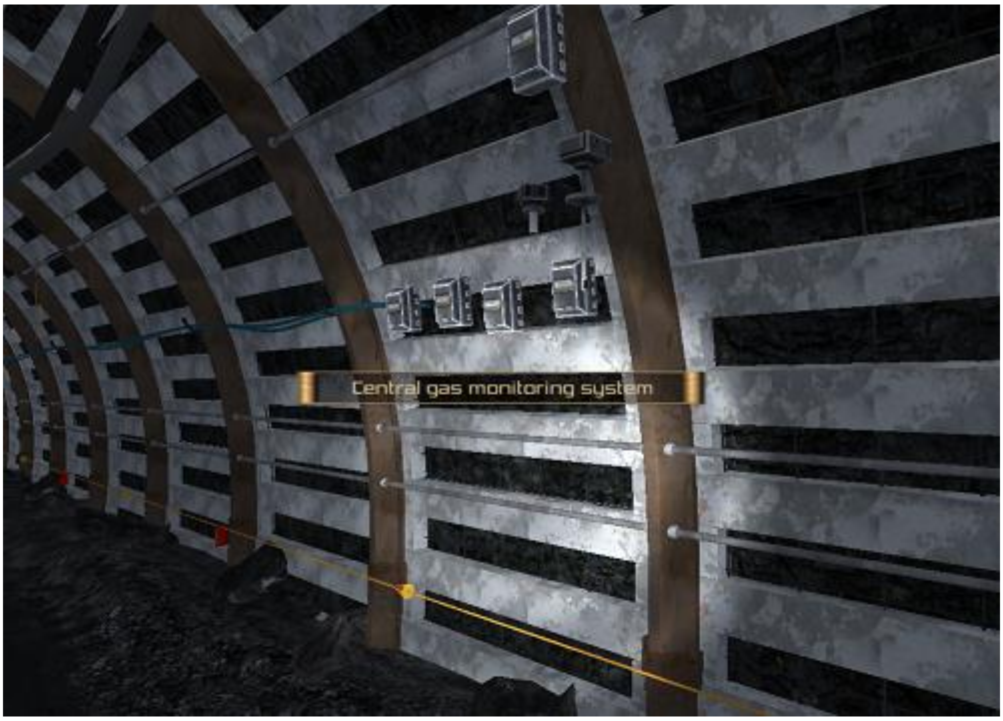


Figure 4.15. Information screen about central gas monitoring system.

Figure 4.16. Information screen about fire dam.

Figure 4.17. Information screen about ventilation door.

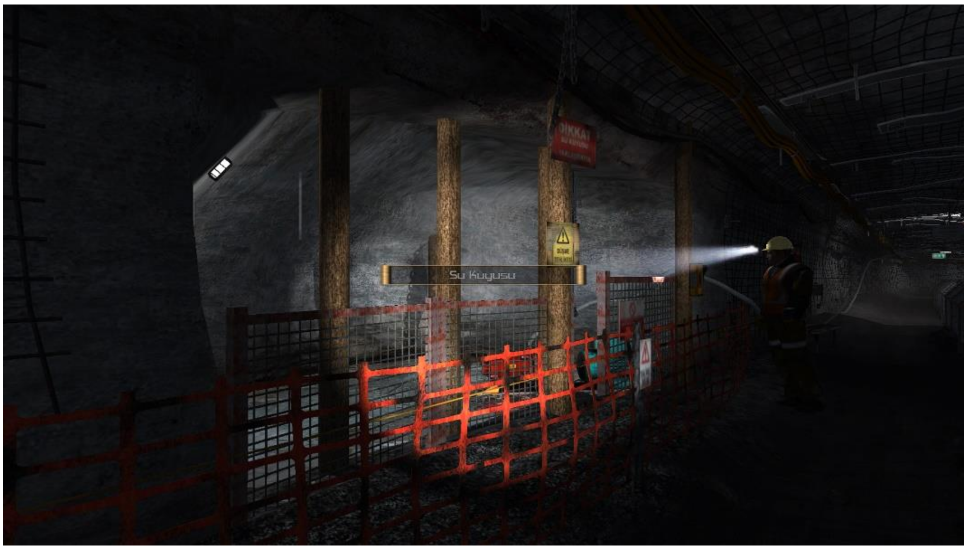


Figure 4.18. Information screen about water well.

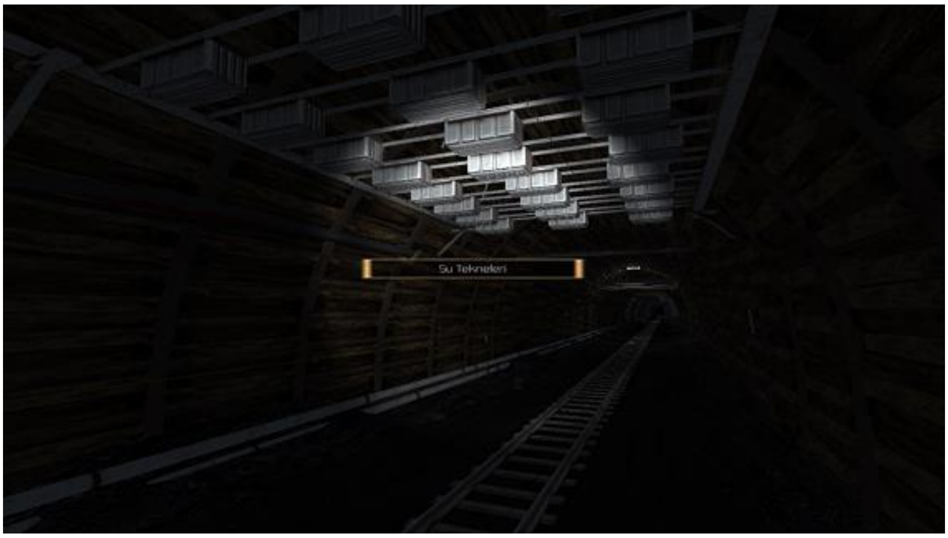


Figure 4.19. Information screen about water barriers.

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Figure 4.20. Information screen about dust barriers.

4.2.4.3 Detailed Information Screens

On these screens, the basic measures to be taken regarding OHS are shown with an emphasis on the legislation. When the information screen is shown to the user, the game stops so that the user can easily read what is written on the screen. After reading the game, the game is resumed when the user clicks the “OK” button.

Detailed informative screen about OSR Change Station is shown in Figure 4.21., detailed, informative screen about the sealed area is shown in Figure 4.22., detailed informative screen about ventilation doors is shown in Figure 4.23., detailed informative screen about underground water pump station is shown in Figure 4.24., detailed informative screen about water barriers is shown in Figure 4.25., detailed informative screen about dust barriers is shown in Figure 4.26.

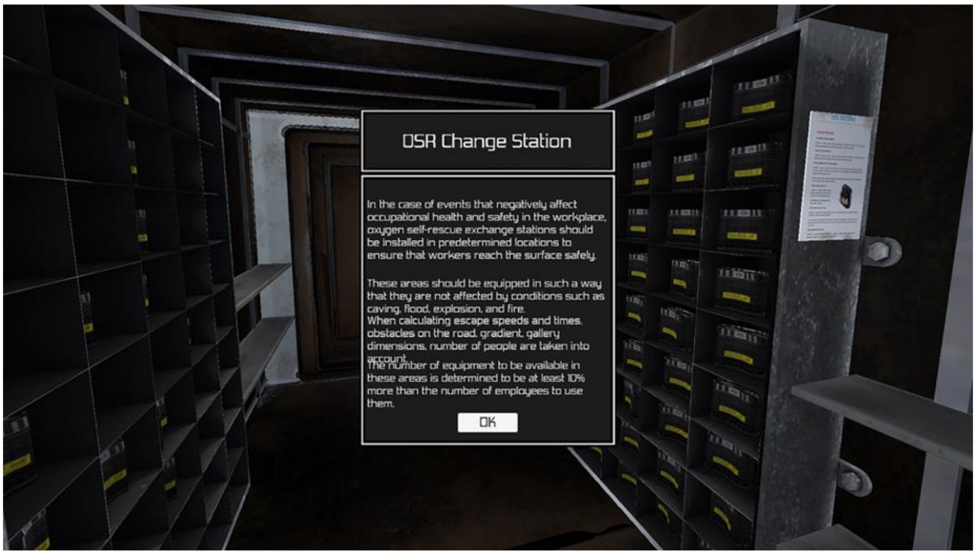


Figure 4.21. Detailed information screens about OSR Change Station.

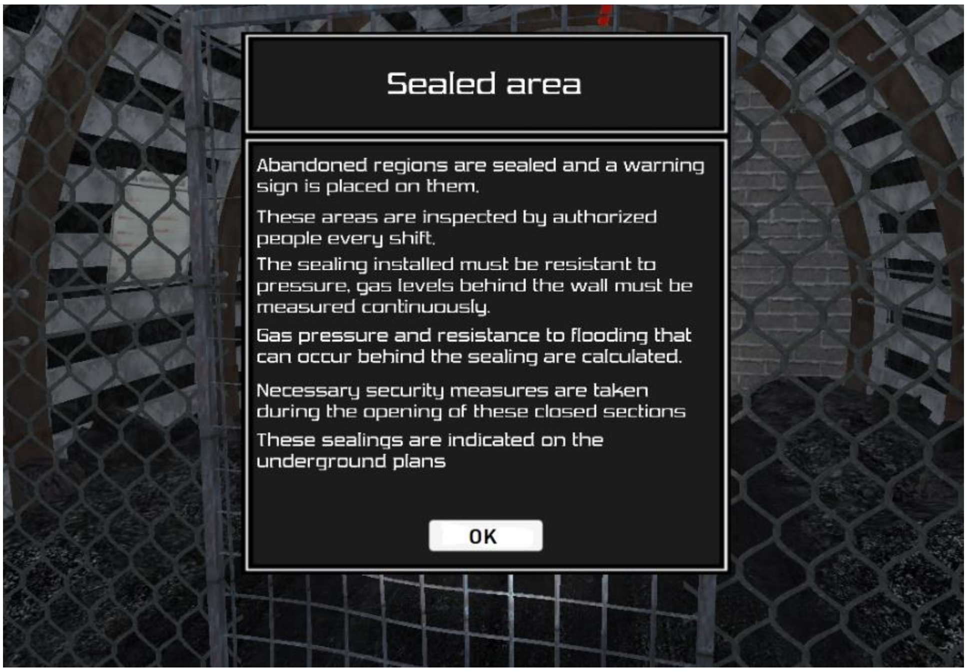


Figure 4.22. Detailed information screens about the sealed area.

Figure 4.23. Detailed information screen about ventilation doors.

Figure 4.24. Detailed information screen about underground water pump station.

Figure 4.25. Detailed information screen about water barriers.

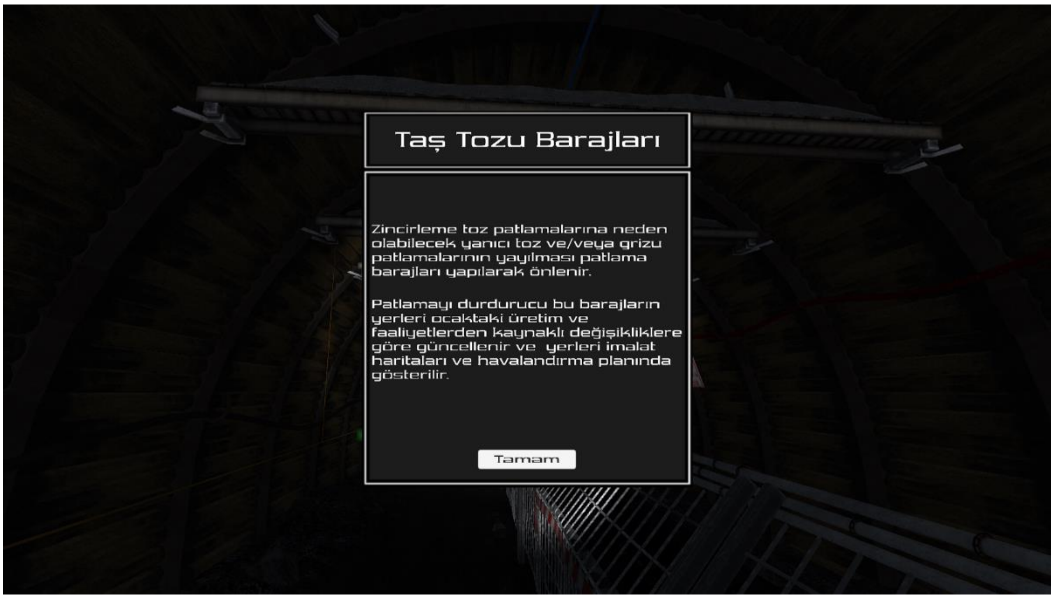


Figure 4.26. Detailed information screen about dust barriers.

4.2.4.4 Question Screens

Various questions have been added in the game regarding common occupational health and safety-related hazardous situations in underground coal mines. These questions are aimed to measure the user’s safety knowledge. The questions are formed in various categories. These categories can be listed as support systems, haulage, electrical operations, and ventilation.

When the question screen is shown to the user, the game pauses, and the user is expected to read the question and choose one of the choices. There are three choices in the questions. When the user answers the question after reading the question if the answer given is wrong, “the wrong answer” is written on the screen, and a “wrong answer sound” is heard, and the user is expected to mark a new choice. Here, the main purpose of giving the user more than one chance is to enable the user to receive information on that subject while answering the question. The ability to choose other options after giving the wrong answer ensures that she/he gets the correct information on the subject instantly. When the user answers the questions correctly, a "correct answer sound" is heard, and the question screen closes.

After the correct answers are given in the simulation, the hazardous situation and the situation after the risk is eliminated are shown to the user. In this way, users were trained while answering the questions, as well as seeing and experiencing wrong and correct practices in terms of occupational health and safety-related to important issues in underground coal mines. In Figure 4.27., a question about the hazardous situation caused by moving part of a machine without a guard is shown. If the question is answered correctly, the guard of the machine is placed on it.

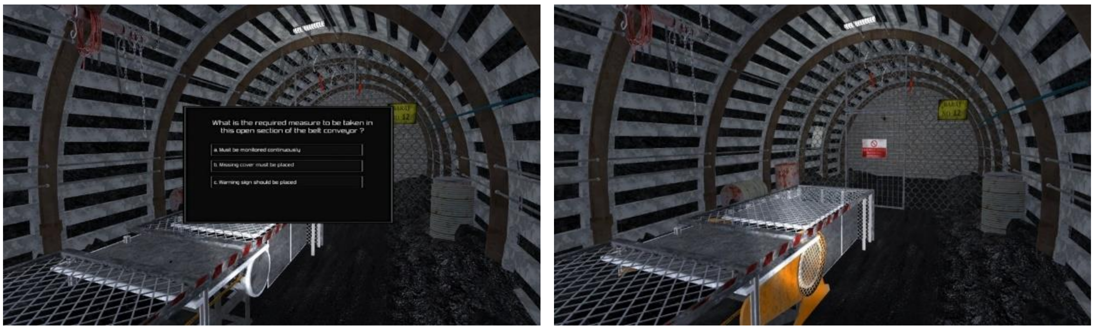


Figure 4.27. Multiple-choice question about moving and rotating parts of machinery.

The broken wooden supports in the mine and the undamaged supports to be replaced are shown in Figure 4.28.

Figure 4.28. Before and after multiple-choice questions about broken wooden supports.

Question about the danger caused by the rotating big and after the question is answered, the rotating cylinder is isolated from the working environment as shown in Figure 4.29.

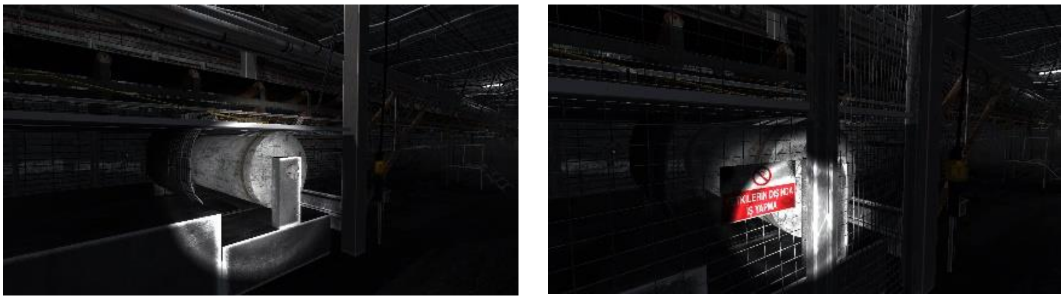


Figure 4.29. Before and after multiple-choice questions about moving and rotating parts of machinery.

Roof fall hazard in a section on the main road of the mine and the question about it is shown in Figure 4.30. After the question is answered, additional supports are made in this section.

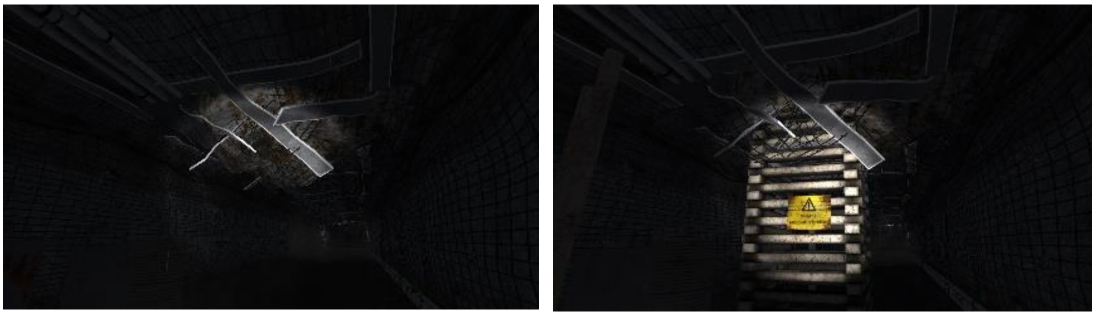


Figure 4.30. Before and after multiple-choice question about roof fall hazard.

4.3 Game Versions

Both the PC version and the VR version of the underground coal mine simulation have been developed.

4.3.1 PC Version

Navigation in the PC version is done with the keyboard WASD keys and the mouse; interactions with the UI in the game are provided with the mouse.

4.3.2 VR Version

The VR version of the simulation developed requires VR Headsets, controllers, and a PC. During the implementation of this study, the VR version was played with HTC Vive Headsets and controllers.

The game enables detailed navigation and interaction inside the virtual mine. HMD is designed to have a continuous screen around the user regardless of where the user turns and looks at. Colliders are not added to some objects in the scene to allow detailed navigation so that the user can move closer and experience the details of the models. Instead of specifying a path for the user to navigate, the user is expected to navigate freely in the game, aiming to provide a more personalized experience.

Navigation in the virtual environment is performed using teleportation. Teleportation is an easy-to-use movement mechanism in VR enabling to reach a target in an instant instead of directly walking to that target. The user can use the option of teleportation within limits determined in the game or for teleportation at the determined teleport points in the important areas. These sections are marked, and the user can navigate through the controller to every point within the scene or only at specified points with teleportation. In the VR version of the simulation, teleportation points were determined by evaluating the locations of information screens and animated sections that are expected to be important for the user who can explore the mine by hovering over these points. The teleport points placed in the VR environment are shown in Figure 4.31.

Figure 4.31. Navigation in the game via VR hardware and teleportation points.

CHAPTER 5

EVALUATION, RESULTS, AND DISCUSSION

A group of 30 people that participated in a workshop consisting of mining engineers and game developers was selected for the questionnaires on the MINING-VIRTUAL game. Questionnaires were conducted on standard usability and technology acceptance in general. The questionnaires are designed to determine the technology acceptance patterns of the computer and virtual reality versions of the game and also to classify the participants' profiles. A total of 28 questions were asked to the participants under the headings of system usability and technology acceptance. The system usability scale (SUS) was determined with the first ten questions, and the technology acceptance model (TAM) was created with the remaining 18 questions.

There are several methods of measuring the usability of a new system, but the most common is to ask users' opinions about their experience after using the system (Albert and Tullis, 2013). User opinions are collected by conducting questionnaires that mainly focus on the system used to understand the user's experience clearly (Macleod, 1994; Rubin and Chisnell, 2008; Albert andTullis, 2013).

In this study, the target groups played the MINING-VIRTUAL game first, and their feelings and thoughts about the game were taken with the questionnaires made afterwards. The group of game developers played only the PC version of the game. The group of mining engineers played both the PC version and the VR version of the game.The main purpose of the questionnaires is to quantitatively evaluate the game, which is introduced as a new system, in terms of usability and user experience quality. The concept of usability is defined as the degree of usability of a system by certain users to achieve the goal in terms of efficiency, effectiveness and applicability (ISO, 2018).

There are different approaches to measuring system availability. In the first parts of the questionnaire, a Likert system usability scale with 5 possible answers (1- Strongly Disagree, 5- Strongly Agree) developed by Brooke (1996) (Brooke, 1996) was used. It is aimed to make the information gathering process fast, easy, and reliable. Among the various scales in which the usability of the systems is measured, the most widely used SUS is defined as having a high-reliability level with 0.91 Cronbach's alpha value (Lewis, 2006).

SUS allows reducing the overall availability of the system under test to a single result. The calculated score represents usability performance in terms of system efficiency. Odd-numbered questions used for the SUS score are positively focused, and the even-numbered questions are negatively focused. The effects of these questions are reflected differently in the score. The resulting calculated SUS score is between 0 and 100 but does not represent a percentage result.

One of the most common approaches to find out why users accept and use new technologies is the technology acceptance model (TAM) developed by Davis (1989). TAM explains and theoretically models how people or societies accept new technologies. TAM takes the theory of reasoned action (Ajzen and Fishbein, 1980) as the theoretical basis. This theory was revealed in their studies on attitude in expectation value models (Davis F., 1993). According to this model, perceived usefulness and perceived ease of use theories are proposed. Other components can be listed as intended use, user satisfaction, and perceived pleasure.

The answers of the questions asked to users within the scope of TAM in the questionnaires were also analyzed statistically. First of all, the reliability of the data received from the users was tested. The consistency of the questionnaires is analyzed using the Cronbach's Alpha (α) value for questions with ordinal scale answers. The α value obtained for all questions indicates the total reliability of the questionnaire and is expected to be greater than 0.7. α values lower than this value indicate that the questionnaire has a poor reliability level (Tavakol and Dennick, 2011).

A group of 30 people consisting of mining engineers and game developers was asked to fill in the questionnaires after the MINING-VIRTUAL game was played. The ages of the individuals in the target group are between 22 and 36, and the participants are at least at the Bachelor of Science level. The questionnaires cover the profile information of the participants and questions about the technology acceptance level of the game.

The distribution of the participants by gender is given in Figure 5.1.

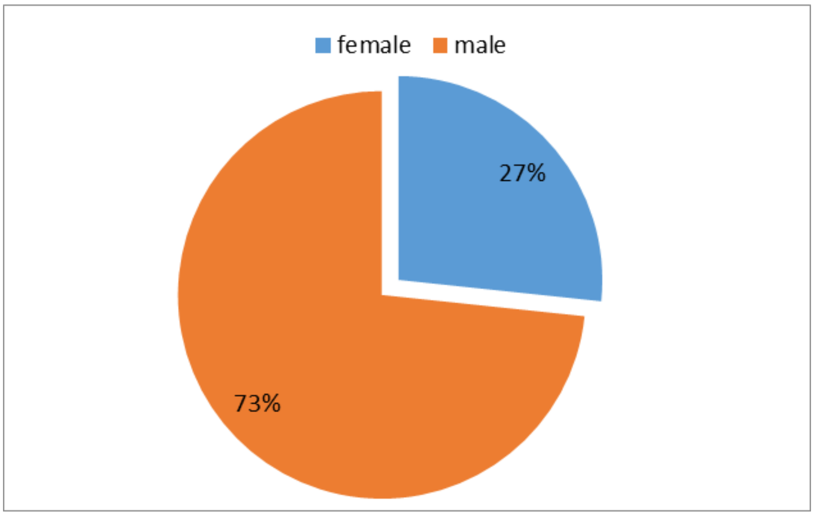


Figure 5.1. Distribution of participants by gender.

Gamer profiles of the ME participants according to their ages are given in the graphic in Figure 5.2.

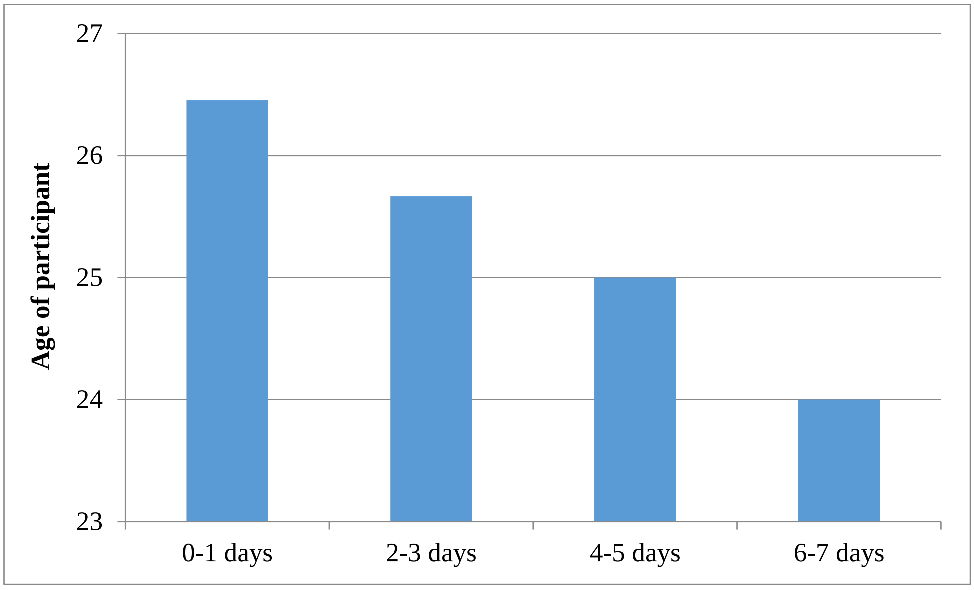


Figure 5.2. Days spending at least 30 minutes per week of playing video games for ME.

Gamer profiles of GD participants according to their ages are given in the graphic in Figure 5.3.

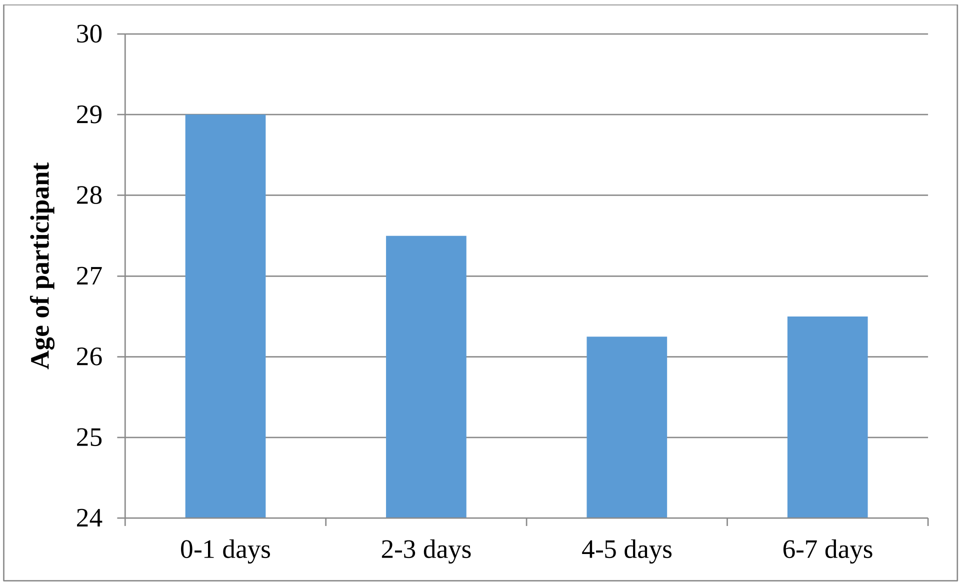


Figure 5.3. Days spending at least 30 minutes per week of playing video games for GD.

With the question in the questionnaire asking the number of days the participants spent playing games for at least 30 minutes, the target groups' player profiles were defined. As a result, as expected, the group of game developers spent more time playing games than mining engineers (Figure 5.3.).

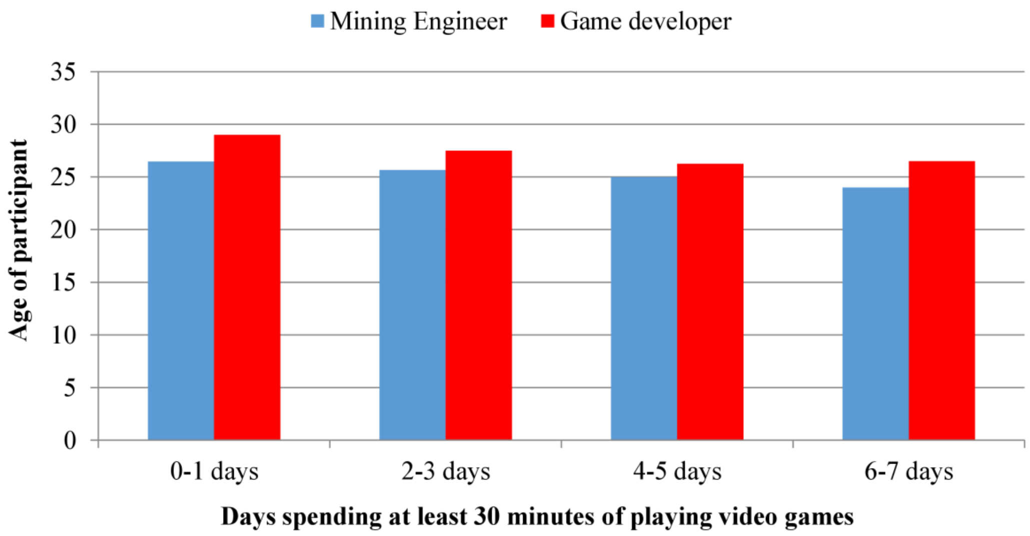


Figure 5.4. The relationship between the age of the participants and their gaming habits.

It was observed that as the age of the participants increased, the time to play games decreased. As a result, game technologies are more common among the younger participants of the target groups.

The SUS scores were calculated as 85 for mining engineers and 87 for game developers. SUS score ranking was evaluated according to the scale developed by Bangor et al. (2008; 2009) and can be classified as "excellent." Brooke (1996; 2013) stated that systems with higher SUS scores are more suitable in terms of usability. Questions 4 and 10 in the questionnaires are about the learnability of the system, and the remaining eight questions are about the usability of the system. The statistical evaluation of the questionnaire results is grouped according to this point of view and the results are given in Table 5.1.

Table 5.1. *Basic statistical evaluation of the answers about SUS.*

	Mining Engineers				Game Developers			
	Mean	**Min**	**Max**	**Std. Dev.**	**Mean**	**Min**	**Max**	**Std. Dev.**
Q4-Q10	2.24	1.00	5.00	0.23	1.86	1.00	4.00	0.30
Q2-Q6-Q8	1.51	1.00	3.00	0.31	1.31	1.00	3.00	0.08
Q1-Q3-Q5-Q7-Q9	4.40	3.00	5.00	0.07	4.47	1.00	5.00	0.46

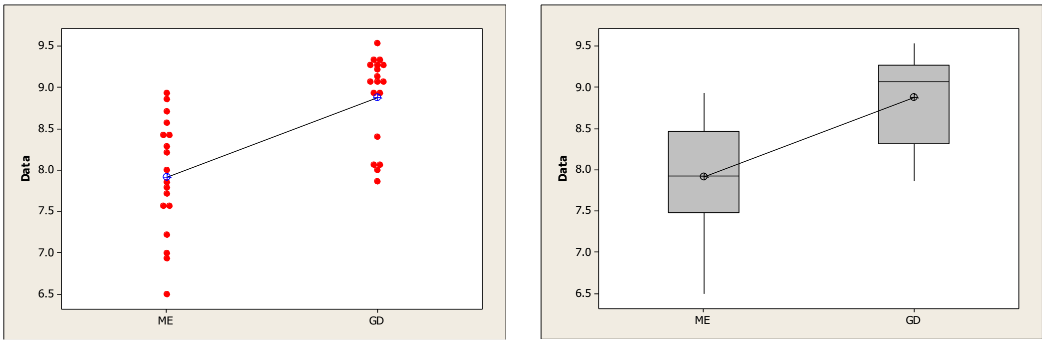
When the answers given to the 4th and 10th questions aiming to measure the learning of the system are examined as given in Table 5.1., it is seen that the system learning ability is at a medium level for mining engineers but at a better level for game developers. The remaining 8 questions are about the usability of the system and include negative and positive questions. It was observed that the answers given to positive questions were close to the highest score of 5. It was observed that the answers given to negative questions were close to 1, which is the lowest score. The second part of the questionnaire contains questions about TAM, and a 10-point-scale (1- Strongly Disagree, 10- Strongly Agree) was preferred for this part. The means of the scores were used to compare the answers of both groups. While the average of mining engineers' responses is 7.92, this result is calculated as 8.88 for game developers. The main reason for the difference is that the game developers are more tech-savvy and have a high capacity to adopt game technologies. Cronbach's alpha value of TAM was calculated as 0.88 in this study, and it was found to be at acceptable reliability level.

Considering the TAM answers, a two-sample-test was applied to determine whether the difference between the two groups' mean values was statistically zero. The null hypothesis (H0) has been determined as "the difference of the mean values from responses of Mining Engineers group and Game Developers group is equal to zero." It is assumed that the TAM scores of the two groups are equal to each other (H_0: μME - μGD = 0). In this case, the alternative hypothesis is two-tailed because the alternative hypothesis assumes that the difference is not equal to zero (H_1: μME - μGD ≠ 0). The results are summarized in Table 5.2.

Table 5.2. *Two-sample t-test scores of ME and GD.*

	Mean	Std. Dev	Std. Error Mean	T	t-two tailed	df	P	95% Confidence Interval for difference	
								Lower	Upper
ME	7.92	0.70	0.17	4.600	2.048	28	0.000	-1.383	-0.533
GD	8.88	0.54	0.13						

The null hypothesis was statistically rejected. Reasons for this are, as seen in Table 3, the p-value (0.000) is less than 0.05, and the significance (cutoff) level is set as %95 confidence interval. Another reason is the two-tailed value (2.048) is less than the t value (4.600). As a two-sample t-test decision, the difference between the two groups was statistically significant. Therefore, "H0: There is not a statistically significant difference between mining engineers and game developers regarding technology acceptance level of this game" is rejected. The difference can be explained by the fact that game developers are more familiar with the technology than mining engineers. The individual plot and box plots are given in Figure 5.5.



(a) (b)

Figure 5.5. Individual and box plot of TAM questionnaire.

For both groups, the effect of variables such as experience and gameplay frequency on technology acceptance for the mining-related game was evaluated with a two-sample t-test. These analysis results allowed us to understand the scale of technology acceptance. For both groups, the two-sample t-test analysis null hypothesis is defined as “There is not a statistically significant difference between sub-groups.”

The experience refers to the participants’ experience in gaming in environments such as MR, VR, and AR, and their experience in game development. The participants were divided into subgroups according to their experience in game development and their experience in MR, VR, and AR environments, and independent t-test results for these subgroups are summarized in Table 5.3.

Table 5.3. *Two-sample t-test scores of not experienced and experienced participants*.

	Mean	Std. Dev.	Std. Error Mean	T	t-two tailed	df	P	95% Confidence Interval for difference	
								Lower	Upper
Experienced	8.76	2.12	0.50						
Not Experienced	7.22	1.67	0.39	2.428	2.048	28	0.021	0.249	2.841

The p-value of 0.021 was found to be lower than 0.05, which is the significance level (cutoff) value set for 95% confidence interval, and based on the statistical data, as seen in Table 4, the null hypothesis is rejected. In addition to this, the t-two tailed value of 2.048 is lower than the t value of 2.428. The main outcome of this two-sample t-test was concluded as the difference between the two groups being statistically significant. For these reasons, the null hypothesis that there is no significant statistical difference between experienced and non-experienced participants was rejected. This result shows that the game developers' group is more advanced in using technology, and their capacity to accept technology is higher than the group of mining engineers.

Table 5.4 shows that two sample t-test scores of the participants divided into subgroups according to the frequency of the target groups' playing games are given. The target groups were classified into sub-groups based on the number of days they played games in a typical week as 0-2 days and 3-6 days. Table 5.4. summarizes the two-sample t-test scores of the participants grouped by their gaming frequency.

Table 5.4. *Two-sample t-test scores of gaming frequency.*

	Mean	Std. Dev.	Std. Error Mean	T	t-two tailed	df	P	95% Confidence Interval for difference	
								Lower	Upper
0-2 days in a week	7.96	1.91	0.45	0.077	2.048	28	0.939	-1.173	1.265
3-6 days in a week	8.01	1.68	0.40						

The null hypothesis is failed to reject based on the analysis presented in Table 5.4. The p-value was found as 0.939, which is higher than the determined cutoff value for the 95% confidence interval. The t-two tailed value was obtained as 2.048 and higher than the t value of 0.077. As a two-sample t-test decision, the difference between the two groups is statistically not significant. Therefore, “Ho: There is not a statistically significant difference between mining engineers and game developers regarding technology acceptance level of this game” is failed to reject.

The frequency of playing games has increased significantly in recent years, regardless of factors such as age, gender, or occupation. One of the important reasons for this is the widespread use of mobile devices. Participants answered the question about the frequency of playing games according to their current situation, but it is estimated that the frequency of playing games may vary. Therefore, it was concluded that there was no significant relationship between technology acceptance level and the frequency of playing games.

The questionnaire was also researched in detail to define groups of questions for specific concepts. The graphical interface and the use of the game, and the questions about the users' feelings were clustered and analyzed separately. The distribution of the ratings of the questions grouped according to the use of the game is given in Figure 5.6.

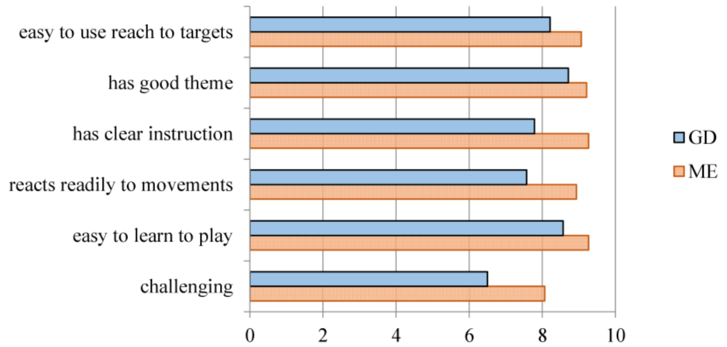


Figure 5.6. Ratings about the usability of the game.

As seen in Figure 5.6., it was observed that mining engineers had higher scores, while game developers who were more qualified in technology gave lower scores than mining engineers. The main difference between these scores is that game developers have more control over game technologies, game design and play different games than mining engineers. The ratings on the emotions that occur in the participants while playing games are given in Figure 5.7.

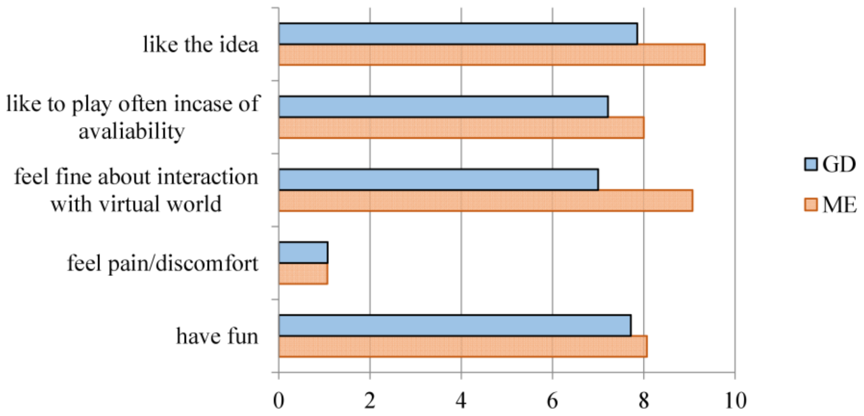


Figure 5.7. Ratings about the feelings/emotions of the participants.

When the feelings and emotions of the participants about the game are investigated, it can be said that the participants generally gave positive scores, and the mining engineer participants gave higher scores. The main reason mining engineer participants gave high scores was interpreted as their motivation to use game technologies in mining training and other fields of activity. The answers given to the questions in the questionnaires such as, “I like the idea” are among the most important indicators that game technologies can be applied to all engineering fields and see virtual reality technology as a necessity for best practice. Ratings related to the graphical interface of the game are presented in Figure 5.8.

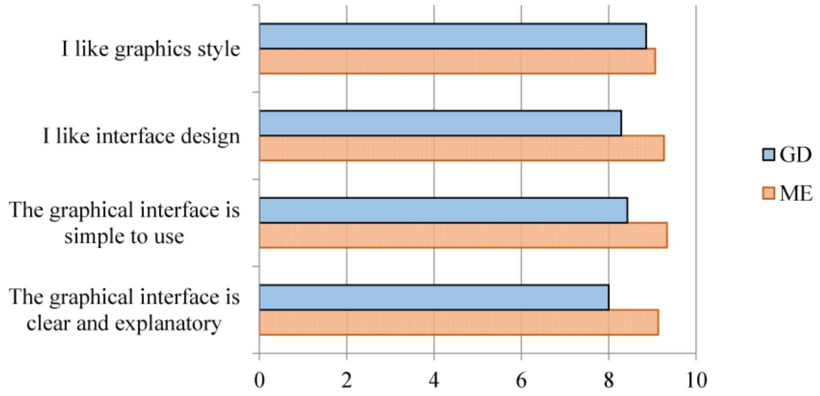


Figure 5.8. Ratings about the graphical interface.

It is observed that mining engineer participants generally tend to give high scores to questions about the game interface (Figure 5.8.). This is an expected result as the mining industry is in the process of adapting to game technologies. The game developers' score is over 8 and shows that the game design has achieved the desired success.

The questionnaires also included open-ended questions that highlighted the strengths and the flaws of the study, which will guide future research. In addition, the opinions of the participants were asked for the improvement of the game.

The majority of the participants answered the question "Which one did you enjoy most? PC or VR version? Why?" as VR, given that it was found to be more realistic. Some of the example answers are as follows:

> *"VR for sure, it feels more realistic. Following headlight in the mining feels very realistic."*
>
> *"VR version as it makes the game way closer to the real-life experience."*
>
> *"VR version should be used. In this way; we feel everything better and as close to reality."*

> *"VR version is the more enjoyable one. Because users can feel themselves in a real mine."*

> *"VR. Virtual images are much more realistic."*

> *"VR one is more realistic."*

> *"VR version is more attractive to feel everything better."*

> *"I think both are enjoyable, but the laptop version is more convenient to use rather than VR. This may be the reason why VR is not used in daily life."*

> *"Both of them."*

> *"If VR can be improved, it will be better than the Laptop version. However, the laptop version was more enjoyable since it was easy to play."*

The participants from both ME and GD target groups were enthusiastic about the game and gave highly positive answers on its potential, suggestions for improvement, and overall evaluation:

> *"It is great to have an opportunity to experience an underground mine in a video game. However, if it will be used for academic purposes, some engineering modifications can make the game more interesting. (ex: the gamer will arrange the operating system, and this arrangement can influence the total production of the mine. There can be some daily, monthly, or yearly challenges for the mine.)."*

> *"The mining game should be improved by adding questions and creating a dynamic scenario where actions will be highlighted. A measurement device might be added to trigger an action where the OHS supervisor is contacted by the system underground."*

> *"The game is close to reality. Events are clear and informative. Texts can be understood without the knowledge of mining."*

"Minimap can be added. Highlight on the target objects can be added. More realistic worker animations can be added. Questions and informative writings can pop up when the player is in the range."

"There are few games like that, so it can easily be the best."

"Different scenarios can be added to the situation. For example, a scenario which shows you where to go in emergency situations."

"It provides the preliminary information for especially workers and even interns."

"I think more questions can be used, and maybe an experience about an accident can be added."

"Design of the animation was pretty good and realistic and appropriate."

To sum up, both the quantitative and qualitative outputs underline the potential the MINING-VIRTUAL both for PC and VR versions. The future study will be shaped by the results of SUS and TAM questionnaires and suggestions from the participants.

CHAPTER 6

CONCLUSION

Mines are high-risk workplaces that are not in sight and are not easily accessible in this sense. When the fields in the world, which are adapted to technology and training tools developed through serious games, are examined, it can be said that all of them have common features with underground mining. It is possible to collect these common sides under two headings. The first is that it is difficult, impossible, or very expensive to create a real-life training environment in these areas. The second is that even if a real-life training environment is created, this will pose enormous risks.

Underground coal mines are among high-risk industries where injuries and fatalities are common. In addition to having a constantly changing work environment, the work and the machinery and equipment increased workers' risk. In addition to being a high-risk industry, mine accidents often affect more than one miner, and there have been numerous mining accidents resulting in mass deaths. Mine fires, collapses, methane and coal dust explosions that may occur in underground coal mines are the main causes of such accidents.

With the introduction of Occupational Health And Safety Law No 6331 in force in Turkey, workplaces are emphasized taking proactive measures. For this, the ability to identify risks is very important. One of the most important tools to reduce the risks that threaten miners' health and safety is to provide efficient training. Thus, it is necessary to benefit from new training tools and develop new training methods to increase the efficiency of the training.

The developments in computer-graphics technology and the advanced and accessible VR technology make it possible to develop more efficient training tools.

These technologies replaced traditional training methods in some areas. Training given in virtual environments does not include real-life risks. At the same time, there is no need to stop or slow down production due to training. Therefore it is cheaper. Once the simulation is developed, it allows training for every miner with the same scenario. Training all miners in the same scenario reduces the cost of training and ensures standardization of the training provided to all employees, which is difficult to achieve in real life.

Due to the fact that simulations do not involve any of the risks in real life, all kinds of high-risk scenarios can be created in virtual environments, and workers can enter these environments without being exposed to any risks. They will neither put themselves nor their colleagues at risk as a result of any wrong choices made by the miners during the training.

Virtual reality training, which has many advantages over traditional training methods, is widely used in many countries and in many high-risk sectors. In some countries simulations are also widely used in the mining industry, but in Turkey there is no widely used underground coal mine simulation for training purposes.

With the developed serious game MINING-VIRTUAL, the most common risks in underground coal mines are analyzed and played within the game. The underground coal mine was modeled in 3D, and an interactive mining education simulation was developed using Unity3D software. Necessary information is provided to the user through informative screens in the game, and it is expected to detect various risky situations. The results of the user’s preferences in the game are instantly shown to them so that they can have an idea about the possible consequences of their choices.

In an area such as underground coal mines where miner training is very important, the simulation developed to increase education efficiency will have a very important role.

PC and VR versions of MINING-VIRTUAL were evaluated with the questionnaires applied to a group of 30 people consisting of mining engineers and game developers. System usability and technology acceptance were analyzed through questionnaires. The SUS score is 85 for mining engineers and 87 for game developers and classified as “excellent.” Similarly, the learning ability of the system was found to be at an intermediate level for mining engineers and a relatively better level for game developers.

As a result of the questions about technology acceptance, it was seen that the average of the mining engineers group was 7.92, and the average of the group consisting of game developers was 8.88. The main reason for the higher score of game developers is that this group has a better command of technology and their capacity to accept new technologies is higher. The evaluation based on the paired t-test for the target groups indicated that the technology acceptance is more sensitive to experience and not related to gaming frequency. With the answers given to the questionnaires’ open-ended questions, the mining engineer group's motivation to provide mining training with a serious game has emerged. As a result, it was concluded that the MINING-VIRTUAL game is a multi-purpose game that can be used in technical training and occupational health and safety training in the field of mining.

Adaptation of mixed-reality for training purposes will be part of future research for different scenarios and mining operations. The evaluation of the users based on their decision-making processes and the other interactive responses in the game will be utilzed for a scoring system in the new version of the game. Multiplayer features will also be included in the new versions of the game to represent collaborative actions of users.

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APPENDICES

A. Game Script

The question script in the game is given below.

```
using UnityEngine;
using UnityEngine.UI;

using UnityStandardAssets.Characters.FirstPerson;

public class Soru : MonoBehaviour
{

    public bool soruldu;

    public GameObject soruObje;

    public Text soruText, c1Text, c2Text, c3Text;


    public GameObject destroyObject;
    public GameObject activeObject;

    public ParticleSystem system;

    public AudioClip trueClip;
    public AudioClip falseClip;
    AudioSource audioSource;


    public string soru, c1, c2, c3;

    public int cevap;


    float timer;
    public float gecikme;
```

```
    bool dogruCevap;


    void Start (){
        timer = 0;
        audioSource = GetComponent<AudioSource>();
    }


    void Update()
    {

        if (dogruCevap) {

            timer += Time.deltaTime;
            if (timer >= gecikme) {

                TrueGecikmeli ();
                dogruCevap = false;
                timer = 0;

            }


        }

    }

    void False()
    {

```

```
        soruText.text = "Yanlış Cevap";
        audioSource.PlayOneShot(falseClip);
    }


    void True()
    {
        soruObje.SetActive(false);

        audioSource.PlayOneShot(trueClip);
        dogruCevap = true;
    }

    public void TrueGecikmeli()
    {


        if(destroyObject !=null)
        {
            Destroy(destroyObject);
        }

        if(activeObject!=null)
        {
            activeObject.SetActive(true);
        }

        FindObjectOfType<FirstPersonController>().enabled = true;


    }

```

```

    public void Cevap1()
    {
        if (cevap == 1)
        {
            True();
        }
        else
        {
            False();
        }
    }


    public void Cevap2()
    {
        if (cevap == 2)
        {
            True();
        }
        else
        {
            False();
        }
    }

    public void Cevap3()
    {
        if (cevap == 3)
        {
            True();
        }
```

```
            else
            {
                False();
            }
        }

        public void Show()
        {
                soruObje.SetActive(true);

                soruText.text = soru;
                c1Text.text = c1;
                c2Text.text = c2;
                c3Text.text = c3;

                soruldu = true;
        }


        public void Hide()
        {
            soruObje.SetActive(false);
        }

    }
```

B. Questionnaire Template

Gamer Profile Questions	
Name and Surname	
Email address	
Profession	
Gender	
Age	
What is your expertise in game development?	
What is your expertise with VR/AR/MR environments?	
In a typical week, about how many days do you spend at least 30 minutes of playing video games?	
Would you consider yourself to be a..	
Console, PC/MAC, Smartphone, Handheld Device	
Which of the MR/VR devices do you usually play games on?	
What are your top favorite games of all time?	
What are some recent games you have enjoyed playing?	
System Usability Scale (1: Strongly Disagree 5: Strongly Agree)	**Mining Game**
I think that I would like to use this system frequently.	
I found the system unnecessarily complex.	
I thought the system was easy to use.	
I think that I would need the support of a technical person to be able to use this system.	
I found the various functions in this system were well integrated.	
I thought there was too much inconsistency in this system.	
I would imagine that most people would learn to use this system very quickly.	
I found the system very cumbersome to use.	
I felt very confident using the system.	
I needed to learn a lot of things before I could get going with this system.	
Technology Acceptance Model (Answers from 0 to 10)	**Mining Game**
I liked the idea that creating a game to teach and improve user interactions with new devices.	
The game helped me to getting used to VR environment and its systems interaction methods.	
Was playing the game fun in VR? (What did you like more? What would you want to change?)	
During the game, I felt pain and/or discomfort.	
The game is challenging and exciting in VR.	
It's easy to learn to play the proposed game.	
The game reacts readily to my movements in the VR environment.	
I did not find it hard to interact with the virtual world using gestures/controllers.	
I found the graphical interface clear and explanatory.	
The interface is simple to use.	
I liked the interface design. (Any advice on how to improve it?)	
The instructions of the game are clear. I understood what to do in the game and how.	
I liked the games theme.	
I liked the graphics style.	
I found easy to reach targets.	
I did not have problems finding targets in the screen.	
I would like to learn new interaction methods of different devices with games in the future.	
If I had the option to keep using the system at home, I would play with them often.	
Suggestions/Additional Comments on Tested Games	
Suggestions on the Mining Game	
What are the main strengths of the current game? Please explain.	
What are the main flaws of the game? Please explain.	
Which additional functionalities will be useful to improve the game?	
Insert here all your additional comments	