DEVELOPING SERIOUS GAMES FOR CBRN-E TRAINING: A COMPARATIVE STUDY OF COMPUTER AND VIRTUAL REALITY PLATFORMS

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ABSTRACT

DEVELOPING SERIOUS GAMES FOR CBRN-E TRAINING: A COMPARATIVE STUDY OF COMPUTER AND VIRTUAL REALITY PLATFORMS

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The resolution of a crisis and dealing with the consequences that come afterward of these events requires comprehensive training of authorized individuals. These training sessions consist of executing a series of different tasks based on a pre-defined crisis scenario. The main challenge of performing such an exercise is reusability. Repeating sessions can be costly in terms of money and time. Terrorism acts such as Chemical, Biological, Radioactive, Nuclear, and explosive (CBRN-e) attacks are classified among main crises and become a focused task across the globe. In this thesis, two CBRN-e based scenarios that are introduced in the EU H2020 European Network of CBRN Training Centers (eNotice) project's joint activities —France and Belgium— are implemented as serious games with the motivation of creating cost-effective and repetitive digital training sessions. The scenarios have different elements such as crisis management in hospitals, deployment of related units to the crime scene, objectives of individuals such as doctors, nurses, and investigation teams. Evaluation of the study has been executed by 16 CBRN-e experts from the eNotice that are also participated in the joint activities in France and Belgium. Experts played the games —both in Desktop and Virtual Reality— and answered questionnaires about presence, system usability, immersive tendency, technology acceptance model. Answers to the questionnaires and feedback indicated that enjoyment of the games had enabled users to enhance their learning while having a good time. Furthermore, Virtual Reality has much more improved the feeling of "presence" and created a unique experience, according to the participants.

Keywords: CBRN-e, Serious Games, Virtual Reality, Crisis Management.

ÖZ

CBRN-e Eğitimleri için Ciddi Oyunlar Geliştirilmesi: Bilgisayar ve Sanal Gerçeklik Platformlarında Karşılaştırmalı Çalışma

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Bir krizin çözümü ve bu olayların ardından ortaya çıkan sonuçlarla başa çıkmak, yetkili kişilerin kapsamlı eğitimini gerektirir. Bu eğitim seansları, önceden tanımlanmış bir kriz senaryosuna dayanan bir dizi farklı görevi yerine getirmekten oluşur. Böyle bir alıştırmayı gerçekleştirmenin temel zorluğu yeniden kullanılabilirliktir. Tekrarlanan seanslar, para ve zaman açısından maliyetli olabilir. Kimyasal, Biyolojik, Radyoaktif, Nükleer ve patlayıcı (CBRN-e) saldırılar gibi terörizm eylemleri, ana krizler arasında sınıflandırılır ve tüm dünyada odaklanmış bir görev haline gelir. Bu çalışmada, AB H2020 Avrupa KBRN Eğitim Merkezleri Ağı (eNotice) projesinin ortak faaliyetlerinde tanıtılan iki CBRN-e tabanlı senaryo —Fransa ve Belçika— uygun maliyetli ve tekrarlayan dijital eğitim seansları oluşturma motivasyonu ile ciddi oyunlar olarak uygulanmaktadır. Senaryolar hastanelerde kriz yönetimi, ilgili birimlerin olay mahalline konuşlandırılması, doktor, hemşire gibi bireylerin hedefleri ve soruşturma ekipleri gibi farklı unsurlara sahiptir. Çalışmanın değerlendirmesi, eNotice'ten Fransa ve Belçika'daki ortak faaliyetlere katılan 16 CBRN-e uzmanı tarafından gerçekleştirildi. Uzmanlar hem Masaüstü hem de Sanal Gerçeklikte oyunları oynadılar ve mevcudiyet, sistem kullanılabilirliği, sürükleyici eğilim, teknoloji kabul modeli ile ilgili anketleri yanıtladı. Anketlere verilen cevaplar ve geri bildirimler, oyunlardan keyif almanın, kullanıcıların iyi vakit geçirirken öğrenmelerini geliştirmelerini sağladığını göstermiştir. Dahası, Sanal Gerçeklik katılımcılara göre "var olma" hissini çok daha geliştirmiştir ve benzersiz bir deneyim yaratmıştır.

Anahtar Sözcükler: CBRN-e, Ciddi Oyunlar, Sanal Gerçeklik, Kriz Yönetimi.

To My Family

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LIST OF ABBREVIATIONS

CBRN-e	Chemical, Biological, Radioactive, Nuclear and explosives
eNOTICE	European Network of CBRN Training Centers
NES	Nintendo Entertainment System
VR	Virtual Reality
AR	Augmented Reality
MR	Mixed Reality
PC	Personal Computer
HMD	Head-Mounted Display
SDK	Software Development Kit
UI	User Interface
GUI	Graphical User Interface
SUS	System Usability Scale
TAM	Technology Acceptance Model
NPC	Non-Player Character

CHAPTER 1

INTRODUCTION

Today's societies need to make serious investments in training individuals who will work in various professional fields like health, science, security, and the economy. These pieces of training should be provided by creating a replica of the relevant profession's physical, environmental, and humanitarian conditions. Recently popular technologies such as software engineering, simulation technologies, serious games, artificial intelligence, and virtual reality have enabled these societies to focus their attention on training professionals in a modern way. This thesis focuses on the development of serious games to train CBRN-e specialists.

CBRN-e is the abbreviation for Chemical, biological, radiological, nuclear explosives. Defense of CBRN-e consists of protective measures taken in related situations like terrorism or natural causes. CBRN-e was known as NBC, abbreviated only nuclear, biological, and chemical during the Cold War. The R term was later added because of the radiological weapon threat, and later, e term that represented explosives was added. Different countries have different forces for CBRN-e threats. For example, Russian Federation has NBC protection troops while the United States army has a CBRN school. All New Zealand Defense Forces members are trained in the CBRN area in Spain, while the Military Emergencies Unit, National Police Forces, and Spanish Civil Guards have their own CBRN units.

The European Network of CBRN Training Centers, also known as eNOTICE [1], is a European Union H2020 project to establish CBRN-e training, testing, and demonstration centers to create awareness and preparedness before a CBRN-e crisis occurs. Optimizing the resources from the investments, effectively pooling and sharing them are some of the purposes of the eNOTICE. By organizing Joint Activities, information about the benefits of sharing their resources and the outcomes have been shown to these activities' participants. Demonstrations about CBRN-e training, duties of different professions, and different real-life-based scenarios are also the topics of these Joint Activities.

In the first part of this thesis, Hospital and Biogarden games, which are based on two different CBRN-e scenarios, are explained in detail. These games have been developed for the personal computer (PC) and virtual reality (VR) platforms.

In the second part of the thesis, a comparison between PC and VR versions of both games was performed using the questionnaires of presence, system usability scale, and technology acceptance model, answered by a group of CBRN-e professionals who tested these games.

1.1. The Goal of the Thesis

The research problem of this thesis and the motivation are developing serious games for CBRN-e training based on the scenarios introduced in the eNOTICE Joint Activities in France and Belgium. Developed serious games will provide testbeds to examine the practicality of using serious games in the CBRN-e field. Besides, the final work is evaluated by a group of experts to benefit from their comments and suggestions in future studies.

1.2. Aim of the Thesis

This thesis started with the previous study that is further explained in Chapter 3. From that point on, new objectives are determined for the study. The study was completed after the abovementioned experts played and evaluated the developed serious games during the eNOTICE Joint Activity, which took place in Ankara, Turkey, in February 2020.

The main objectives of this thesis are listed as:

- Determining the parts of the scenarios which can be turned into playable serious games;
- Designing the environments for the games based on the scenarios;
- Developing games that have not only training purposes but also entertaining learning experiences;
- Testing the games with participants who are professionals in the CBRN-e field;
- Evaluating the results of the surveys to determine the differences between VR and PC platforms in terms of presence, usability, and technology acceptance.

1.3. Developed Serious Games

For this thesis work, two serious games were designed and developed.

The Hospital game is based on the scenario that is introduced in the eNOTICE Joint Activity, which took place at Nimes, France, in 2018. In the game, players can select two different professions, Doctor and Nurse, responsible for the preparations before the arrival of the patients, meeting the patients, decontaminating the contaminated individuals, and giving them the correct treatment during a CBRN-e crisis. Patients are NPCs that are randomly selected due to their situation. Patients can be sent to a different hospital or proceed to treatment based on their condition. Players are expected to answer the questions about the treatment process, such as the patient's condition, which room to proceed with, and which treatment tool to use. The game is over once the player finished the treatment of all patients.

The Biogarden game is based on the scenario that is introduced in the eNOTICE Joint Activity, which took place in Brussels, Belgium, in 2018. In the game, players can select two different professions, Local Investigation and Restaurant Investigation. These two professions have separate tasks of taking samples from their areas and sending them via drones to the analysis team. Players both control the drone and the analysis team. After that, both teams report to the crisis center. The Local Investigation team proceeds to the decontamination area if they are contaminated. The players also control the decontamination team. The decontamination team is responsible for choosing the correct instrument such as detectors, taking the contaminated team members to the decontamination area, quarantining the area until the decontamination process finishes, starting the decontamination process and reporting the decontamination results to the crisis center.

1.4. The Contributions and Novelties

The main contributions of this thesis are as follows:

- Two fully playable serious games were developed with the scenarios designed by eNOTICE to be tested by a CBRN-e community of experts in the field. These games are designed as tools that provide real-time training without excluding the fun factor.

- The games were developed on PC and VR platforms.

- These games were played by CBRN-e experts in an eNOTICE Joint Activity in February 2020 and evaluated in terms of Presence, System Usability Scale, and Technology Acceptance Model.

- There was a previous work about this topic which is further explained in Chapter 3. A scenario-based game generator was created, and two serious games, Hospital and Biogarden, were developed with the basic features to compare a real game and a generated game by the game generator [2]. In this thesis work, these games are entirely re-designed with non-linear scenario features, upgraded graphics, mechanics, and gameplay.

The work reported in this thesis made the following joint publications possible:

- Surer, E., Erkayaoğlu, M., Öztürk, Z.N., Yücel, F., Bıyık, E.A., Altan, B., Şenderin, B., Oğuz, Z., Gürer, S. and Düzgün, H.Ş. (2020). Developing a scenario-based video game generation framework for computer and virtual reality environments: a comparative usability study. Journal on Multimodal User Interfaces, pp.1-19.

- Altan, B., Gürer, S., Alsamarei, A., Demir, D. K., Düzgün, H. S., Erkayaoğlu, E., Surer, E. (2020) "Serious Game Development for CBRNe Training: A

Comparative Analysis in Virtual Reality and Computer-Based Environments," SICC Series 2020 – 2nd Scientific International Conference on CBRNe, 10-12 December 2020.

- A journal article including this study has recently been submitted, and it is currently under review.

1.5. The Outline of the Thesis

The rest of the thesis is outlined as follows: In Chapter 2, a literature survey of serious games, VR, and CBRN-e training are presented. In the following section, Chapter 3, the development process of the Hospital and Biogarden games is explained in detail. In Chapter 4, the comparison results of VR and PC versions of the games are given. In Chapter 5, the questionnaire results about Presence, System Usability Scale, Technology Acceptance Model, and answers to the open-ended questions are discussed. In Chapter 6, the conclusion of the study and potential future work are presented.

CHAPTER 2

LITERATURE REVIEW

2.1. History of Video Games

Video games have become an industry of almost 100 billion dollars, recognized by the entire world [3]. By 2017, video games had more than two billion users worldwide [4], and the amount of time spent playing video games is 6.5h/week [5]. Decades of development, success, and failures made video games what they are today. Before discussing the history of video games, the term should be explained. According to research about the definition of a videogame, “A game which we play thanks to an audiovisual apparatus and which can be based on a story” [6] can be the general explanation of what a video game is. The audiovisual apparatus defined can be a television, computer screen, or nowadays smartphone screens. The earliest known game played by the public is the Bertie the Brain, a game of Tic-Tac-Toe built by Josef Kates for the 1950 Canadian National Exhibition [7].

After Bertie the Brain, Nimrod computer, which is used to play the game of Nim [8], Tennis for Two, which is a game that simulates tennis with an oscilloscope [9], and many more have been developed until 1972, which is the development date of the first home video game console, the Magnavox Odyssey and its arcade game named PONG. Everything begins with creating a television set, including interactive games, which gives birth to the PONG, and the world would never be the same [10].

PONG was just the beginning; until the mid-80s, different video games and game consoles were created by different companies. Nintendo and their Family Computer also known as NES (Nintendo Entertainment System), became a massive hit with their legendary titles such as Super Mario Bros. NES as one of the third generation of video game consoles, sold over 35 million in the US and nearly 62 million sold globally [11]. Companies like Sony, Microsoft, and Sega created their video game consoles and dominated the market from time to time. Sega with Mega Drive, Saturn, and Dreamcast were among Nintendo’s primary competitors in the video game industry until 1994. In 1994 Sony stepped to the market with their PlayStation and sold over 120 million units [12]. After that, Sony became the leader of the video games industry until today with their PlayStation, PlayStation 2, PlayStation 3, PlayStation Portable, PlayStation 4, and finally, the latest version of the console PlayStation 5 with huge titles like Crash Bandicoot, God of War, Uncharted, and Last of Us.

When discussing the video game industry, PCs must be mentioned separately, given their huge success in the industry. MS-DOS and Windows operating systems became platforms for many popular game titles over the years, such as Doom, Quake, Wolfenstein, Volfied, Half-Life, and many more.

In this thesis work, two serious games are developed on the PC platform. Furthermore, VR versions of the games have been developed. In the past decade, VR gaming platforms such as Oculus and Steam VR became popular, which will be further discussed in Section 2.4.

2.2. Concept of Serious Games

"A serious game is a game in which education (in its various forms) is the primary goal, rather than entertainment" [13]. It is a platform that uses game design, elements, and game art to achieve its training or education goals by allowing users not only to learn but apply what they learn in a specific scenario [13]. One of the early examples of serious games for preparedness is 3D Wild Land Fire Simulation, which allows firefighters to train over a network on various scenarios to make decisions under stressful situations [13]. It allows simulating multiple scenarios in a controlled and safe environment that are difficult to replicate in real-life situations, such as diseases or disasters, which allow users to learn and train for these scenarios [14]. Using scenarios for training is an effective strategy for training [15].

Serious games have been used in health care, such as board games for management simulations and training simulations [16]. They were implemented in triage training, a process for decision-making that prioritizes mass casualties for treatment; Jarvis and de Freitas [17] stated that more accuracy was achieved among participants who utilized the serious games concerning specific measures in applying the triage protocol. Smith et al. [18] explain another example of utilizing serious games for decision making. They developed a matrix game (scenario-based games that develop over a few rounds), which motivates critical reflection on readiness and response for infectious disease outbreaks. Their result suggests that such an application can reflect real-world decision-making during a crisis and give opportunities to test ideas and test cooperation through global health challenges.

This thesis originated from several studies that have been made in the Middle East Technical University. One of those studies is based on developing a scenario-based game generation framework [2]. That study aims to create a video game generator with different scenarios, and those scenarios were the same scenarios that are used in this thesis work, Hospital and Biogarden. A comparison has been made between the framework and two developed serious games based on the scenarios in the study. In this thesis, these serious games can be considered alpha or pre-alpha versions of the games developed and improved. This thesis started after evaluating the questionnaire results of the previous work, and those results became helpful resources in developing the games.

Serious games can be used as educational tools. Girard C. analyses recent studies [14] to demonstrate serious games as new educational tools. The article discusses two concepts, video games and serious games, and their differences. This result concludes that serious games are a subfield of video games with a specific purpose and target audience. Examples from various research show divergent ideas about using video games for educational tools and serious games. In the light of the results, in terms of learning skills, serious games are more effective tools than video games, but the author still underlines that an absolute result cannot be reached by merely looking at nine studies that have been discussed in the article.

Julia Smith discusses a serious game called Pangea 2030 [18], which has been developed by Global Affairs Canada and the Department of National Defense. This serious game takes place in an infectious disease outbreak situation, and the authors mentioned that it could be used as a training tool for these kinds of crisis management scenarios. The study gives global coordination and ideas to test for health professionals. It also sets an example of the advantages of serious game areas like global crisis management. Rosy Tsopra developed a serious game called AntibioGame [19] for teaching medical students about antibiotic use. The game contained had graphics, educational questions, and gamification methods like mascots, avatars, rewards, and leaderboards. This game sets a good example for the usage of serious games in medical education. The participants considered the game "good" with a 60 score on the MEEGA+ scale [20]. VR4Health [21] is an application for medical education by using a Head Mounted Display (HMD) VR device. Apart from learning anatomy by making the students interact with the virtually created organs, this study's main contribution is the teacher helping mechanism. While students are using it, the application registers information about their learning process. The application saves information like what structures the student inspected and how long the student dedicated to each structure. This study shows that serious games and VR educational tools can benefit teachers and students by storing the session information for analysis.

Research has been made to show the effects of serious games that are developed in virtual reality for experiential learning. In the study, Enas Alrehaili has used the RPG (Role Playing Game) type and tried to teach the behavior pattern of honeybees by making them do specific tasks from the eyes of a honeybee [22]. Also, the study comes up with two different kinds of VR: IVR (Immersive VR) and DVR (Desktop VR). IVR is the VR by using today's HMD technologies, and DVR is the PC version of a game. Results show that there are no significant differences in terms of experiential learning between the two versions. However, according to the participants, the IVR version has provided a rich, engaging, and motivating experience.

Finally, studying different approaches and topics of the game development life cycle has been used for this thesis work [23]. Results of this study can become references while developing serious games in the CBRN-e domain.

2.3. Evaluation of Results

2.3.1 System Usability Scale

System Usability Scale (SUS) is used to evaluate the usability of a specific system via questionnaires. The questionnaire consists of 10 questions with a 0–5-point scale. John Brooke created the SUS questionnaire, which evaluates services and products such as hardware, software, mobile devices, websites, and applications. The score calculation for SUS can be calculated by the formula below [24][25]:

- X = Sum of the points for all odd-numbered questions – 5
- Y = 25 – Sum of the points for all even-numbered questions
- SUS Score = (X + Y) x 2.5

2.3.2 Presence

Witmer stated that [26], Presence is about several factors such as Control, Sensory, Distraction, and Realism. Control is explained as the degree of control, immediacy of the control, anticipation of events, mode of control, and physical environment modifiability. Sensory factors are sensory modality, environmental richness, multimodal presentation, consistency of multimodal information, degree of movement perception, and active search. Distraction factors are isolation, selective attention, interface awareness, while the realism factors are scene realism, information consistency with the objective world, the meaningfulness of experience, and separation anxiety/disorientation. Presence questionnaires used in this thesis are directly derived from these factors. Each question can be about one or more factors and be answered based on a 1 to 7 scale.

2.3.3 Technology Acceptance Model

Davis [27] states the details of the Technology Acceptance Model questionnaires as: "The model, referred to as the technology acceptance model (TAM), is being developed with two major objectives in mind. First, it should improve our understanding of user acceptance processes, providing new theoretical insights into the successful design and implementation of information systems. Second, TAM should provide the theoretical basis for a practical "user acceptance testing" methodology to enable system designers and implementors to evaluate proposed new systems before their implementation." The questionnaire consists of 16 questions with a 0–10-point scale.

2.4. Virtual Reality-Related Technologies and Researches

Virtual reality (VR) can be described as an experience similar or completely different from this world's reality. VR is creating the experience with devices such as headsets or head-mounted displays (HMDs) as a technology today. Morton Heilig has created the design of the first HMD in 1960. The name of the device was "The Telesphere Mask" [28]. After that, another device named Sensorama has been developed by Heilig, which is an immersive movie experience with 3D images, wind, vibration, and stereo sound is involved [29]. The Sword of Damocles can be considered the first HMD with a head tracking feature in 1968 that Ivan Sutherland has developed [30]. Before the Sword of Damocles, Ivan Sutherland stated his thoughts for virtual environments in "The Ultimate Display" [31], which made the definition of an ultimate display as; "The ultimate display would, of course, be a room within which the computer can control the existence of matter." Currently, VR technology is getting closer to this idea. The industry of VR provided solutions for the medical, automotive industry, flight simulations, and military purposes. One example is the VR technology developed by the National Aeronautics and Space Administration (NASA) [32]. Apart from HMDs, there was research about creating virtual environments with different technologies. CAVE was an example of a virtual environment, a room-sized visualization project which contained stereoscopic image projection on room walls and provided a different experience with an enhanced field of view [33]. BOOM was a project in which Fakespace Labs developed and introduced a VR tracking device named Binocular Omni-Orientation Monitor, BOOM [34]. Nintendo created a device called VR-32, which was later named Nintendo Virtual Boy, as the first console with a VR display [35]. In 1975, Myron Krueger created a video game project based on the interaction between two users in a virtual environment by visualizing their silhouettes in 2D space and interacting with each other [36]. In the late 1990s, there were several research outcomes about VR and virtual environments.

Augmented reality and mixed reality are terms that are used to define different layers and types of virtuality and reality. Augment reality can be described as "An interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory" [37][38]. The main examples for AR are smartphone games such as Pokémon Go and Jurassic World Alive, also known as fitness games where players travel around the real world and play the game by finding game elements in specific locations [39]. Azuma explained augmented reality with features such as combining real and virtual content, real-time interaction, and a 3D system [40].

Mixed reality (MR) can be described as "The merging of real and virtual worlds to produce new environments and visualizations, where physical and digital objects co-exist and interact in real-time. Mixed reality does not exclusively occur in either the physical or virtual world but is a hybrid of reality and virtual reality" [41]. Today's most advanced MR device is the HoloLens from Microsoft. HoloLens (Figure 1), also known as Project Baraboo, is the first device to use the Windows Mixed Reality platform as part of Windows 10 [42]. The device is working with an accelerometer, gyroscope, and magnetometer for tracking movements [43]. Milgram introduced a continuum called reality-virtuality [44]. The research explains how difficult it is to distinguish between virtual reality and augmented reality and introduces different virtuality and reality spectrum types. As an improvement to Milgram's work, Tham introduced the modern reality-virtuality continuum element [45].

Figure 1: Microsoft HoloLens, a mixed reality device [46].

In this thesis, serious games are developed on PC and VR platforms. Before developing a game in VR, some technological capabilities and constraints must be considered. Also, the specifications of the selected game engine should be determined. VR applications offer immersion, interactions, and imagination [47]. VR allows immersion in learning, manipulating 3D objects, and multi-user collaborative training [48].

The higher fidelity the VR displays, the higher the sense of presence and the feeling of being there [49]. Using a 3D visual environment for online cooperative training allows reparative training for uncommon situations in safe and reproducible settings [50]. Mixed Reality training can train users to make difficult decisions in various stressful situations and help rehearse various scenarios to improve skills [51]. VR-based training tools have been used with real-life traditional drills, and many government agencies have started utilizing such tools [48]. There are few types of VR training systems, and the first one is utilizing desktop setup with either monitors or projectors. Maciejewski et al. [52] suggest using the CAVE automatic virtual environment systems, the high immersion version of a six-faced cubical room with 3D projectors aimed at the walls to provide immersive simulation by tracking the user's head. Such a system will not require the users to wear an HMD while allowing them to see their bodies in the projected environment. Maciejewski et al. state that such a system is cost-effective, safer for trainees, and allows training in multiple scenarios.

VR is one of the popular technologies of recent years. The enormous size of virtual environments is a limiting factor for current developments in VR. Teleporting mechanism in virtual environments is an approach to overcome that limitation. In a study about teleporting through virtual environments [53], the specifications of teleporting mechanism have been discussed. Path and environment scaling have been achieved using the spatial updating method to show the effects of rotational self-motion cues in VR for pathfinding.

Apart from the studies that have been made in similar fields, the emotional consequences of VR were analyzed [54], and the results show the negative effects of VR in terms of emotional consequences. VR has been generally discussed with its benefits, but the side effects of VR are motion sickness, nausea, or vertigo. However, this study's results show that VR can elicit negative emotions in the users depending on the content. So, the negative sides of VR must be considered as well as the positive sides while creating content for the technology.

The main feature of VR applications is the presence which can be defined as the feeling of being or acting in some other place, and this feeling can be measured with presence questionnaires. There is a study about the application of these questionnaires in VR [55]. Because VR itself is a tiring experience, the need to go in or out of VR to answer the questions can be troublesome for the users. Results show that there is not any significant difference between the answers that participants have made. However, answering the questions in VR increases the consistency of answers and saves time because the participants do not need to remove their headsets between processes.

There are two fundamental setups in VR applications: room-scale and seated experience. Room-scale can allow users to move freely in the virtual space using sensors, and the seated experience creates an environment in which users can interact by sitting. These two setups have been compared with a medical application called epidural preparation by developing a serious game [56]. This way, the effects of serious games on a medical topic have been discussed and compared between room-scale and seated experiences using quantitative and qualitative methods. Results of this study show that room-scale setup can create a more immersive experience than the seated setup. To analyze the effects of VR on users, HMDs, and Desktop displays have been compared using a driving simulation game [57]. Mainly, finding out the optimal time spent on VR environments and Desktop environments has been discussed. Furthermore, this study shows that less time can be spent in a VR environment by discussing motion sickness and simulator sickness.

David Checa analyzed 86 articles for measuring the usability of learning and training with serious games [58]. By doing so, creating a road map for future studies has been possible. Different game engines and different HMDs on learning have been evaluated. For example, the most preferred game engine is Unity, but a few games that have been developed in Unreal Engine had an impact on experiencing VR.

2.5. Choice of a Game Engine

A game engine is development software that is used to create games. Until the 1990s, developing games with third-party software was not common. Some game creation systems were introduced, such as Thunder Force Construction [59] and War Game Construction Kit [60]. After that period, the term "game engine" came up with popular first-person shooters such as Doom and Quake, developed by Id Software [61]. Later in 1998, Unreal was created by Epic Games, which lay the foundation for the Unreal Engine known today, which was more popular than Id Software's id Tech game engines [62]. This thesis work uses the Unity game engine for both PC and VR versions of the games.

In this thesis, the Unity game engine (Figure 2) was used. Unity game engine uses C# as a programming language instead of C++ used by Unreal Engine and CryEngine. C#

is a modern object-oriented programming language that can be used with even basic programming background, while C++ has a more complicated nature and can be challenging to use. For this reason, Unreal Engine created Blueprint visual programming system for users without or with a little programming background. Apart from that, Unity integrates VR development with SDKs of Oculus, Open VR, and Steam VR.

Figure 2: Unity Game Engine screenshot from the Hospital Game.

Some of the publications and research about Unity game engine are as follows: The comparison between CryEngine, Hero Engine, Source Engine, Unity, Unreal Engine 3, and Vision Engine has been made [63] in terms of platform dependencies, interface supports, API supports, inbuilt physics engine supports with pathfinding capabilities. The study also indicates the world and GUI editor supports, rendering techniques, and inbuilt supports of those selected engines. According to the survey done on 100 executives from different game industries, the Unity game engine is the most popular game engine. Also, in terms of practical industry acceptance of popular game engines, the Unity game engine has over 60% acceptance compared to the other game engines.

User experience is an essential metric for software products like video games. In contrast to other studies on the field, there was research about evaluating the usability of the Unity game engine, a software used for game development [64]. According to the feedback from selected developers, there were no major problems but minor concerns regarding the usability of the Unity game engine. One of the main strengths of the Unity game engine is its cross-platform application development. There is a study about the implementation of the cross-platform game called Air Hockey [65]. Air Hockey has a table that looks like a background, two paddles of two players, and the puck which players hit for scoring. The game is developed for Android, Windows Phone, and Windows platforms. The cross-platform development feature of the Unity game engine was used in this thesis work to develop VR and PC versions of serious games by just changing the build options from the user interface.

2.6. Research Area of the Thesis

CBRN-e is an acronym for Chemical, Biological, Radiological, Nuclear, and Explosive materials. These materials can be weapons of mass destruction when they fall into the wrong hands. Also, these events can happen accidentally [66]. Countries worldwide are working on having preparations and prevention mechanisms in case of a CBRN-e related event [67]. Types of CBRN-e weapons can be listed as nerve, blister, blood, choking and incapacitating agents for chemical weapons [68]; bacteria, viruses, and toxins for biological weapons [66][68]; radiological weapons that spread radiation, nuclear weapons as the atomic bombs that hit Hiroshima and Nagasaki [69], and finally explosives such as nitroglycerin. For example, Ricin and anthrax were sent to different people through the mail as a biological attack [69].

This thesis aims to develop serious games on CBRN-e training. Individuals trained for CBRN-e events must recognize CBRN-e incidents, know about the protection of responders and the safety of the victims, medical and psychological considerations, and the basic principles of detection and sample taking [70]. Due to the unusual nature of the CBRN-e agent, medical personnel usually have no familiarity with its health risk. To meet the required competency standards for CBRN-e crises, emergency respondents need to go through an adequate education and training phase. Threat identification and risk analysis are important components of medical personnel training, and having enough information about the characteristics of CBRN-e threats and acquiring fundamental skills to perform their tasks are essential. The lack of knowledge can have an impact on morbidity and mortality rates [71]. The regular training for CBRN-e cases may include using live agents to train responders for CBRN-e cases. This is done by working with real hazardous materials to include the stress factor in the training. This will allow responders to use the equipment effectively to protect themselves while working with such materials and help them have confidence with the equipment and the team [72]. Moreover, Sandström et al. [73] suggested using a table-top exercise card system based on various scenarios, and their study aimed to create more generic tools regardless of the scenario. It is primarily for health care professionals, but it may also allow multidisciplinary participants. e-Learning is also used in training for CBRN-e emergencies, and it is participant-oriented and allows flexibility in time and place for learning [74]. A study about CBRN-e disaster management shows how software engineering has been used to manage CBRN-e and adapt to its evolving needs [75]. Austrian Armed Forces have developed ABC-IS software, which discusses ABC-IS software development, design, and test processes. Also, it shows that how software engineering can be an effective field of study for global crises like CBRN-e attacks. Different studies on the education of health professionals for CBRN-e emergencies have been compared by Mayumi [76]. These studies include computer-generated simulations, table-top exercises, face to face lectures. The study shows that the discussed articles have contents like decontamination, disaster management, and briefing. Furthermore, the study gives information about how health professionals can access their research.

The scenarios of the serious games in this thesis are based on the eNOTICE project. On the website of the eNOTICE project, the goal of the project is stated as: "to establish a European network of CBRN training, testing and demonstration centers aiming at enhancing CBRN training capacity for improved preparedness and incident response through increased collaboration between CBRN training centers and practitioners' needs-driven CBRN innovation and research" [77]. The eNOTICE project's consortium sets up an operational network by organizing joint activities between eNOTICE members and external partners. There are some publications of the eNOTICE project about their work, their workflow, research domain, and documents. As stated in one of the publications of the eNOTICE D2.1–Catalogue of CBRN TCs, Testing, and Demonstration Sites [78]: "A CBRN Training Centre is a civil or military organization that provides education and training in the field of public safety and security. The Training Centre can be monodisciplinary, such as firefighting, medical, police or military academy and/or multidisciplinary, including disaster management. Education and training cover the thematic areas of Chemical, Biological, Radiological and Nuclear. The eNOTICE project focuses on those Training Centers with a CBRN thematic capacity and corresponding infrastructure to organize first responders or civil protection practitioners such as demonstrations, tests, tabletops, field exercises, simulations, and serious gaming." The eNOTICE defines the key actors of the network of CBRN training centers as the demanders, suppliers, intermediary facilitators, needs, capabilities, facilities, and objectives in a CBRN or CBRN-e related situation [79].

CHAPTER 3

PREVIOUS WORK

3.1. Initial Prototypes of Developed Serious Games

Joint Activities were organized within the eNOTICE consortium in 2018, including participants from Middle East Technical University (METU). In these events, subjects such as CBRN-e training, the cost of these pieces of training, and sample scenarios based on real crises were discussed. METU team, part of the eNOTICE consortium, informed the participants on how the serious game concept can reduce the costs of these pieces of training and create repeatable, educational, and dynamic training environments. After that, research on the use of serious gaming in the CBRN-e domain was presented [80]. In the study (Figure 3), 14 CBRN-e professionals from different backgrounds gave feedback about their expectations on using serious games in the CBRN-e domain.

Figure 3: Initial Prototype of Hospital Game.

3.2. First Playable Versions

In the summer of 2019, eNTERFACE’19, an international workshop event where participants from different universities were included, was held at Bilkent University between July 8th and August 2nd of 2019. In this event, METU took part in developing a game generator based on CBRN-e scenarios. The project included a game generator to create different games based on a linear scenario using pre-defined assets. For the evaluation and the comparison of the generator, two serious games based on the Hospital and Biogarden scenarios of the eNOTICE joint activities were developed. Games were improved from the previous prototypes, which are shown in Figure 4. Although the developed serious games improved their predecessors with new features like third-person camera, different actions, new environmental setups, and improved UI elements, they still were incomplete in terms of non-linear scenario implementation, providing different choices, animations of actions, different characters, and professions, more detailed dialogs, mechanics, and enjoyable game elements. Games were played by participants with game development backgrounds and got positive feedback and suggestions about future work.

This thesis work is the continuation of the previous work mentioned above, and the abovementioned games were entirely newly designed, created, and finalized based on the feedback from the previous studies and played by the participants from the eNOTICE community at the Joint Activity, which was held in February 2020 in Ankara, Turkey.

Figure 4: Screenshot from First Playable Version of Hospital Game.

CHAPTER 4

MATERIAL AND METHODS

4.1. Identification of Requirements

The development of a serious game begins with determining the requirements of the field on which the game will be built. CBRN-e training is the main topic of this study, so the first step is to answer this question: "What is the main reason for CBRN-e professionals to use serious games for their training?"

CBRN-e is a subject that concerns the safety of civilians in a country. Terrorism attacks and wars can contain CBRN-e related risks. Because of that, governments focused on the need to train their special forces in this area over the years. Police forces, medical personnel, special security forces, military forces, scientists are examples of the individuals that need to be trained in case of a CBRN-e threat. Creating a training environment and executing a session has enormous costs, both economic and timewise. Simulations, or as in this thesis's case, serious games, can be perfect tools to avoid these costs. Therefore, the focus of this study is to create a cost-effective solution for the training of CBRN-e professionals.

Another question to answer is "What are the main phases of CBRN-e training?"

CBRN-e training sessions are usually based on scenarios that contain specific actions/response phases for the trainees, such as preparation of quarantine zones, decontamination process, treatment, and evacuation of civilians. Accordingly, a serious game that is based on CBRN-e training must implement pre-determined scenarios and teach its players what to do in certain situations. These scenarios need to be examined so that the tasks of each professional are determined, and critical points of the scenario should be given to the development team as an implementable artifact.

The final question to answer before starting the development cycle is, "Will the final product be a training simulation or a serious game?"

The key difference between a formal training simulation and a game is the fun factor. In this thesis, the proposed serious games have fun factors like driving vehicles to create an entertaining experience while training the participants. The balance between the fun factor and learning must be provided to create a serious game.

In the games, questions about CBRN-e crises are asked at specific points of the game to teach the players how to react to specific tasks.

4.2. Game Development Lifecycle

There are different approaches in the game development lifecycle, which are based on similar concepts of the software development lifecycle. Saiqa Aleem classified the game development lifecycle studies based on the previous studies on software development and game development lifecycles. The classification of these topics and the frequency of the articles on each topic have been shown in the study. The development process of the serious games that have been developed in this thesis can be explained based on the topics of that classification [23].

The main purpose of this thesis is to develop serious games for CBRN-e professionals to train in the field and give the required responses during a crisis. Our team included a software engineer responsible for the game logic, implementation, and combining the artifacts from other team members. Also, a scene designer who creates the visuals and level designs of the game and an animator who creates the character animations are members of the project team. The artifacts of this study —two serious games with PC and VR versions— have been played at the eNOTICE Joint Activity, which took place in Ankara, Turkey, in February 2020. The development of the games began in September 2019. During six months, four serious games, including PC and VR versions, were completely redesigned, developed from scratch, and finalized for eNOTICE participants. Participants, CBRN-e experts from various countries within the eNOTICE project, were between the ages of 28 and 56.

Requirements of both games are based on the needs of the CBRN-e professionals. To determine those needs, information from the eNOTICE Joint Activities has been used, such as presentations of CBRN-e professionals from different areas and different CBRN-e scenarios to create the baseline of the developed games. During the study, two gaming laptops and two HTC Vive VR HMDs were used. Besides, for the scene design of the games, some assets for the hospital and laboratory environment were bought from the asset store.[81][82]

The teams with multiple software engineers can communicate with description languages such as the UML model. In this thesis, a system description language has not been used; instead, a verbal discussion has been made between team members. Reusability is the key factor of this thesis. Because of the time and resource-consuming nature of CBRN-e training, serious games are developed in a reusable manner.

There were various projects developed by METU Multimedia Informatics Department that are based on the eNOTICE scenarios. One of these projects was "Developing a scenario-based video game generation framework for computer and virtual reality environments: a comparative usability study" [2]. In that study, a game generator has been developed that takes pre-determined scenarios as inputs. Also, for comparison, two serious games were developed based on Hospital and Biogarden scenarios.

These serious games can be thought of as the alpha version of this study. Considering the feedback from that study, there were drastic changes made in the project, and this study's serious games were developed from scratch. These changes will be explained in the following sections.

4.3. Storyboard and Gameplay

The scenarios/stories of the games are based on two scenarios that are introduced in Nimes, France, and Brussels, Belgium in 2018 eNOTICE Joint Activities. The hospital scenario was introduced in France, and the Biogarden scenario was introduced in Belgium.

4.3.1 Hospital Game

The hospital game scenario begins with the arrival of a plane from London to arrive at the Nimes airport. Armed attackers carry out a terrorist attack while more than 250 passengers are waiting in the lobby. The attackers are neutralized, but there are many injured. Also, due to some suspicious packages in the attack, the wounded are transferred to the nearest hospital since it is suspected that the attack is related to CBRN-e. Hospital management quarantines the entire hospital upon arrival based on the suspicion that the attack is related to CBRN. Hospital staff checks whether there are sufficient water and medical supplies. The part up to this section has been depicted with narrative in the game, after which it was designed as a playable part.

In Figure 5, the hospital secretary can be seen when talking to the hospital staff and informing them that the decontamination area has been set up.

Figure 5: Hospital scenario secretary sequence.

An ambulance brings patients to the hospital. As seen in Figure 6, players can drive the ambulance as part of the mini-game sequence. The hospital staff completes the preparations (Washing hands and wearing a mask). Doctors and Nurses welcome patients. Doctors determine the condition of the patients. There are three conditions of the patients in the scenario: Not Critical, Critical, Good. If the patient's condition is "Good," the patient is taken to the waiting area and sent out of the hospital after the necessary controls are made. If the patient's condition is "Critical," the patient is sent to the emergency response center, and the doctor will make an emergency intervention there. Later, the treatment of these patients continues over the “Not Critical” scenario. If the patient’s status is “Not Critical,” the patient is sent to the decontamination area, and the decontamination process is performed.

New clothes are provided to the patients by the Nurse. The Nurse calls the secretary to find out whether there are enough beds in the hospital. If there are enough beds available, she accompanies the patient to the hospital. If there are not enough beds, the patient is transferred to another hospital. At the hospital, the doctor determines which CBRN-e related condition the patient has. If exposed to the radioactive substance, the patient is sent to RN Ward, Chem Ward if exposed to a chemical substance, Bio Ward if exposed to the biological substance. The nurse accompanies the patient to the Wards (If the patient needs to be kept under quarantine, the staff will make the necessary clothing changes if his condition is contagious).

Nurses take different actions for the patient in each ward. For example, Chem Ward -> Put Oxygen Mask, BioWard -> Give Vaccine, RN Ward -> Put IV. Then, the patient starts the treatment process for a certain period.

Figure 6: Hospital scenario ambulance driving mini-game.

The Doctor and Nurse welcome new patients, and this process continues until all the patients are accepted to the hospital. The hospital scenario is implemented with its non-linear parts. Actions of the player or the randomized conditions of the patient result in a different choice pattern for each patient. As seen in Figure 7, players can sometimes see the other main characters’ status by a mini camera on the left side of the screen. This feature is triggered when players wait for some process to finish, for example, waiting for the decontamination process to be completed.

Figure 7: Player as a doctor who waits for the nurse so that the decontamination process starts.

In Figure 8, the decontamination sequence can be seen. Patients who are NPCs are completing their decontamination process in a shower cabinet (decontamination area). The Nurse is waiting for the process to be finalized, and after that, a new action of giving clean clothes to the patient starts.

Figure 8: Player as a nurse during the decontamination sequence.

4.3.2 Biogarden Game

Biogarden game scenario begins with two different events on the day of the Champions League final. The first incident is the reporting of poisoning of a person from a pizzeria called BioPizza in a restaurant near the stadium, and the second incident is the discovery of a secret laboratory called Clandestine Lab. Considering that both events may be related to CBRN-e, two different teams are assigned to investigate the events. These teams simultaneously lead the investigation. The part up to this section has been described in the game with a narrative, while the latter part was designed as playable. Restaurant Investigation Team enters the restaurant. Necessary samples are collected from the pizzeria named BioPizza where the poisoning incident occurred. In Figure 9, as a restaurant team member, the player collects food samples from the restaurant by pressing the interaction button E. At the same time, other NPCs, such as decontamination members, can be seen with suits while doing their investigation. Samples are sent to the mobile laboratory called B-Life Lab via a drone for analysis. In the game, the drone is controlled by the player (PC Only).

B Life Lab Team: Takes samples from the incoming drone. Analyzes the samples. Notifies the test results to the Restaurant Investigation Team. There are two different results. Either results are clear, and BioPizza is a simple poisoning case, or results indicate that BioPizza is a CBRN-e related biological weapon, and this biological weapon is promptly sent to the restaurant. The player also controls B Life Lab employees.

Figure 9: Biogarden scenario, the player as a restaurant team member.

In Figure 10, the drone mini-game can be seen. When teams put the collected samples on the drone cabinets, the drone sequence is activated, and the game camera focuses on the drone itself. The drone can be controlled with WASD keys for movement and IJKL for hovering options. Until the drone is placed on the objective marker, players can freely roam inside the map and see the environment's buildings and terrain. After the drone is placed in the objective marker, the camera focuses on the B-Life Lab Team.

Figure 10: Biogarden scenario, the drone driving mini-game.

In Figure 11, the B-Life Lab member can be seen analyzing the samples with a microscope. B-Life Lab sequence is the central part of the Biogarden game and is played on both Restaurant Investigation Team and Local Investigation Team options.

Figure 11: Biogarden scenario, the player as a B-Life Lab team member.

Local Investigation Team: The team enters the secret lab, collects samples of the substances they find inside, and sends them to B-Life Lab by a drone. This part is the same as the B-Life Lab Team section above. Here again, there are two different results. If the results are clear, it indicates that the laboratory is set up for the purpose of a CBRN-e-related attack. In this case, the team is directed to the "Decontamination" area for decontamination. Decontamination teams wear the necessary clothes and prepare for the procedure. Then, the team selects the relevant detectors to detect the type of substances in the laboratory, prepares the Local Investigation Team for the decontamination process, and directs them to the relevant department. When the processes are finished, the team reports the results to the central team. In Figure 12, the player can be seen as a local investigation team member when they find the secret part of the Clandestine Lab. There are broken chemical tubes in the environment and shattered glasses used from the previous work of eNTERFACE'19. Apart from that, a newly designed basement for the lab, floors, lockers, microscopes, and faucets have been added to the game.

Figure 12: Biogarden scenario, the player as part of a local investigation team.

4.4. Implementation, Physics and Game Design

The PC version of the games was developed in Windows 10 operating system, and the VR version was tested on an HTC Vive headset. Unity 3D was used as the game engine and primary development environment. For scene design, modeling, and animations, 3DS Max software was used. Steam VR SDK was also used during the HTC Vive development. During the modeling and design phase, a hospital design was made by combining the purchased assets [81][82], and some objects were designed from scratch. The exterior of the hospital was equipped with emergency response tents to suit the scenarios.

The continuation of the stage consists of environmental elements such as buildings and trees. The hospital is designed as two floors, but only one floor is used in the game. In the introduction section of the game, the player sees a secretary's desk. There are also benches where the relatives of the patient wait. There are doctor's room, nurse's room, RN Ward, Bio Ward, and Chem Ward. There are objects used by the actors, such as a vaccine, oxygen mask, and serum, in these rooms. Beds are available for the treatment of the patients.

A bigger world was designed in the Biogarden game compared to the Hospital game. The crisis management tent, which includes the restaurant, clandestine labs, and various mobile labs in the scenario, is placed in different parts of the game world. Besides, a stadium where the Champions League final will be played in the scenario was visually added to the stage. For the scenes in the introductory sequences of both games, music from the news bulletins was used. Besides, sounds such as telephone ringing, water sound, drone, and ambulance sound were also used in animations and vehicle driving sections. As for physics, similar physics and game mechanics features are used in both games.

The selected characters can walk in the game world with the WASD keys and change direction with the mouse. During the scenario sequences, dialogues are displayed on the game interface, and these dialogues are advanced with the click of the mouse. In various parts of the games, some questions are asked to inform the users, and these questions are displayed with their answers in a panel on the game interface. Users choose the answer they think is correct, and they get plus 10 points if the choice is correct and minus 10 points if the choice is incorrect.

The next objectives that the players must do in the scenario are written in the lower part of the graphical user interface (GUI). When the character enters the task area, an interaction button (e for pc, the trigger for VR) appears in the interface, and the player is guided to press that button. The areas where the quests are located are indicated by the circles of colors specific to the selected character. In Figure 13, the character can be seen on an interaction trigger, and the game waits for the player to press E to continue. When the players hit the interaction button, they trigger sequences with animations, dialogues, or questions. The hospital game also has game mechanics to calculate the total number of patients and the remaining beds.

These numbers are displayed on the upper right of the game interface, and according to the scenario, if the hospital capacity is full, the patient is transferred to other hospitals and is removed from the game world. There are mini-games in both games. In the Hospital game, there is an ambulance driving sequence at the very beginning of the game.

Moreover, bringing patients to the hospital is an essential task in the game. In the Biogarden game, drones are used to take the collected samples to mobile laboratories. Using drones emerges as a mini-game.

Figure 13: Player using an interaction trigger.

In Figure 14, a question pop-up can be seen to ask about the patient's condition in the Hospital game. This pop-up mechanism is used on every question in both games to inform players about what to do next in a crisis. Questions usually have two or three answers, as in the figures, and these answers send the patient to a dirty holding area, urgent medical treatment area, or decontamination area. The correct answer is based on the information text at the top of the pop-up question. The central question in the middle of the pop-up is: 'Which unit should we send the patient to?' Finally, at the bottom of the pop-up, the answers are given.

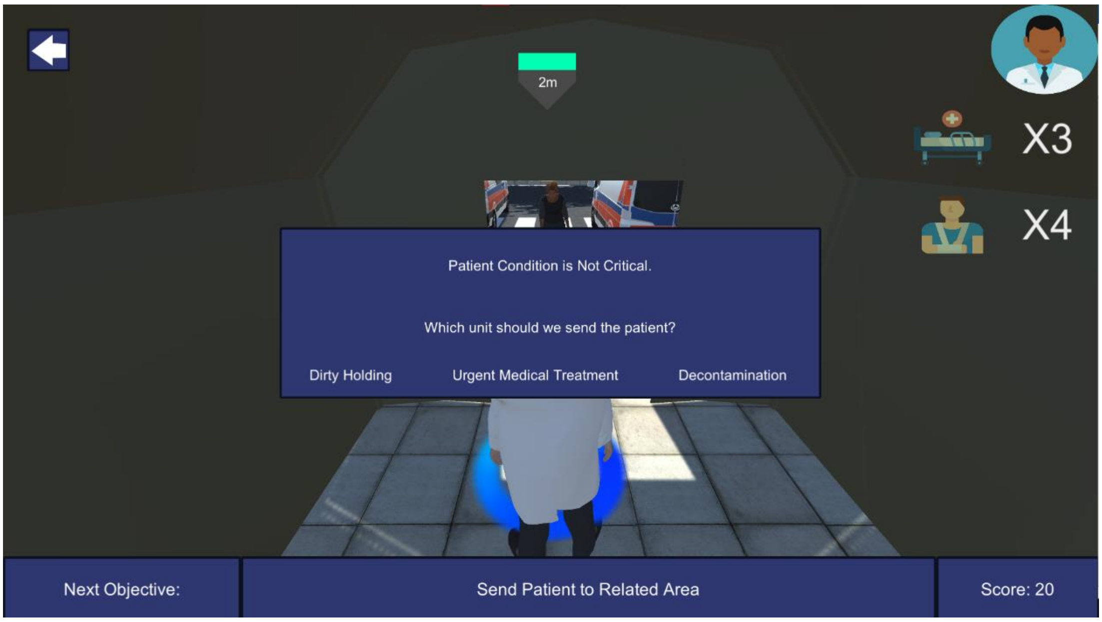

Figure 14: Hospital scenario, the patient answers a question.

Similar elements are used as interfaces in Hospital and Biogarden games. The Main Menu starts with the new game and exit buttons and continues with the character selection screen after the new game. In Figure 15, the login option of the menu is displayed. This is the character selection screen of both games. In the Hospital game, the player can select to play either as the Doctor or Nurse. In the Biogarden game, as shown in Figure 15, players can select the Restaurant or Clandestine Lab sections, where the restaurant section enables the players to play as part of a restaurant investigation team, and the clandestine lab section enables them to play as part of a local investigation team. B-Life Lab team is not selectable at this point of the Biogarden game, and it is playable both in the Restaurant and Clandestine Lab sections.

After the character selection, there is an image of a news presenter describing the beginning of the scenarios and a figure to depict the plot set. In the background, there is music to reinforce the presentation of the news. When the games start, dialogues and tasks are located at the bottom of the screen, the key to return to the main menu is on the left of the screen, and the UI elements with the necessary information are located on the right of the screen (number of beds and remaining patients in the hospital scenario). Since it is not possible to use an interface embedded on the screen in VR versions of the games, the player can see the interface by holding the controller in the left hand in the form of a clock and interact with the interface elements with the controller in the right hand. PC versions of the games are designed in Third Person, and VR versions are designed in First Person. Main Menu is only available on the PC version because using a menu lessens the feeling of immersion in VR. For each character option, different playable builds have been created.

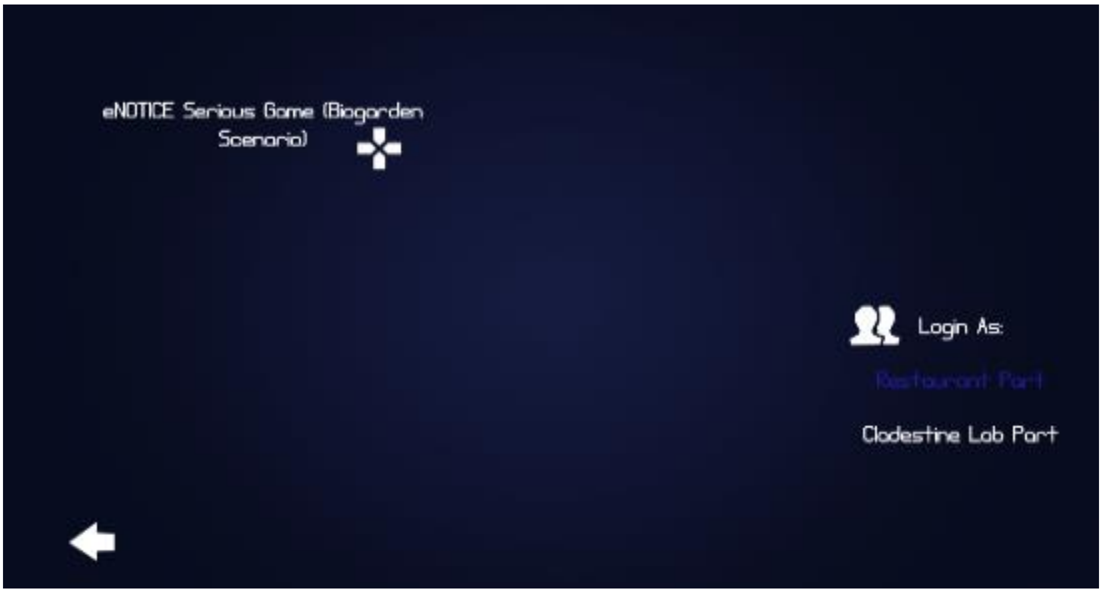

Figure 15: Biogarden game's character selection screen.

In Figure 16, the news sequence of the Hospital Game is given. The anchorwoman image, background, and news' labels are the same in both games, while the dialogue texts about the scenario's initial information and the images located on the right corner of the screen are different. For example, in the Hospital Game, an airport image is shown initially because the hospital/Nimes scenario starts with a terrorist attack on an airport. On the other hand, the Biogarden game has a stadium, restaurant, and secret lab images since the Biogarden scenario begins on the day of the Champions League finals, and a secret lab is found followed by an incident occurring at a restaurant.

Figure 16: Hospital game, the news sequence.

C # programming language was used in the programming phase of all games. There are Interaction trigger scripts (Doctor, nurse, and local investigation), model classes, camera scripts, Game Manager, Drone and Ambulance controls, Dialogue scripts, NPC behavior scripts, and Interaction systems in the games. Features such as scoring tasks, moving to the next task, and pointing the next task's distance on the user interface (UI) are implemented in these scripts, such as which button the user must press to perform the task. A dynamic scenario development structure was used while Hospital and Biogarden scenarios were integrated into the games. For the implementation of the scenarios, normally, all steps must be coded. This situation increases the "code complexity" in the coding stage and becomes difficult for the programmer. In this project, a feature of Unity called "Animation State Machine" was used. This structure is typically used to program interconnected animations. The "Animation State Machine" has become very suitable for the project as it is like scenario-based programming methods such as Finite-State Machines and can express the added elements visually. All the scenarios (taking samples and sending them to the lab) have been added to the structure as state machines and have been used to trigger the score and transition to the following mission features in the game instead of triggering the animation.

In Figure 17, a scenario state machine from the Hospital Game is given. In this example, the tasks of the player as a doctor are given. The first state is the idle state. All actions connect the idle state as a continuation for programming purposes, but its logic is different. Because interactions' triggers cannot be available before the previous action is completed, first, the doctor must trigger the "get ready" action for washing hands and putting on a mask. After that, the interaction trigger in front of the sink in the doctor's room is disabled. The new interaction trigger appears on the patient's arrival. After the doctor checks on the patient, the doctor is asked about the patient's condition, triggering one of the "send" actions. Then, the scenario continues.

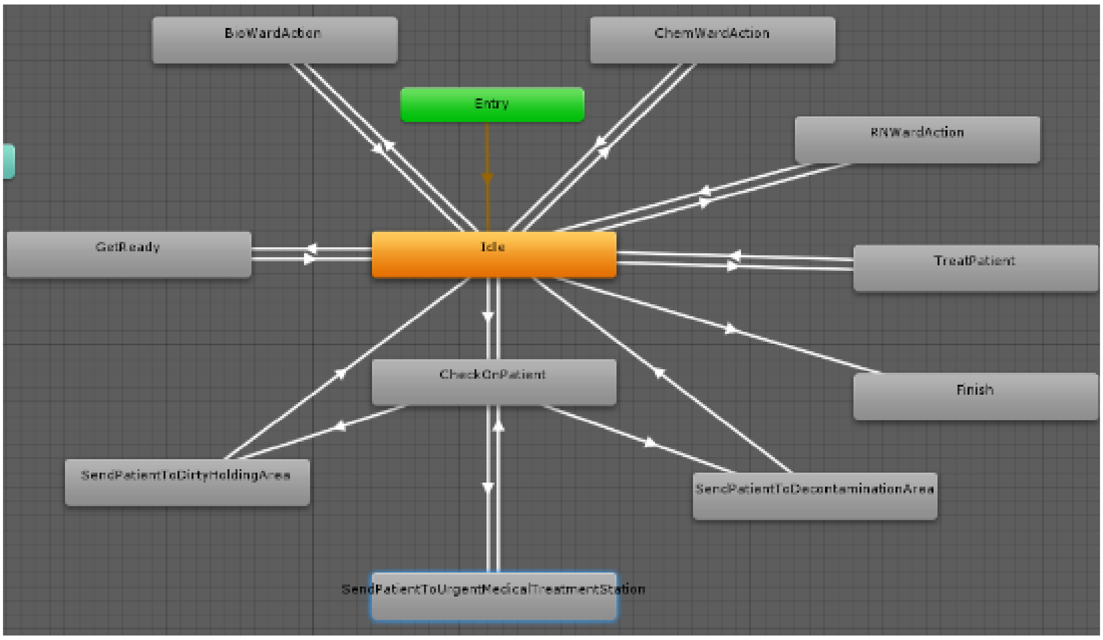

Figure 17: The state-machine example of the Hospital scenario.

In Figure 18, an example state-machine from the Biogarden game is given. This is not an action state machine of the scenario but the animation state machine of the Local Investigation Team. For example, after the character collects a sample from the ground or on a desk, it triggers the walking animation while holding the sample tube.

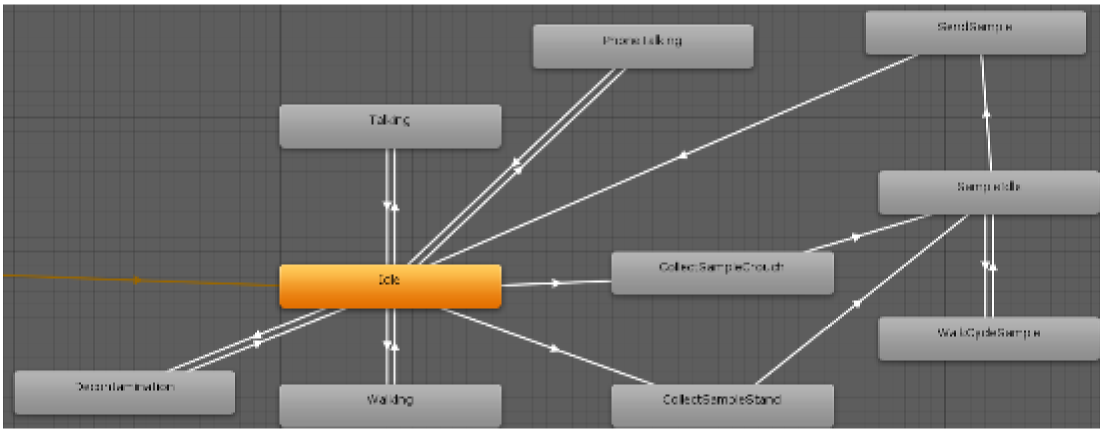

Figure 18: The state-machine example of the Biogarden game.

The questions asked in the games contain essential information that CBRN-e officials need to know. Mini-games such as using drones are challenging, and some improvements have been made to balance their difficulty. The entertainment factor is also critical in serious games, and the training is aimed to be both educational, instructive, and enjoyable. For this, sequences such as mini-games, ambulance, or a drone have been added, and the game elements have been diversified without going beyond the scenarios.

4.5. Final Versions of the Developed Serious Games

Two serious games named Biogarden and Hospital game are the final products of this thesis work. After both games' design, implementation, and tests are finished, the latest versions of the games are built in the Unity game engine. The PC builds are created in PC, Mac, and Linux Standalone platform, Windows target platform, and x86_64 architecture, as shown in Figure 19. VR versions are developed with the same build settings and are also checked for the VR. Four different builds are created for VR versions as Biogarden-Lab, Biogarden-Restaurant, Hospital-Doctor, and Hospital-Nurse. The reason was to remove the Main Menu scene from VR versions, as the menu used in the PC versions breaks the feeling of immersion, especially while waiting for the loading of the game scenes after the character selection.

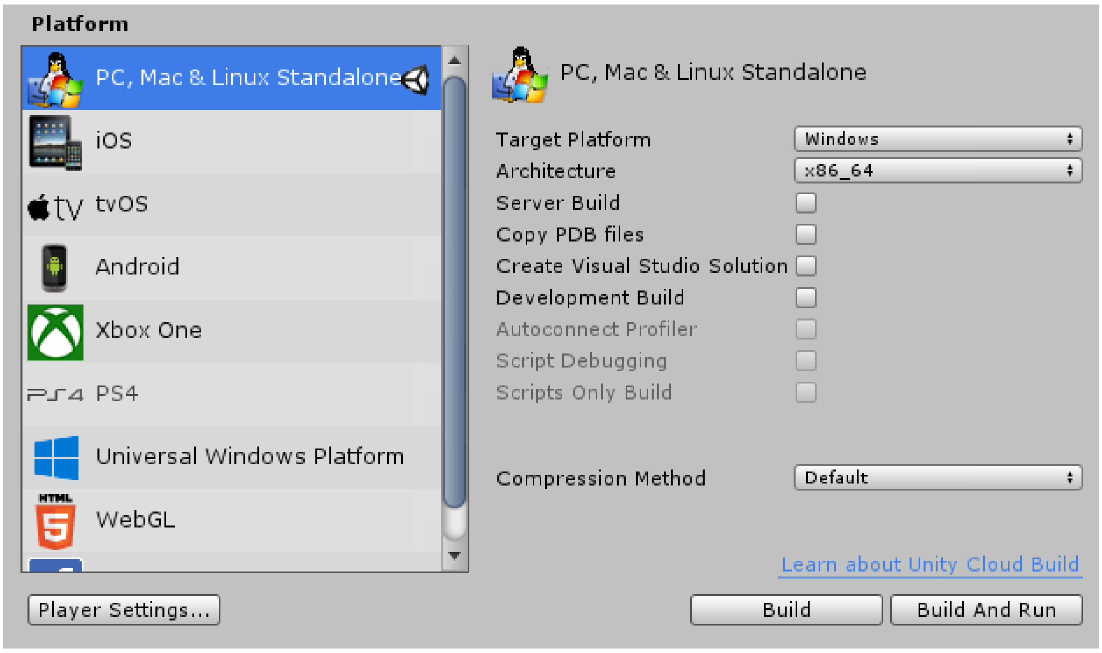

Figure 19: Build Settings in the Unity game engine.

The final version of the Biogarden game starts with the main menu, as seen in Figure 20. After the player selects the "Start New Game" option, the character selection menu, previously mentioned in Figure 15, is displayed. If the player selects the "Exit" option, the game closes immediately. In the character selection menu, two "Login As" options can be selected. The restaurant section starts with the player being a part of the restaurant investigation team, and the Clandestine Lab section starts with the player being a part of the local investigation team. After the selection, the "Breaking News" section appears while an anchorwoman explains the beginning of the Biogarden scenario to the player. The rest of the game continues with the scenario as explained in the Storyboard and Gameplay section. After the player finishes the game, the "Game Over" popup is shown, displaying the Main Menu. The main menu is not available for the VR versions as parts of the game can be directly executed from different builds.

The final version of the Hospital Game is similar to the Biogarden Game as the games are standardized for the CBRN-e training with different scenarios. The game starts with the same menu screen, as shown in Figure 20. After the player selects the “Start New Game” option, the character selection menu appears with different character selection options from the Biogarden Game as Doctor and Nurse. After the character selection, the news sequence starts the same way as the Biogarden Game. With the finishing of the news sequence, players were asked to drive an ambulance in a mini-game. From this point, the process of the game is the same as explained in the “Storyboard and Gameplay” section with the secretary narrative sequence, preparing for the patients, meeting the patients, giving the correct treatment, and sending the patients to the correct ward until the patient counter hits zero. After the player finishes the game, the “Game Over” popup is shown, displaying the Main Menu. As in the Biogarden game, the VR version of the Hospital game does not have the Main Menu, and the Doctor and Nurse options can be directly executed.

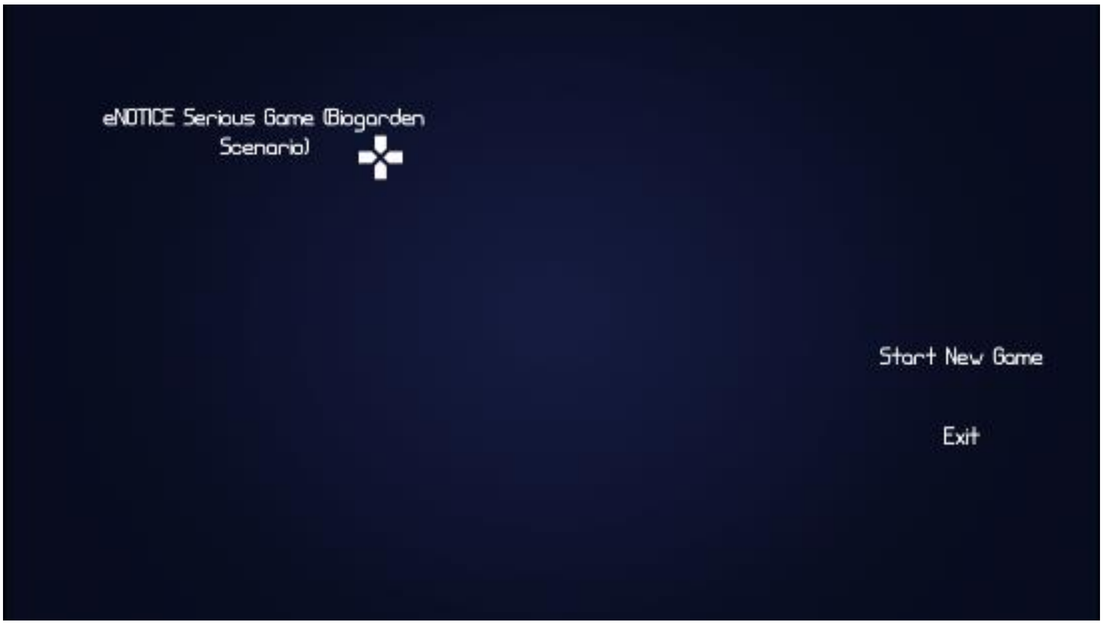

Figure 20: Main Menu of the Biogarden game.

4.6. Joint Activity

This thesis aims to develop serious games for CBRN-e training and compare different development platforms. Because of that, the marketing section of the development lifecycle was not considered, but instead, the results were evaluated with the Joint Activity. The participants played the games in the eNOTICE Joint Activity organized by METU, and they evaluated the games with the questionnaires on Presence, System Usability Scale, and Technology Acceptance. Also, participants’ responses to open-ended questions have been essential resources for shaping the future of the study. As seen in Figure 21, participants played both PC and VR versions of the games. Multiple participants can play the games simultaneously and switch between platforms when they finish playing on the current platform. Other participants and instructors can watch the playing session of VR games from the connected PCs. Two rooms consisted of the hardware for the sessions. Room 1 had two desks with multiple PCs, a space for VR setup, and two LCD TVs. Room 2, on the other hand, had only space for the VR setup, smaller than Room 1. Room 2 had enough space for both VR setups and could separate the PC and VR players of Room 1 and 2.

Figure 21: A participant is playing the PC version of the Hospital game.

CHAPTER 5

RESULTS

5.1. Questionnaire Results

Two different serious games developed in this thesis have been played by a group of CBRN-e experts during the eNOTICE Joint Activity in Ankara, Turkey. The age profile of the target group was between 28 and 56. The questionnaires cover the sense of presence, system usability, and technology acceptance in these games. The comparisons have been made between the VR and PC versions of the Biogarden and Hospital games to determine how different platforms such as VR and PC can affect the user experience. According to Witmer [26], presence questionnaires consist of control, sensory, distraction, and realism questions. Control is about users' control over the task environment or interacting with the virtual environment. More control means a greater user experience in terms of presence. Sensory factors are the factors or elements that are stimulating all senses of the users.

Greater sensory experience means the greater experience of presence. Another topic about the questionnaires is the distraction factors. Users' ability to focus on the virtual environment and isolation from the physical environment are key factors when creating a VR experience. Virtual reality HMDs create the isolation of the user from the physical environment. Distraction factors are the users' lack of focus and distraction caused by other environmental elements like noise, feeling of touch, smells, or created environments lacking immersion elements such as low pixels from the HMD, poorly created scene elements, and third-person camera angles. In the questionnaires, some questions about distraction are positive, and some are negative. For example: "How aware were you of events occurring in the real world around you?" is a positive question. If the user gives a higher score, it means a greater user experience in terms of presence. "How distracting was the control mechanism" is a negative question where a higher score highlights the problems in the user experience in terms of presence. Specifically, distraction has three positive and two negative questions. The final part of the presence questionnaires is the realism factors. Scene realism is the realism factors caused by the virtual environment like resolution, textures, and field of view. A higher score means a realistic user experience in terms of presence.The answers given to the presence questionnaire are about the sense of immersion in the games. There are 28 questions in the questionnaire with a 7-point scale (1 to 7 from negative to positive). The maximum score of the presence questionnaire is 28 x 7 = 196. The first 14 questions are about Control, eight questions are about Sensory, five questions are about Distraction, and one is about Realism factors. Primary statistical evaluation results (Table 1 and Table 2) show that VR versions of both games have slightly higher scores than the PC version of the games.

The second part of the questionnaire, the System Usability Scale (SUS), determines user experience in games. There are ten questions in the questionnaire with a 5-point scale (1 to 5 from negative to positive). However, the SUS questions are grouped into positive (odd) and negative (even). The score calculation of the SUS is presented below [24][25]:

- X = Sum of the points for all odd-numbered questions – 5
- Y = 25 – Sum of the points for all even-numbered questions
- SUS Score = (X + Y) x 2.5

The third part of the questionnaire is related to the Technology Acceptance Model (TAM), which contains questions about the games' acceptance in terms of technology [27]. TAM questionnaire has 16 questions on a 10-point scale (0–10 from negative to positive). The reliability of a TAM test can be determined by Cronbach's alpha (α) value which should be greater than 0.7 as a threshold, and if α> 0.8, it shows that the questionnaire has good reliability.

5.1.1 Results of the Biogarden Game

Table 1 shows the evaluation of presence in the Biogarden game's PC and VR versions. In terms of control, the Biogarden VR version has a mean score of 63.33, while the Biogarden PC version has a mean score of 62.75. Although the scores are very close to each other, it can be said that the VR version provided users with better control in the virtual environment.

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

Presence	Group	Mean	Std. Deviation	Std. Error Mean
Control	Biogarden VR	63.33	17.89	5.16
	Biogarden PC	62.75	7.73	2.23
Sensory	Biogarden VR	35.83	12.86	3.71
	Biogarden PC	32.25	7.95	2.29
Distraction	Biogarden VR	22.33	7.77	2.24
	Biogarden PC	21.91	3.65	1.05
Realism	Biogarden VR	4.25	165	0.47
	Biogarden PC	4.16	0.93	0.27
Sum of all variables	Biogarden VR	125.50	38.27	11.04
	Biogarden PC	121.08	16.57	4.78

On the sensory side, Biogarden VR has a mean score of 35.83, and the Biogarden PC version has a 32.25 mean score. Using the opportunity of new user experience provided by the HTC Vive platform, the VR version has slightly higher scores than the PC version. As mentioned above, distraction questions have both positive and negative questions. Biogarden VR got 22.33 while Biogarden PC 21.91, which are nearly identical with each other with a 0.42 difference. Finally, realism scores are 4.25 for the VR and 4.16 for the PC. The reason was that both versions were developed with the same textures, assets, sounds, and gameplay. With a total mean score of 125.50, the Biogarden VR version provided a better experience on presence than the Biogarden PC version, which got a 121.08 score.

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

The null hypothesis is accepted based on the statistical data in Table 2. The reason for this result is that Sig. (two-tailed) value (0.71) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Biogarden Game in terms of presence. Other statistical data follows, t: 0.36, mean difference: 4.41, std. error difference: 12.04, lower confidence interval of the difference: -20.55 while upper confidence interval is 29.38.

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

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

Table 3 presents the basic statistical evaluation of the SUS answers. The Biogarden VR version has a 66.00 mean SUS score, while the Biogarden PC version has a 65.75 mean SUS score. These values are almost the same, with only a 0.25 difference. Also, similar standard deviation with 14.58 for Biogarden VR and 16.45 for Biogarden PC, a standard error mean of 4.61 for Biogarden VR, and 5.20 for Biogarden PC.

Score evaluation results show that (Table 3) PC version of Biogarden Game has slightly lower scores than VR Version. Scores 65-66 mean "OK" in the SUS score scale means that participants found the games pleasing, but the usability of the games needs to be improved. It is stated by Bangor [24][25] that the systems with higher SUS scores are better in terms of usability. To determine whether the difference between the mean values of PC and VR versions are statistically zero considering the responses, independent samples t-test was conducted. The results are summarized in Table 4.

Table 3: Score evaluation of SUS in Biogarden Game.

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

The null hypothesis is accepted based on the statistical data in Table 4. The reason for this result is that Sig. (two-tailed) value (0.45) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Biogarden Game in terms of usability. Other statistical data follows, t:0.76, mean difference: 1.70, std. error difference: 2.21, lower confidence interval of the difference: -2.94 while upper confidence interval is 6.34.

As for the TAM questionnaire results, α(Biogarden) = 0.79 has been calculated, indicating that the tests are reliable. Table 5 is the basic statistical evaluation of the answers. VR version of the Biogarden game has a slightly higher score than the PC version in TAM. Table 6 summarizes the comparison results.

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

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

Table 5 shows that the Biogarden VR game had a 116.66 mean TAM score while the Biogarden PC game had a 109.25 mean TAM score, which means that the VR version got a slightly higher score in terms of technology acceptance. Other statistical data follows standard deviation: 15.29 and standard error mean 4.41 for Biogarden VR while standard deviation: 18.66 and standard error mean: 5.38 for Biogarden PC version.

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

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

The null hypothesis is accepted based on the statistical data in Table 6. The reason for this result is that Sig. (two-tailed) value (0.29) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Biogarden Game in terms of technology acceptance. Other statistical data follows, t:1.06, mean difference: 7.41, std. error difference: 6.96, lower confidence interval of the difference: -7.02 while upper confidence interval is 21.86.

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

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

5.1.2 Results of Hospital Game

Table 7 shows the evaluation of presence in Hospital PC and Hospital VR games. Hospital VR had a 67.35 mean score in control, while Hospital PC had a 61.92 mean score. Like the Biogarden game, the VR version of the Hospital game had higher scores on control. As seen in the sensory scores, the Hospital VR version again exceeded the Hospital PC version with a 6.29 difference by 39.35 mean scores for VR and 33.07 mean scores for PC. On the distraction side, Hospital VR got 23.64 while Hospital PC got 21.42. The difference is much higher on the realism scores than Biogarden game with Hospital VR 4.42 mean score while Hospital PC has 3.92.

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

Presence	Group	Mean	Std. Deviation	Std. Error Mean
Control	Hospital VR	67.35	8.55	2.28
	Hospital PC	61.92	7.92	2.11
Sensory	Hospital VR	39.35	8.69	2.32
	Hospital PC	33.07	7.61	2.03
Distraction	Hospital VR	23.64	3.75	1.00
	Hospital PC	21.42	358	0.95
Realism	Hospital VR	4.42	1,15	0.30
	Hospital PC	3.92	1.07	0.28
Sum of all variables	Hospital VR	134.28	18.64	4.98
	Hospital PC	120.21	16.02	4.28

To sum up, with a 134.28 score, Hospital VR presented a better user experience than Hospital PC with a 120.21 mean score. To determine whether the difference between the mean values of PC and VR versions are statistically zero considering the responses, independent samples t-test was conducted. The null hypothesis (H0) defined in this research is "the difference of the mean values from responses of PC and VR versions of the game is equal" (H0: $\mu PC - \mu VR = 0$). The alternative hypothesis (H1) is two-tailed because it assumes that the difference is not equal to zero (H1: $\mu PC - \mu VR \neq 0$). The results are summarized in Table 8.

The null hypothesis is rejected based on the statistical data in Table 8. The reason for this result is that Sig. (two-tailed) value (0,04) is lower than 0.05. This means that participants had a significantly different feeling of presence between PC and VR versions of Hospital Game. Other statistical data follows, t: 2.14, mean difference: 14.07, std. error difference: 6.57, lower confidence interval of the difference: 0.56 while upper confidence interval of the difference is 27.57.

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

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

Figure 22 shows the box plot of the presence questionnaire result of all games and versions. As seen in the plot, the VR version has higher scores than the PC version. Also, Hospital VR and Biogarden VR scores are similar. Hospital and Biogarden PC versions are slightly lower than the VR versions, and both games are similar in terms of PC version scores.

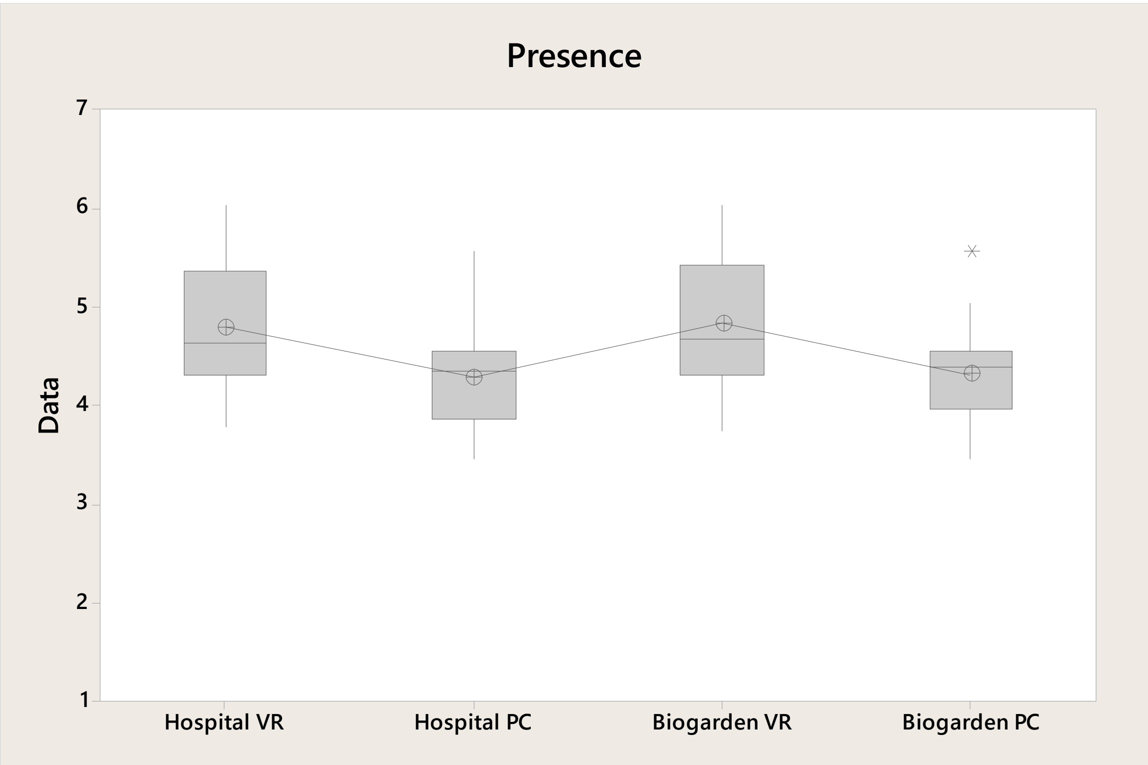

Figure 22: Box Plot of the Presence Questionnaires.

Figure 23 is the individual value plot of presence questionnaire results from Hospital VR, Hospital PC, Biogarden VR, and Biogarden PC versions. As seen in the plot, scores are intensified on a 4-5 scale on both games and versions. However, VR versions have higher scores on the 5-7 scale, but PC versions do not mean scores are higher than 6.

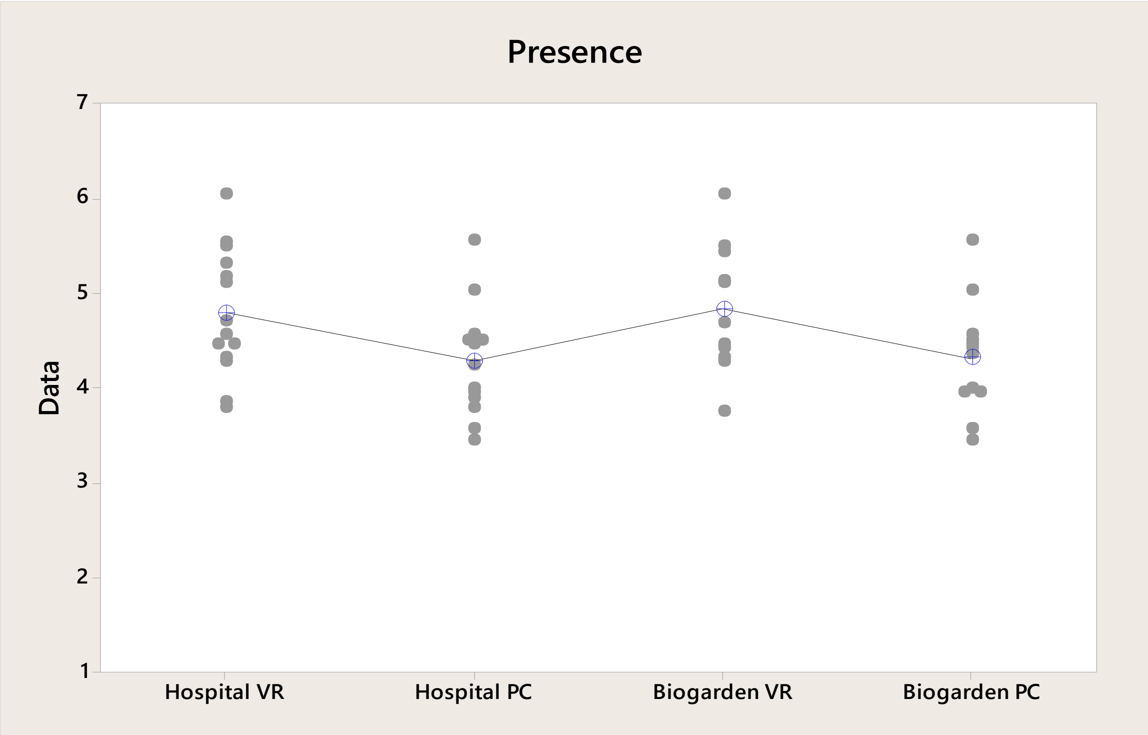

Figure 23: Individual value plot of the Presence Questionnaires.

For the SUS results, as seen in Table 9, the Hospital game also had similar scores on both PC and VR versions with a 66.78 mean SUS score for Hospital VR, and 66.25 mean SUS score for Hospital PC. Also, similar standard deviation with 16.47 for Hospital VR and 17.77 for Biogarden PC, standard error mean 4.40 for Hospital VR and 4.75 for Biogarden PC.

Table 9: Score evaluation of SUS in Hospital Game.

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

The null hypothesis is accepted based on the statistical data in Table 10. The reason for this result is that Sig. (two-tailed) value (0.43) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Hospital Game in terms of System Usability. Other statistical data follows, t: 0.78, mean difference: 1.85, std. error difference: 236, lower confidence interval of the difference: -3.00 while upper confidence interval is 6.71.

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

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

Figure 24 shows the box plot for SUS questionnaire results of Hospital and Biogarden games' VR and PC versions. Results show that both games' PC and VR versions have nearly identical scores, and Biogarden and Hospital games are also close. As seen in the box plot, the mean score point of each game and platform is connected with an almost straight line.

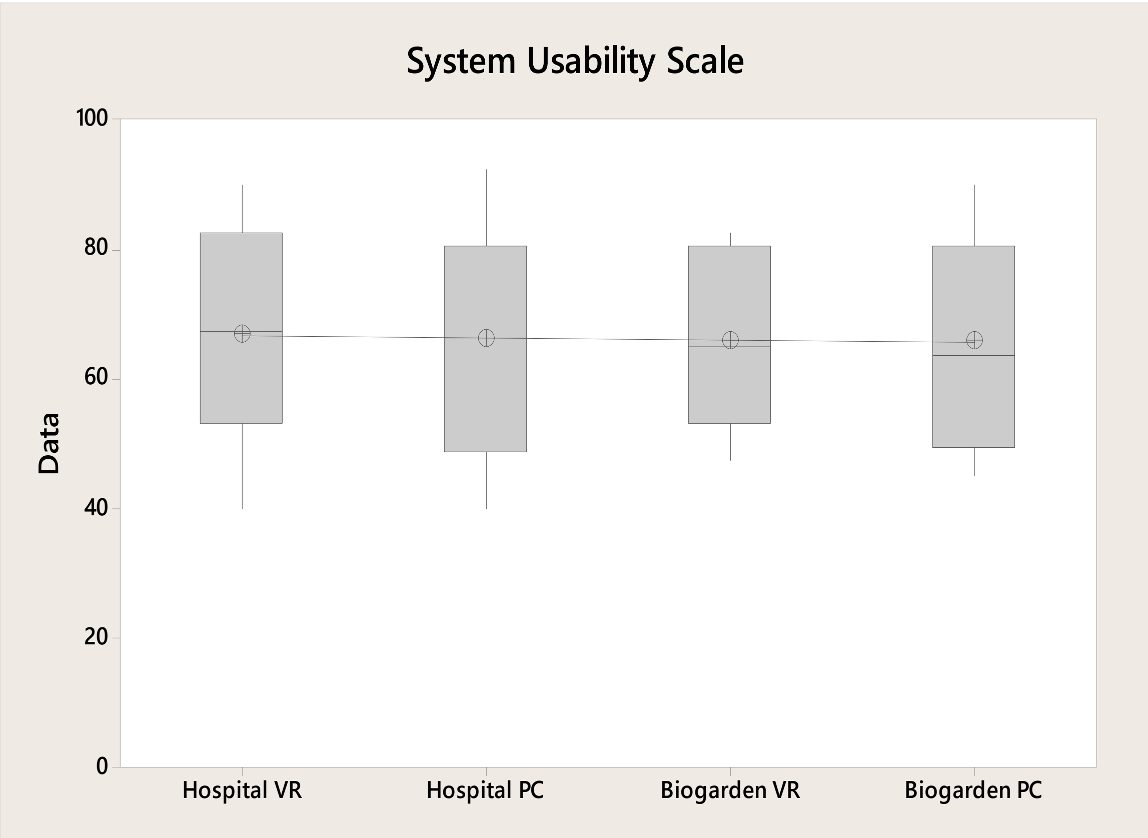

Figure 24: Box Plot of the SUS Questionnaires.

In Figure 25, individual value plots of SUS questionnaire results can be seen. Although both scores are intensified on the 80-100 scale, the mean scores below 60 lower the

SUS scores of the games to between 60-70 points. The Hospital PC game has a higher mean score between 90-100.

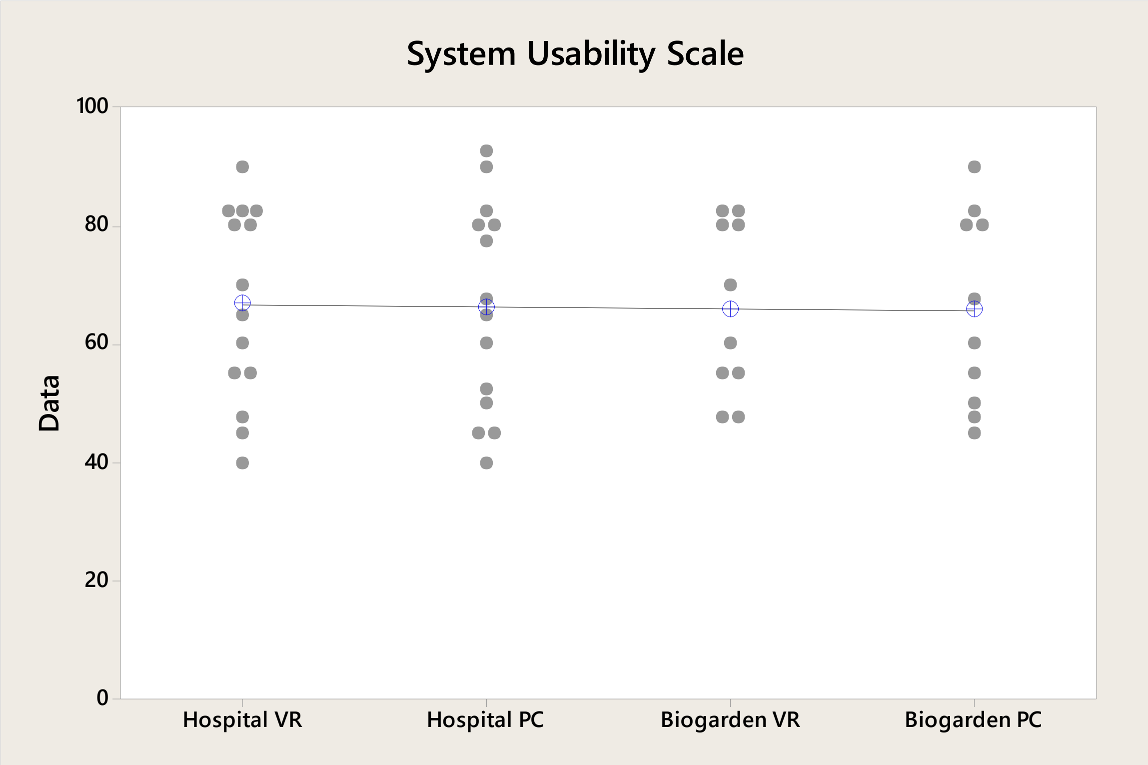

Figure 25: Individual value plot of the SUS Questionnaires.

Finally, for the TAM results, as can be seen in Table 11, the Hospital VR game had a 117.28 mean TAM score while the Hospital PC game had a 110.92 mean TAM score, which means that the VR version got a slightly higher score in terms of technology acceptance. Other statistical data follows standard deviation: 18.40 and standard error mean: 4.91 for Hospital VR while standard deviation: 21.43 and standard error mean: 5.72 for Hospital PC version.

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

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

The null hypothesis is accepted based on the statistical data in Table 12. The reason for this result is that Sig. (two-tailed) value (0.40) is higher than 0.05. This means that participants did not feel any significant difference between PC and VR versions of Hospital Game in terms of technology acceptance. Other statistical data follows, t:

0.84, mean difference: 6.35, std. error difference: 7.55, lower confidence interval of the difference: -9.16 while upper confidence interval of the difference is 21.87.

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

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

In Figure 26, the box plot of Hospital VR, Hospital PC, Biogarden VR, and Biogarden PC games can be seen in terms of the TAM questionnaire. The plot shows that VR versions of both games have slightly better scores than their PC version counterparts. Hospital VR and Biogarden VR show similar results as the Hospital PC and Biogarden PC. This shows that Biogarden and Hospital games are considered to be similar on the same platforms.

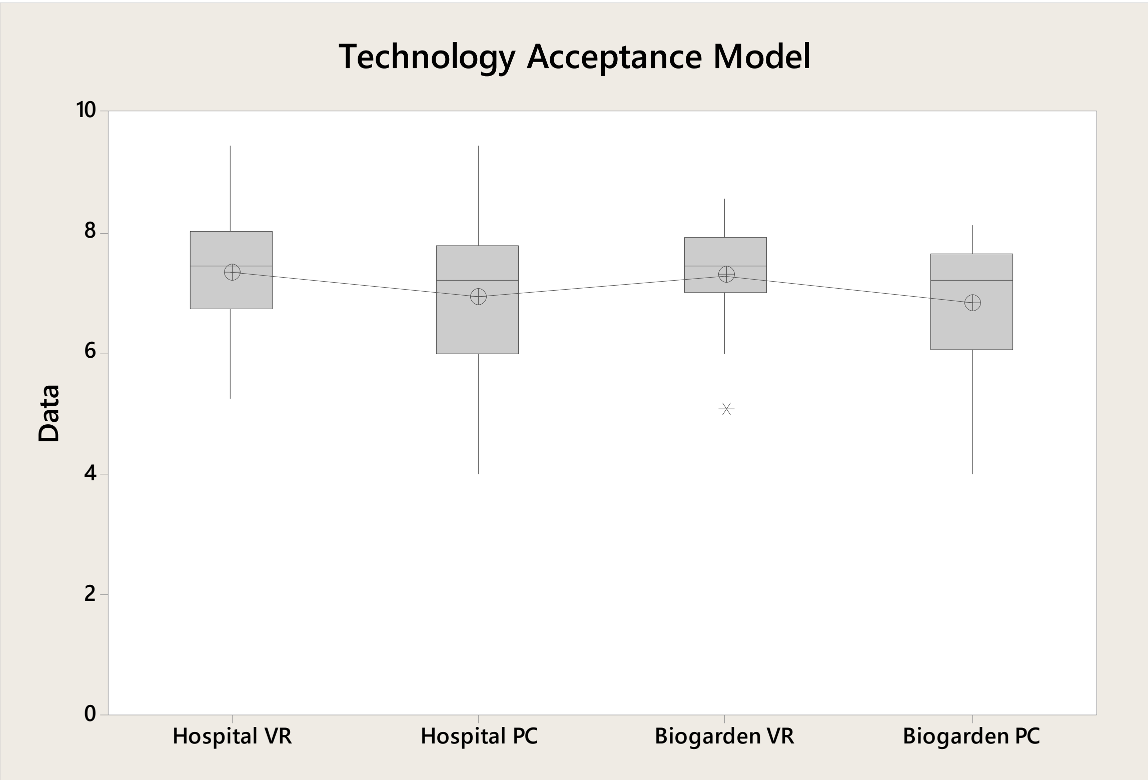

Figure 26: Box plot of the TAM Questionnaires.

In Figure 27, the individual value plots of TAM questionnaire results are represented as individual mean scores. The plot shows that Hospital VR and Hospital PC versions had higher scores than their Biogarden game counterparts with 9-10 scale mean scores. Apart from that, Hospital VR and Biogarden VR have higher scores than Hospital PC and Biogarden PC individually. For both games and platforms, scores are intensified between a 6–8-point scale.

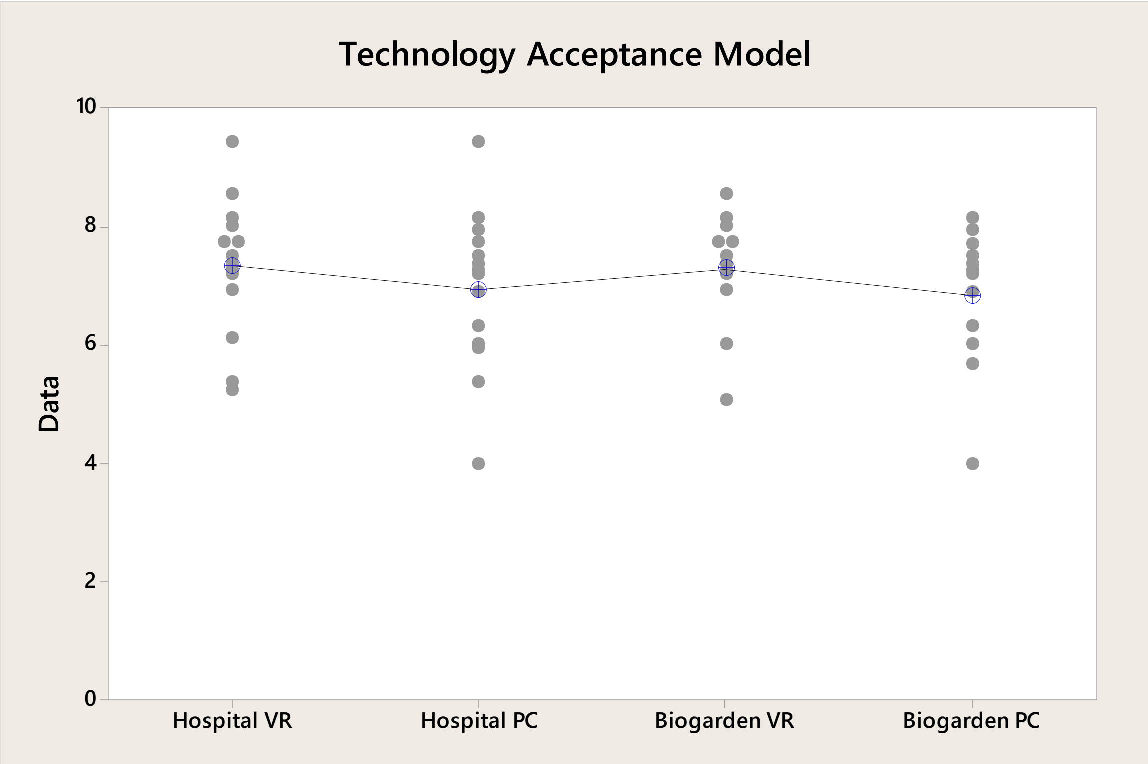

Figure 27: Individual value plot of the TAM Questionnaire.

5.2. Answers to the Open-Ended Questions

After the presence, system usability, and technology acceptance questions, participants answered open-ended questions to provide suggestions and feedback on the Hospital and Biogarden games. Participants will be referred with numbers, for example, Participant #1 for the following section. The first question was 'What are your suggestions to improve the Hospital and Biogarden games in VR?'. Participant #1 said that games need different actions. This can be achieved with different scenarios, and there are different possibilities. Participant #2 thinks that interaction with the objects and menu must be increased. Participant #3 suggests that information about symptoms can be added. For this, more information from the professionals of the domain is needed. According to Participant #4, getting familiar with the environment before performing tasks is important in a real-life situation. An introduction can be given to the players before the training starts. Participant #5 thinks that the character should be introduced in the game by telling the character's name to the player, and there should be a narrative experience about the actions like wearing protection clothes or washing hands. Participant #6 mentions that the medical objects and instructions were unclear. As being said, more information from health professionals is needed for Hospital Game. Participant #7 said that answers were too obvious, and the player should not walk through walls and objects. Participant #8 suggested that the procedures of lab and hospital should be improved. For example, a doctor/nurse cannot approach an R patient without PPE, and it is too late to get the vaccine for a patient who is already contaminated with a bioagent. Participant #9 commented as follows, "For Biogarden Game, I do not use an alias for the action. Watch in the microscope and so on. I would prefer to watch it". Participant #10 suggested making the decision-making system more complex and sticking more with reality since the sequence in the third person (narrative) breaks the immersion. The mission should be vocal first, and the left-hand task should only be a reminder. According to Participant #11, both games would benefit from an on-screen map of the area to facilitate situational awareness. When they say, "go to X" in VR, it is not possible to know where X is. In PC, the arrow would have you walk through buildings.

The second question was, "Which game did you enjoy most? Personal Computer or VR versions? Why?". Only one participant said that the PC version was more fun because the storyline made more sense and was immersive. Other participants think that the VR version was more fun because of immersion, experience, being close to real life. The third and fourth questions were 'What are the main strengths of the current games in VR? Please explain. (Hospital and Biogarden)'. Participants gave the following answers. Participant #1 said that scenario experience is the main strength of both games. Participant #2 mainly focused on the Hospital game and believed that the ability to play as a doctor or a nurse and the interactions with the environment are the study's main strengths. For Participant #3, it was the virtualization of the scene of exercise. Participant #4 focused on immersion and usability as a powerful learning tool. Visuals, interface, different rooms, graphics, the flexibility of moving around clear objects, and being close to objects were important for Participant #5. Participant #6 mentioned that in the Hospital Game, "The sequence of actions is reasonable; you can well remember the environment" while in the Biogarden Game, "Biogarden components were well shown." Participant #7 mentioned how easy it is to get used to the training procedures as a strength of the proposed games. Participant #8 mentioned that in the Hospital Game "Learning to get used to the hospital environment and, generically speaking, getting used to a new environment" and in the Biogarden Game, "Learning the logical succession of actions taken during a CBRN event by first responders" were the main strengths. The visualization of the victims and the environment replacement were the strengths of both games, according to Participant #9. The fifth and sixth questions were 'What are the main flaws of the current games in VR? Please explain. (Hospital and Biogarden)'. Participant #1 thinks that the information texts do not match the bar, and the triage procedure is not clear to decide on further treatment. For Participant #2, there is a lack of additional information about the track of the game. Participant #3 and Participant #4 noticed that some people are walking through the player character, and the feeling of height when performing tasks is not realistic. For Participant #5, scenarios were too static, and there is a lack of change. Participant #6 said that "Not much real action/choice. Only macro actions". A small map would be useful, according to Participant #7. Participant #8 said that in the Hospital Game, "Too simple scenarios and actions are too basic" while in the Biogarden Game; "No main flaw, but a good basis for building and deepening specific actions from end-users." Participant #9 thinks that the time it takes to make actions are not representative to reality and, players should know the whereabouts of tools and do not need to search. For Participant #10, it is difficult to click an answer and no indicator of where to go for VR versions. Participant #11 considered that some procedures should be more detailed.

The seventh and eighth questions were 'What are the main strengths of the current games (PC version)? Please explain.' Participant #1 liked the idea of driving a drone. For Participant #2, "Displaying additional information about the current status instead of displaying the next step of playing the role" is a strength. These games are strong learning tools for the concrete handling of tasks, according to Participant #3. Participant #4 said that "The environment is real, with good graphics, good movement, and great views"—other answers were similar to the strengths of VR versions. The ninth and tenth questions were 'What are the main flaws of the current games (PC version)? Please explain.' Participant #1 did not like the distance indicator mechanism much. Participant #2 thinks that the decontamination information and the colors of the detection devices should be changed. For Participant #3, "Tasks and handlings are less concrete than VR. Not easy to use without a gaming experience. It is an accessible storyline, but that makes it quite easy." Games could be expanded to work in a multidisciplinary way, according to Participant #4. Participant #5 thinks that procedures can be improved, and we shall consult the experts. Other participants said different critics about the animation and control errors throughout the games which can be improved and fixed.

The eleventh question was, 'Did you notice any differences between the games and their real scenarios demonstrated during the eNOTICE joint activities of Nimes, France 2018 and Brussels, Belgium 2018? Please explain.' Some of the participants did not attend these activities. Other participants think that there are differences, and not all scenario components were implemented. However, this can be improved. The final question was about general suggestions and feedback. Participant #1 suggested changing the difficulty based on the skills of the player. Participant #2 thinks that we should add more specific data to give more information to players according to the scenario. Participant #3 thinks that "It could have been useful for us to be informed about the learning goals and the targeted user group, and where the development process is situated" Participant #4 said that "This is a way to make people aware of difficult situations, multi attacks, scenarios, difficulties with communication management and decision-making." For Participant #5, the most challenging part is well done: 3D environment, interactions, characters, and graphics. Details for the protocols and procedures can be added. Other participants commented similar to the strengths and weaknesses sections. To sum it up, Figure 28 shows the participants' answers on the project's strengths as a word cloud. Some of the keywords for the strengths are; immersion (especially for VR versions), new experience (again, most of the participants think the VR as a whole new experience), scenario, virtualization of the scenes, and interactions.

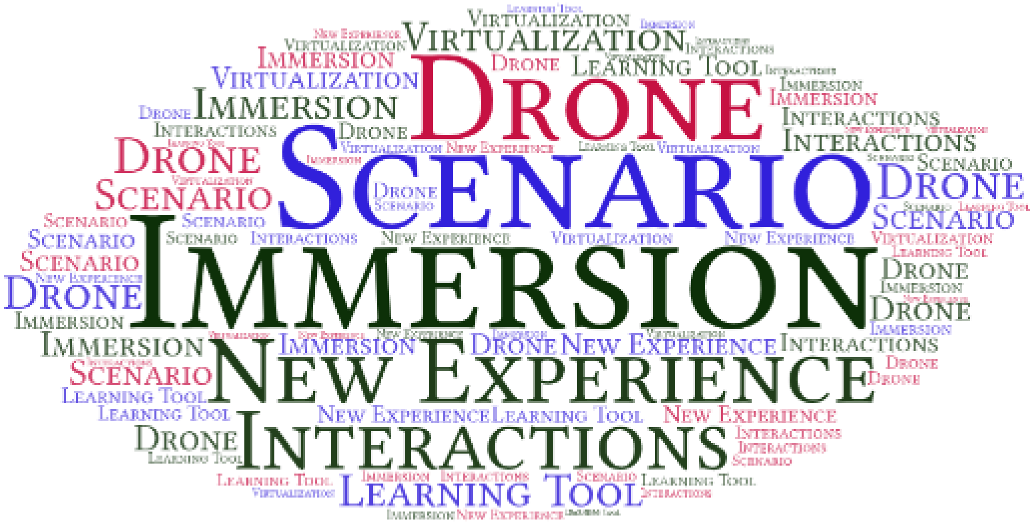

Figure 28: Strengths of the project visualized as a word cloud.

Participants gave valuable feedback on strong points, weak points, and suggestions about the project. In Figure 29, this information has been represented as a word cloud. Some of the keywords for the suggestions are different actions, improving procedures, making complex decisions, first-person camera view, difficulty or difficulty adjustment, specific data for scenarios, using a mini-map, and variation of elements in games.

Figure 29: Participants' suggestions are visualized as a word cloud.

These suggestions will be further discussed in the next chapter, Chapter 6: Discussion.

CHAPTER 6

DISCUSSION

In this chapter, the data obtained from the joint activity are discussed in detail. The questionnaires show that Hospital and Biogarden serious games were found satisfactory in terms of presence, system usability scale, and technology acceptance model for both PC and VR versions. Another focus of this thesis work is to compare the PC and VR versions and determine the benefits and disadvantages of using these platforms when developing a serious game in the field of CBRN-e. Hospital and Biogarden games are evaluated separately.

In terms of presence, t-test results show that PC and VR versions of Hospital games are different. VR version is considered a slightly better experience than the PC version. However, the scores are very close, and this might be the effects of some disadvantages of the VR platform voiced by the participants discussed in the Biogarden section in detail.

In terms of presence, t-test results show no difference between PC and VR versions of the Biogarden game. The main reason for developing a VR game is to enhance the feeling of presence. However, VR can be considered new technology and has flaws such as low pixels compared to the human eye. Furthermore, the strong points of the PC versions, such as mini-games, GUI elements for navigation, lacked in the VR versions because of the constraints in the VR game development. Different approaches could be used to overcome these constraints, but these approaches could make the VR version very different from the PC version and not comparable with each other. Even though most participants considered VR a unique experience, these disadvantages could be why VR versions do not provide a better experience than the PC version for presence.

In terms of system usability, scores are evaluated, as stated by Bangor [24][25]. SUS scores and t-test results show no significant difference between PC and VR versions of the Hospital and Biogarden game. When the participants' answers are taken into consideration, the advantages and disadvantages of both versions are considered equal in terms of the system usability scale. Overall scores are 66, which means "OK," as stated by Bangor [24][25].

Participants were experts in the CBRN-e area, and they proposed improvements in their answers to the open-ended questions. Technology acceptance model results show that the PC and VR versions of both games are evaluated as equal. To sum up, despite its disadvantages as a new technology, the VR platform is considered a good experience in gaming, and it competes with the PC platform —which is a game platform for quite a long time— successfully. Apart from the objective of this thesis work, both platforms should be considered separately, and teams should focus on improving the weak points when developing a serious game.

The answers to the open-ended questions reveal that the participants generally stated that the VR version in the sense of "Presence" gave them a better experience and felt more realistic. However, according to the survey results, there is a clearer difference between Hospital VR and Hospital PC, with no significant difference between Biogarden VR and Biogarden PC version. SUS and TAM results show that there is no difference between PC and VR versions. Although the VR versions create a different and enjoyable experience, due to some limitations of VR game development, we could not use the features such as duty distance indicator, drone and ambulance use, news bulletin, and entry sequences of the PC versions in the VR, which limited the experience in VR versions. In VR versions, the "First Person" camera was used to increase reality, but since the character animations are prepared according to the "Third Person" when the animations are triggered, the camera switches to "Third Person," and we see our character in this way. This situation greatly reduces the sense of realism and presence.

Answers given to the open-ended questions summarize the strengths of the study as being able to play with different characters, using drones and ambulance, stage designs, being updatable and adaptable to other scenarios, having different versions (VR-PC, Biogarden-Hospital), and multiple-choice options, learning the logical succession of actions taken during a CBRN-e event by first responders. The participants' feedback given to the open-ended questions highlighted that the scenarios could be more detailed, and the errors could be corrected.

There were some errors in the animations of the games. As mentioned, no transition to a third-person camera was requested in VR. The third-person camera diminishes the feeling of presence in VR. However, without it, the character animations for the game will be useless, and this makes a VR version with the only first-person camera is an entirely different game with different mechanics. This makes the comparison between the PC and VR versions. To enhance the experience in the games, a mini-map can be helpful. The feedback given to the open-ended questions by the participants, in general, is as follows: This study has high potential and is a pleasant experience. VR version is an example for better immersion and a realistic user experience. More coordination with the CBRN-e experts can give better results so that this thesis work can become a practical solution in CBRN-e training.

CHAPTER 7

CONCLUSION AND FUTURE WORK

In this thesis, two serious games for the purpose of CBRN-e training have been developed on PC and VR platforms. Scene designs, animations, sounds, scripts, physics have been designed under the pre-defined scenarios. The hospital game is for the CBRN-e crisis training of hospital professionals, as doctors and nurses. Biogarden game is for the purpose of training the security personals to collect and analyze the samples to detect CBRN-e related attacks. Participants tested the games during the eNOTICE Joint Activity in Ankara, Turkey. Sixteen participants played the games using PCs and HTC Vive headsets. The results show that these games can become good examples of using serious games in specific areas such as CBRN-e. However, to amplify the user experience and provide a better training session, the benefits of recent technology such as VR or MR can be used. User feedback shows that the following improvements and extensions can be made as to future work.

Creating UI in VR games is difficult since the embedded interface cannot be used in VR, and UI elements must be used as game objects. Dialogues, tasks, and score information were displayed when the player kept the left controller in a clockwise way, such as a wristwatch. Although this mechanic works well in most VR games, it was considered difficult to use by the participants. One of the reasons why some of the features are available in the PC version but not in the VR version is that the versions are as similar as possible to make a comparison. If very different mechanics and elements were used in VR versions than PC versions, maybe the results would favor the VR versions, but two very different games would have emerged (Between PC and VR).

To improve the non-linearity aspect, scenarios can be expanded, and the consequences of wrong choices can be shown in more detail. For example, in the Hospital game, if the player as a doctor chooses the wrong ward for an infected patient, they can spread the infection to the other patients in that ward, and their condition can change when that patient arrives at the selected ward. Levels of difficulty can be added, and a gradual training approach can be applied to better understand the information provided. To increase the difficulty, the number of patients and their arrival rate can be increased, and treatment of multiple patients simultaneously with multiple doctors and nurses can be added to the game.

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APPENDIX A

QUESTIONNAIRES – PRESENCE (FIRST PART) [26]

Presence (Answers from 1 to 7, 1 being most negative)
How much were you able to control events?
How responsive was the environment to actions that you initiated (or performed)?
How natural did your interactions with the environment seem?
How much did the visual aspects of the environment involve you?
How natural was the mechanism which controlled movement through the environment?
How compelling was your sense of objects moving through space?
How much did your experiences in the virtual environment seem consistent with your real-world experiences?
Were you able to anticipate what would happen next in response to the actions that you performed?
How completely were you able to actively survey or search the environment using vision?
How well could you actively survey or search the virtual environment using touch?
How compelling was your sense of moving around inside the virtual environment?
How closely were you able to examine objects?
How well could you examine objects from multiple viewpoints?
How well could you move or manipulate objects in the virtual environment?
How involved were you in the virtual environment experience?
How much delay did you experience between your actions and expected outcomes?
How quickly did you adjust to the virtual environment experience?

QUESTIONNAIRES – PRESENCE (SECOND PART) [26]

Presence (Answers from 1 to 7, 1 being most negative)
How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?
How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?
How much did the control devices interfere with the performance of assigned tasks or with other activities?
How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?
How completely were your senses engaged in this experience?
To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?
Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?
Were you involved in the experimental task to the extent that you lost track of time?
How easy was it to identify objects through physical interaction, like touching an object, walking over a surface, or bumping into a wall or object?
Were there moments during the virtual environment experience when you felt completely focused on the task or environment?
How easily did you adjust to the control devices used to interact with the virtual environment?

QUESTIONNAIRES-SYSTEM USABILITY SCALE [83]

System Usability Scale (1: Strongly Disagree 5: Strongly Agree)
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.

QUESTIONNAIRES – TECHNOLOGY ACCEPTANCE MODEL [84][85]

Technology Acceptance Model (Answers from 0 to 10)
I liked the idea of creating a game to teach and improve user interactions with new devices.
The game helped me to get used to the 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 is 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 found it easy to reach targets.
I did not have problems finding targets on 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.

QUESTIONNAIRES – SUGGESTIONS AND FEEDBACK

What are your suggestions to improve the Hospital and Biogarden games in VR?

Which game did you enjoy most? Personal Computer or VR versions? Why?

What are the main strengths of the current games in VR? Please explain.

Hospital Game in VR:

Biogarden Game in VR:

What are the main flaws of the current games in VR? Please explain.

Hospital Game in VR:

Biogarden Game in VR:

What are the main strengths of the current games (PC version)? Please explain.

Hospital Game (PC Version):

Biogarden Game (PC Version):

What are the main flaws of the current games (PC version)? Please explain.

Hospital Game (PC Version):

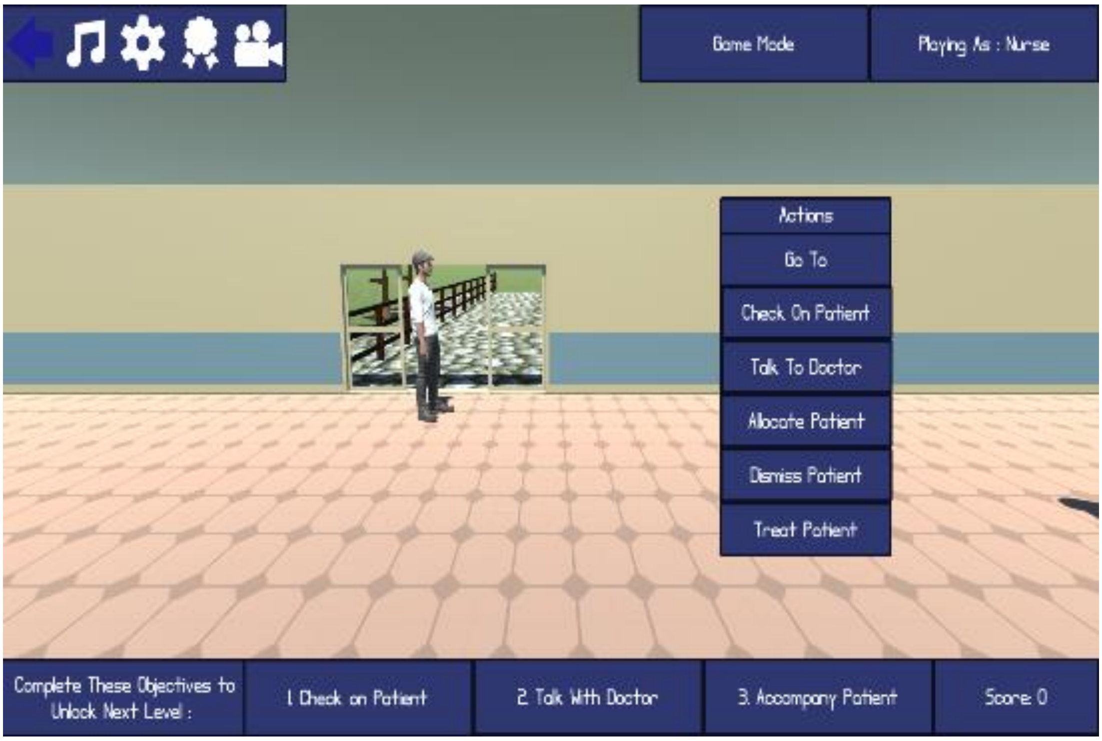
Biogarden Game (PC Version):

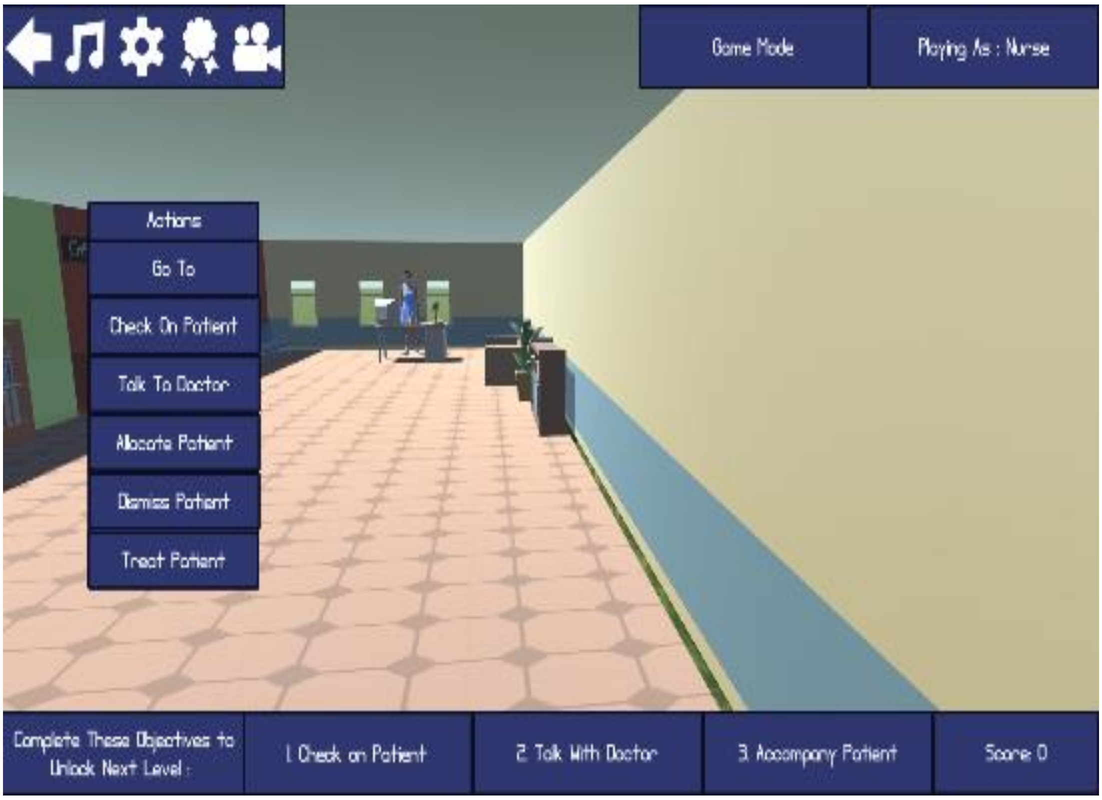
Did you notice any differences between the games and their real scenarios demonstrated during the eNOTICE Jas of Nimes 2018 and Brussels 2018?

Please explain.

Suggestions and Feedback:

B. SCREENSHOTS FROM THE ENTERFACE'19 VERSIONS


Game Mode
Playing As : Nurse
Actions
Go To
Check On Patient
Talk To Doctor
Allocate Patient
Dismiss Patient
Treat Patient
Complete These Objectives to Unlock Next Level :
1. Check on Patient
2. Talk With Doctor
3. Accompany Patient
Score 0


Game Mode
Playing As : Nurse
Actions
Go To
Check On Patient
Talk To Doctor
Allocate Patient
Dismiss Patient
Treat Patient
Complete These Objectives to Unlock Next Level :
1. Check on Patient
2. Talk With Doctor
3. Accompany Patient
Score 0


Actions
Cladestine Lab
Game Mode
Playing As : Local Investigation Team
Detect Sample
Collect Sample
Send Sample to Mobile Lab (Before Analysis)
Analyse Sample
Send Sample to Mobile Lab (After Analysis)
Get Results
No Problem
Set Up Crisis Center
Go To Decontamination Center
Complete These Objectives to Unlock Next Level :
??
??
??
Score : 0

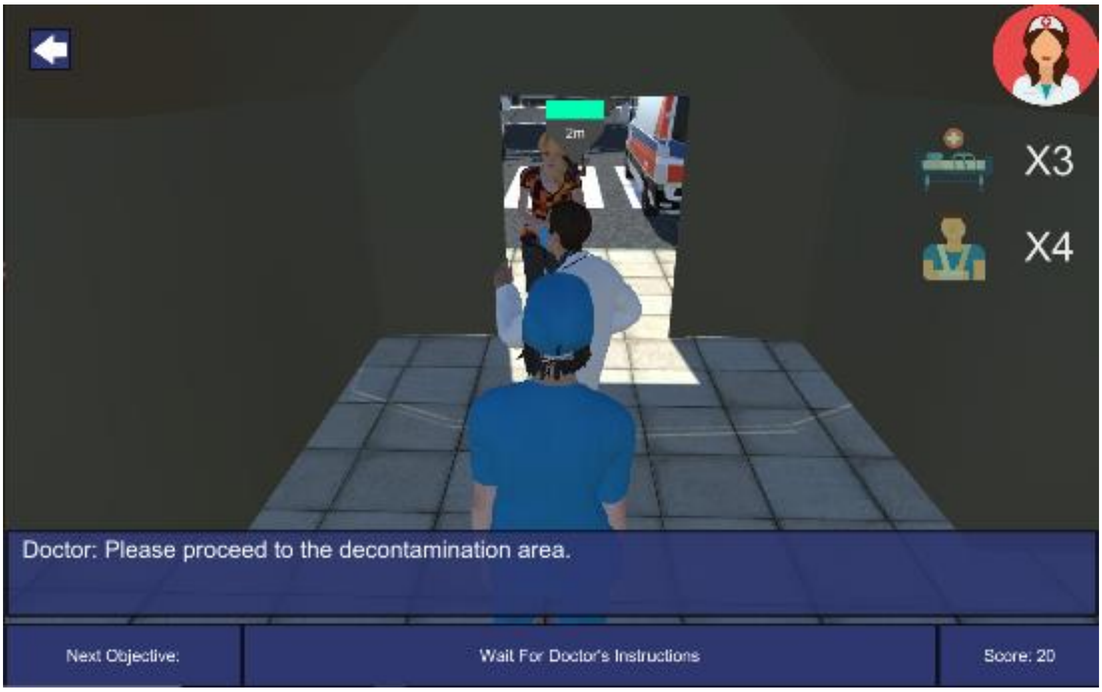

Game Mode
Playing As : Local Investigation Team
Decontamination Unit
Complete These Objectives to Unlock Next Level :
Collect Sample
??
Score : -180

SCREENSHOTS FROM THE FINAL VERSIONS


14m
X3
X4
Next Objective:
Check Incoming Patients At The Entrance of The Crisis Center
Score: 10


2m
X3
X4
Patient has been affected by a chemical agent!
Which action should we take for the patient ?
Put IV
Give Vaccine
Put Oxygen Mask
Next Objective:
Meet Patient and the Nurse at the Chem Ward
Score: 50


X3
X4
2m
Next Objective:
Prepare for Incoming Patients. Wash Your Hands
Score: 10


X3
X4
2m
Doctor: Please proceed to the decontamination area.
Next Objective:
Wait For Doctor's Instructions
Score: 20


Playing As Restaurant Investigation Team
14m
POLICE
Next Objective:
Go to the Entrance of the Restaurant
Score : 0


Playing As Restaurant Investigation Team
3m
POLICE
POLICE
Next Objective:
Send Sample To B Life Lab with Drone
Score : 30

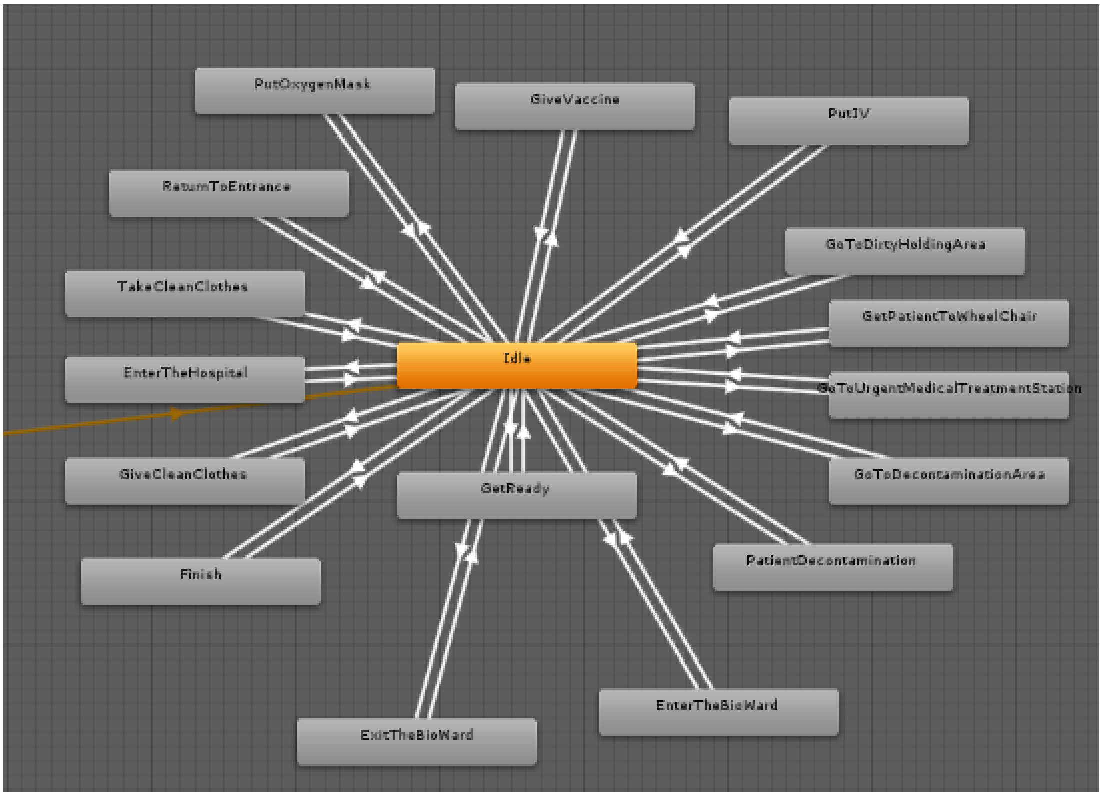

Playing As: Restaurant Investigation Team
171m
Next Objective
Send Sample To B Life Lab with Drone
Score : 30

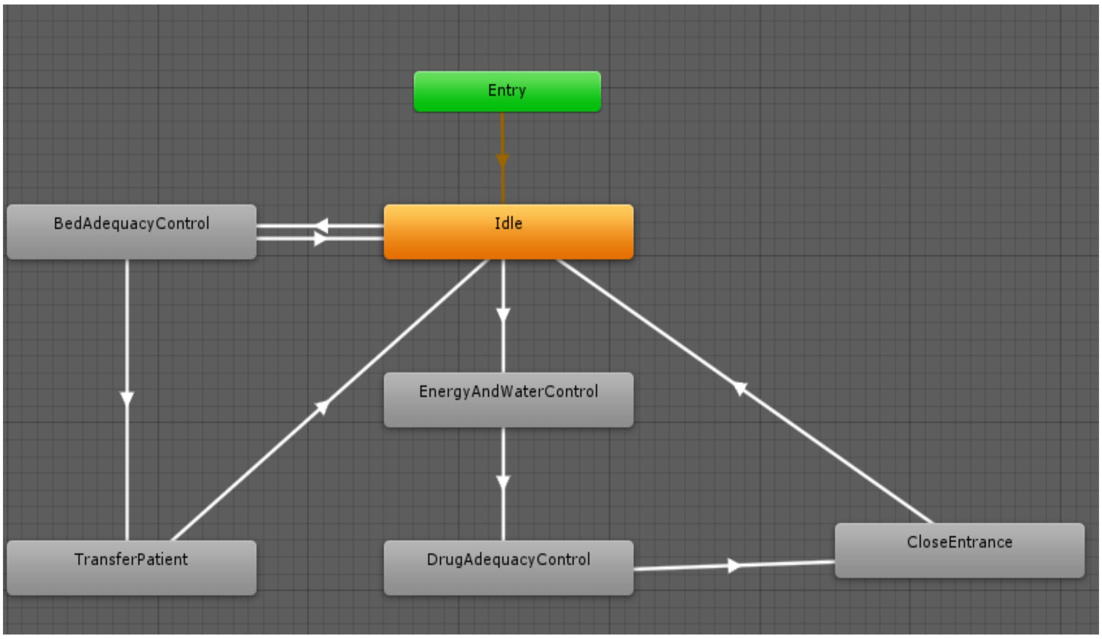

Playing As: Local Investigation Team
32m
POLICE
Next Objective
Go to the Downstairs of the Dadesine Lab
Score : 0

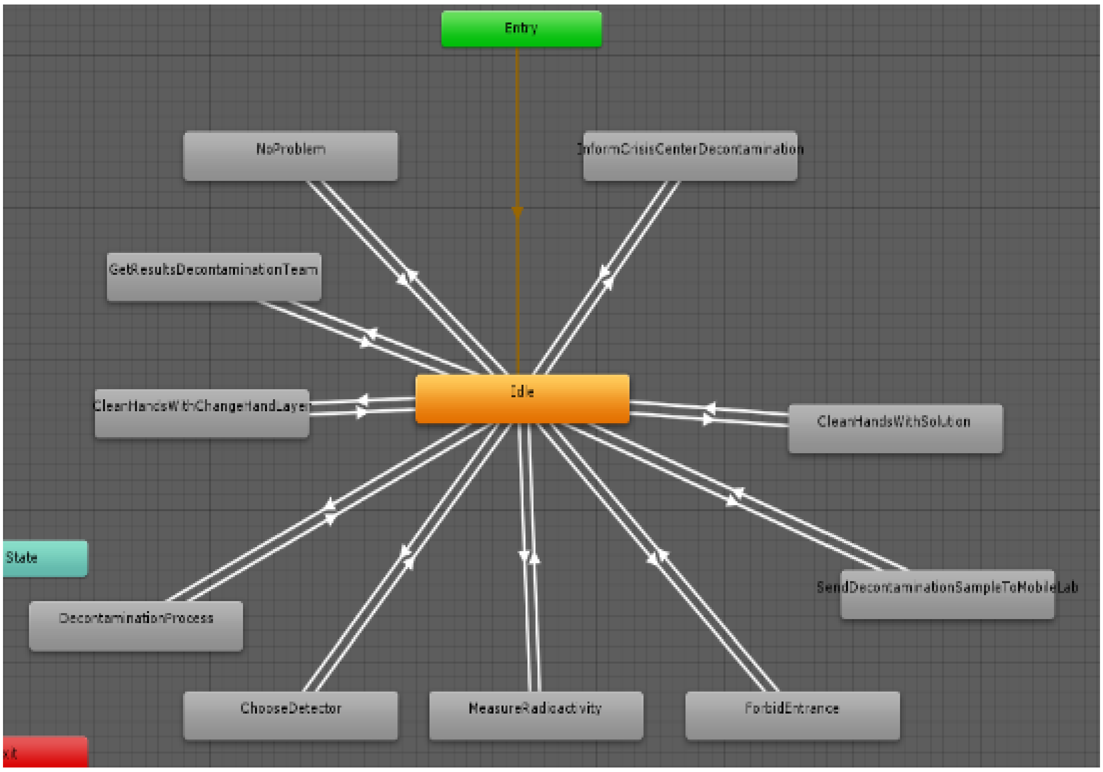

Playing As: Decontamination Team
3m
Next Objective:
Measure Radioactivity on the Contamined Team
Score : 90


994
X2
X3
Next Objective:
Check Incoming Patients At The Entrance of The Crisis Center
Score: 80

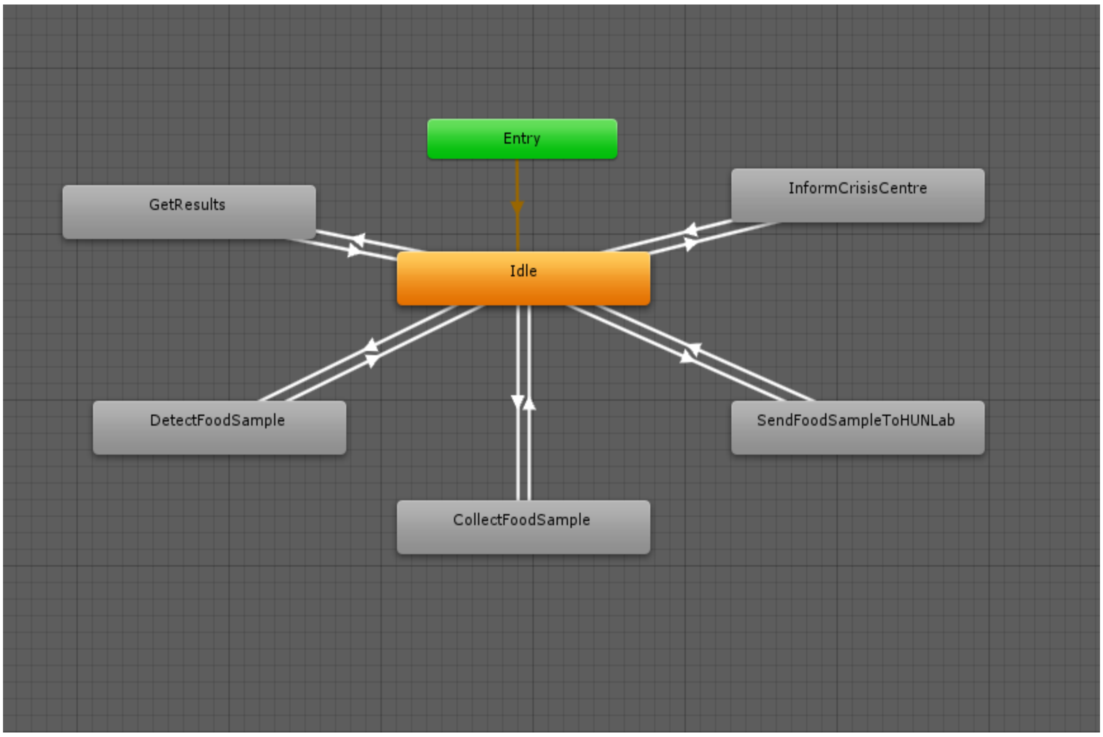
SCREENSHOTS - FROM THE SCENARIO TO STATE MACHINES







Entry
NoProblem
InformCrisisCenterDecontamination
GetResultsDecontaminationTeam
Idle
ClearHandsWithChangeHandLayer
CleanHandsWithSolution
State
SendDecontaminationSampleToMobileLab
DecontaminationProcess
ChooseDetector
MeasureRadioactivity
ForbidEntrance



Entry
GetResults
InformCrisisCentre
Idle
DetectFoodSample
SendFoodSampleToHUNLab
CollectFoodSample