University of Sheffield

Investigating Crime Scenes in Virtual Reality

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Declaration

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Abstract

Training crime scene investigators is a complicated task due to the limited amount of crime scenes that can be recreated in real life for training purposes.

This document investigates the use of serious games and virtual reality as vehicles for training crime scene investigators on forensically investigating crime scenes. The aim of the project is to recreate a crime scene realistically in virtual reality that investigators can navigate and interact with realistically, in the search for evidence of cybercrimes.

The application was created as a single level game in which the player has to look for a number of SD cards hidden in different spots throughout the room to encourage a more thorough search of the room.

Despite some limitations with the technology that keep it from being fully realistic, from the user feedback we can say that the system overall achieves its goals, and given more time and the lack of competition, the application could become an interesting option when it comes to utilizing serious games for training crime scene investigators.

Contents

Chapter 1

Introduction

1.1 Background

Event thought there isn't a specific definition for the term "serious game", we can say that serious games are those games where entertainment isn't the primary purpose. Throughout many centuries, serious games have evolved from tabletop games to digital games driven by the demand of digital teaching tools. From text-based games to virtual reality simulations, the advancements in technology combine very well with serious games, allowing for realistic virtual simulations of real-world scenarios making this a very effective tool for training.

1.2 Aim

The aim of the project is to produce a serious game to train members of the National Crime Agency (NCA), more specifically, investigators from the National Cyber Crime Unit (NCUU). The game will provide a virtual reality simulation of a crime scene, which the investigators will have to navigate through following the usual forensic procedure as if they were in a real-life scenario. The crime scenes could be set in different scenarios such as a living room or a teenagers bedroom. Different rooms will have different layouts and different objects with which the user can interact (drawers, beds, chairs, tables, phones, etc.) in a realistic way, e.g., to open a door the user must grab the door handle with the HTC Vive's controller and pull like they would do in real life.

The investigator's objectives will be to find one or more pieces of evidence, which can be hidden in different places of the room. During an investigation, investigators will search thoroughly throughout the rooms in the search of potential evidence. Typically investigators will be searching for electronic devices such as laptops, SD cards, hard drives, etc.

Once they've found the evidence they must store the evidence securely in evidence bags and continue searching for more objects or return to the officer in charge of the investigation to finalize the search.

Once the search is finalized the investigators and the supervisors will receive some sort of feedback on-screen which may consist of a list of object in the room showing which ones have been found and which ones haven't, the time spent by the user in the crime scene or a 2D map of the scene which shows the navigation path followed by the user

1.3 Challenges

Initially the project was broken down into three different challenges.

- Creating a realistic, configurable 3D scene
- Make interactions as realistic as possible
- Consider effectiveness of the serious game alongside formal training

1.4 Overview of the report

The literature review section reviews core literature relevant to serious games and crime scene investigation. Furthermore it reviews similar solutions and the available technologies.
The requirements and analysis section identifies the features that are to be implemented in the solution. It proposes ideas and functionality relevant to the solution and it utilizes the knowledge from the literature review.
The design section outlines the system's proposed design.
The implementation section describes in detail how all the features of the system were implemented.
The results and conclusion sections analyze how effective the solution is by the means of analyzing participant feedback and an evaluation of the features implemented.

Chapter 2

Literature Review

2.1 Literature Review Overview

The literature review is split up into various sections, firstly serious games and its applications are reviewed, then and analyzes the hardware and software available to produce the game and explores the challenges and aims

2.2 What is a crime scene?

Every month, 400,0000 crimes are committed in the UK and Wales[18] combined. This figure doubles if we add fraud and computer-misuse to the previous figure[12]. A crime scene is a physical scene which is related to a committed crime, in which an investigator could potentially find evidence, to better the chances of a fair trail. The location of a crime scene doesn't necessarily have to be the place where a crime was committed, a crime scene is anywhere evidence can be found. Evidence can be found in many form, there's physical proof such as pictures, fingerprints, weapons, drugs, etc., there's digital proof hard-drives, smart phones, etc., there's scientific evidence and there's witness testimony.[6]

2.3 Investigating a crime scene

The evidence in these scenes is collected by criminal investigators by the means of forensically analyzing the scene, following a set processes and pro-

cedures. It is important to follow the set processes and procedures whilst analyzing a crime scene because usually there's only one opportunity to assess and recover evidence from the scene.[11].

The common procedure for this would be similar to the following: Firstly, upon their arrival on the crime scene, whichever official arrives there first must ensure the correct preservation of the crime scene to avoid the loss or degradation of potential evidence and maximize the probability of forensic retrieval of evidence[21]. To ensure this officers must cordon the scene, remove non-essential personnel from the scene and ensure that appropriate clothing is used[11].

Once the previous are done, then the officers in charge of the investigation will have to produce an initial record of the scene by using non-intrusive procedures such as taking still-pictures, videos, 360º pictures[1], etc. Then the scene will be searched systematically and thoroughly by the agents in charge, these agents will put special attention to areas where they deem can contain more evidence based on the information they have and their experience. The agents will note down the different areas or items of interest in order to label the evidence once its all collected.

During the investigation, the handling of evidence must be done carefully. It is important for officers to wear rubber gloves and correct protective clothing to avoid cross contamination of the evidence. Evidence should be handled as little as possible and placed in a protective evidence bag, the faster the better. Once the evidence is inside the plastic bag, the form in the front face of the evidence bag must be filled in accordingly.[11].

Once all the evidence is securely packed up, it is brought back to the headquarters, where the group of officers in charge of the investigation will collate the evidence further. Finally, a report with the findings or a statement of witness is produced and sent to other investigators or court prosecutors.[11].

2.3.1 Training Criminal Investigators

It was previously stated that "It is important to follow the set processes and procedures whilst analyzing a crime scene because usually there's only one opportunity to assess and recover evidence from the scene"[11]. Mistakes at crime scenes are inevitable, as humans we will eventually make mistakes, therefore training is fundamental to forensic investigations, the more training an investigator undergoes, the less mistakes that will be made in a crime scene such that there's a higher chance of collecting more evidence which will

help building-up a case against a suspect. Training for these investigators is usually delivered through classrooms, seminars and practical exercises and assessed through exams. [7]

Over the last couple of years, serious computer games have been used used by law enforcement agencies to aide in the training of their agents, these games vary in complexity and aim. We can find simple computer-based games like the one used by the Dubai Police[4] and very complex 360º interactive video scenes like VirTra[27]. All of the systems aim to ensure that agents have the necessary skills to perform their job succesfully.

2.4 Serious Games

Games have been around since the times of ancient empires, one of the first dice finding dates back to the Persian empire back in 3000BC[20] and was found in a box of backgammon, a board game that is still played now a days in eastern Mediterranean countries and the United States[14]. Further on in history, between the 6^{th} and the 7^{th} century India we can find the game Chaturnaga a game with military aspects to it. Historians believe it is the predecessor of a more familiar game, chess[28]. It is believed that Chess was used originally to train military strategies to kings and nobles. In the modern era, Benjamin Franklin described chess as a medium that, whilst still being amusing it teaches players several valuable qualities of the mind: foresight, circumspection and caution.[10]

Fast forward to the digital era, It was in 1970 when Clark Abt coined the term "serious game" as follows:[2]

> "Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining."

Which in essence means that a serious game is a game in which entertainment isn't the primary objective, we can find this same definition in Michel and Chen's book, Serious Games: games that educate, train and inform[9]. We can think of Chess as one the first serious games, based on the previous knowledge on chess and the definition given by Abt in his book, a game that has an educational purpose and is still entertaining.

By the time that Clark Abt published his books, the first digital serious games were being developed and available to the public. One of the first games is The Oregon Trail[22], published in 1974, a game that was designed to teach school children about the realities of 19th century pioneer life on the trail. This piece of "Edutainment" is still available to users on their smartphones or in Facebook and thus can be considered successful. From here onward, the most notable serious games produced have been military related games[16] Battlezone, Bradley Trainer, Marine Doom, Americas Army, etc. From simple text-based games to full 3D games, the advancement in computational power has been exponential for the last 50 years[17].

The military has played a big part in the increase in computation power during the post WWII era. Before games where called games, they were called simulations, and they were usually aimed towards business situations and military warfare. Military generals would then invest millions of dollars on both the software that run these games and simulations and the best hardware available to run the software. Consequently the prices of computers and software decreases and the simulation potential increases[9]. With the explosion of 3D Graphics the available game technology and hardware is sufficient for most applications of serious games. Virtual Reality is the next step in serious gaming, the wrapping, 360^{a} immersive experience that VR provides is unmatched when it comes to training and big companies around the globe know it.

2.5 Effectiveness of serious games

Effectiveness can be measured in many different ways, for a project such as this one, an effective serious game would be one that managed to transfer knowledge to the player, but, how does learning work?

David Kolb presented a learning style model in 1984 in which he describes learning as a cyclic process in which "knowledge is created through the transformation of experience"[15]. The cyclic process described by Kolb is defined by four stages: 1. concrete experience, 2. reflective observations, 3. abstract conceptualisation, 4. active experimentation (as illustrated in figure 2.1).

Effective learning can be observed when an individual advances through the stages of the aforementioned cycle, firstly a person undergoes a new experience, secondly this person reflects on that new experience, thirdly the reflection over the new experience can then produce new abstract concepts

or modifies the existing ones related to that experiences, finally, the new concepts are then applied to the world which produces new experiences for the person.[15] In this learning process, all of the stages are supportive of each other and depend on the previous stage to be effective.

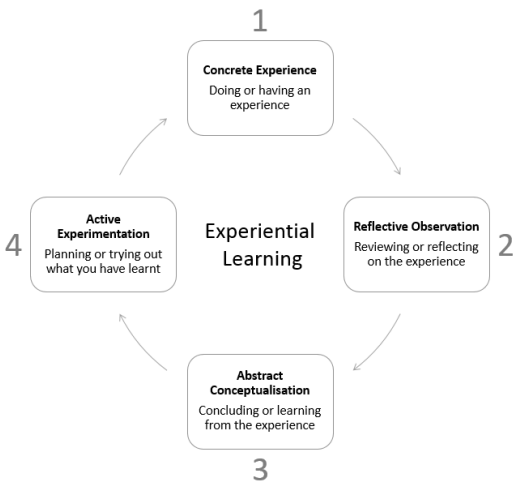

Figure 2.1: A representation of Kolb's cycle (Source: www.symplyphychology.org)

Virtual reality provides a virtual world in which the player can experiment and apply knowledge related to the simulated world. A realistic simulation of the world supports the fourth step in Kolb's[15] experiential learning cycle, but in order to do this effectively the simulated world has to be a close representation of the real world. The level to which a game aims to simulate reality is known as fidelity, and it is made up of three different categories[3]:

- Physical fidelity: the degree to which the virtual environment simulates how the real world looks, sounds and feels.
- Functional fidelity: the degree to which the environment reacts to the players interactions with it.
- Psychological fidelity: the degree to which the simulation makes the user believe he is present in the environment.

A high fidelity virtual reality simulation provides a safe training environment for different people in different lines of work, from firefighters and

soldiers, to oil-rig ad healthcare workers, all of these can benefit from the use of VR training techniques. This new technology engages more with the young and uprising workforce[23], it is though that people under the age of 35 adapt faster to simulated environments and have a higher retention rate when using this technology therefore advancing their careers more quickly[23]. Adrian Leu, chief at Innation sees few limitations to the range of applications that virtual reality has and states the following: ""In some areas of training, it's about a task list", he then goes on to state that "The immersive nature of VR and AR embeds the task list deeper in the memory"[23]. We can then infer that the combination of a serious game with virtual reality for forensic analysis will be effective, because as we learnt earlier, the forensic investigation of a scene requires following a set protocol, which is basically a series of task carried out in certain order.

Big companies are aware of this, they know that these training methods are cost-effective by skipping the barriers of cost, time and legislation and producing better results than conventional training methods.

2.6 Crime-related applications of serious games

The software, known as SGTAI[4] produces a first-person experience to teach traffic investigators the knowledge and the skills required to deal with a traffic accident. The software focuses on improving the skills and knowledge required when investigating traffic accidents by reproduces realistic traffic accidents scenes which vary in size and complexity. The game provides a high fidelity reproduction of the different stages involved in a traffic accident investigation, from the moment a call is received to the moment a report is filled. The game allows the player to move around investigating the scene and interacting with it by placing cones and markers, taking photos, interrogating witnesses at the scene or collaborating with other forces found in the scene, like paramedics.

The game aims to provide a fun factor by the means of a high-score to engage more with the players although the environment is simplified in order to focus on the skills required to carry out the investigation, similar to Abts guideline[2].

Another application which was developed by DRoman Crime Solutions,

Scotland Police and Abertay University. In their application, users can move around a virtual crime scene whilst looking for evidence and answering questions about legislation and police powers[19]. From the video available in the DRoman site[8] we can see that the game uses some sort of point and click control system for navigation and interaction. Once the user interacts with an object, a window with information relating to the object is displayed and the user has to select what to do with the evidence. Once an answer is selected some more information is displayed to the user related to the object and the procedure to follow to ensure digital data evidence is not lost. I consider the game to be more of an interactive quiz than an actual game because of the lack of interaction with objects and the crime scene aside from pointing and clicking on the, also because when the player finishes analyzing the crime scene if he answers correctly the questions they are awarded a diploma.[19]

The Guardian also has a VR application in which the player has to find relevant evidence in a murder scene, to be processed at the lab. I[26]. From the video available on the guardian's site we can see the user is set in a small dark room in which he can move around and aim around with his torch which illuminates the scene and casts a ray forward from where its pointing, which is probably used to interact with objects. The scene was constructed using 3D scanning techniques on a real set with actors and props. It is developed by ScanLAB Projects and available for Google Cardboard[25].

2.7 The hardware

The HTC Vive (figure 2.2) will be the hardware of choice to display and interact with the virtual world that will be created. The Vive is a piece of hardware developed in conjunction by two big technology companies such as HTC, one of the biggest brands in the smartphone sector, and Valve, developers of the steam platform and some of the most critically acclaimed games ever made, such as the Half-Life series, Counter Strike, or Portal.

Figure 2.2: An image of the HTC Vive headset and wands

The joint-venture between both this companies results in a fantastic piece of hardware. The headset includes a dual

AMOLED 3.6" display[13] with a resolution of 1080x1200 pixels per eye, for a total resolution of 2160x1200 at a refresh rate of 90Hz. This specs are on-par[24] with its biggest competitor the Oculus Rift and above other headsets like the Samsung VR wich works at a frequency of 60Hz.

In addition to the high refresh rate, the Vive offers a wide field of view of 110º, which makes the game scene wrap around the headset for a more immersing experience and on top of that, the sensors that come pre-packed with the Vive track the players movement in real life once they are set up properly. They headset also provides Chaperone play are boundaries[24] inside the games so that the player doesn't move out of the allocate space for the Vive. On top of this, the Vive allows to adjust the interpupillary and eye distance for eye relief.

2.8 The Software

Programming a game such as this one is a big task, it would be very complex and time consuming to code everything from scratch using OpenGL, but luckily there's a couple of game engines available to help with the development of the game. The 3 biggest game engines available as of now are Unity, Unreal and CryEngine. Im not taking into consideration the latter due to the lack of support it has received from VR hardware manufacturers. Now, both Unity and Unreal support the HTC Vive headset[5], but given the size of Unity's assets store and the publicly available tutorials and documentation Unity is the game engine of choice.

Chapter 3

Requirements And Analysis

3.1 The Project

The initial project aim was to develop a serious game to train operational officers on how to forensically investigate a crime scene utilizing videogames and virtual reality as a vehicle to achieve this.

The initial requirements were the following:

- Creating a high-fidelity, configurable 3D scene
- Make interactions as realistic as possible
- Consider effectiveness of the serious game alongside formal training

Given the initial requirements and after the literature review carried out in the previous chapter the aim and scope of the project could be defined better.

The goal was to produce a high fidelity virtual crime scene for investigators to investigate. Investigation would involve navigating around the scene and performing a forensic search of evidence using the virtual reality headset and controllers. The evidence which could be hidden or visible in plain sight, once found, a piece of evidence has to be secured and placed with the rest of the evidence. The project had to focus on providing a realistic experience and mechanics such that investigators use the game as another method of training. Although virtual reality brings many advantages when it comes to training, the technology is still fairly new and has some limitations of its own, like the lack of support and development kits for this technology.

3.2 Analysis of the Project

3.2.1 Creating a realistic, configurable 3D scene

From the literature review we more clearly understand that we are aiming at producing a scene with a high physical fidelity[15], a scene that is realistic. When the players put the headset on, they will be placed inside the virtual crime scene. Virtual reproductions of a crime scene with high physical fidelity can be done using a variety of tools and techniques. Tools such as laser scanners or the OSCR360[1] are used when capturing crime-scenes, these are combined with the use of sketches of the crime scene to produce a 3D representation of the crime scene using different software like, Unity, SketchUp or proprietary software(like the OSCR's software). The use of such tools is out my scope, so I will be recreating the crime scenes in Unity. At first the idea was to offer the user some sort of level editor in which the user could select different room layouts and choose the furniture they want in the room, alternatively the rooms and the layouts could be generated randomly and saved in the system so that it can be replayed later on. Although this is achievable it is probably out of my time frame, so initially there will be one room ready for investigation. If time allows it more rooms will be produced.

Initially, the room will be that of a teenager and thus will include the typical furniture that would be found in a bedroom, a bed, a night-stand with a lamp, a desk, a computer, some drawers, etc., and one or more pieces of evidence which can come in the form of tablets, laptops, hard drives, SD cards or similar. Attention to detail is critical when producing a high fidelity scene, for example, if a SD card was taped under the computer desk or a shelf rack then there's probably a tape roll in the room. Small details like these that can point investigators in the right direction and increase the realism of scene.

Creating all of the furniture and objects in the scene would take a lot of time and artistic skills, luckily the Unity asset store and the internet have a lot of high quality assets for the grab, so whenever possible these will be used.

Even though in real life you can grab and move around furniture in a room, this will not be necessary in the game, it is unlikely that evidence is hidden in a place where access is complicated, like behind a shelve or a dresser, therefore big furniture will be static in the scene, and smaller, lighter furniture like the bed or a chair will be able to be pushed around the scene.

In addition to all of this, ambient plays a big part in making a scene's physical and psychological fidelity better, for example, The Guardian's VR experience[26] places us in a flat, at night, we can see rain and a police car's lights coming in through the window making the scene more believable, more alive. An audio track could be reproduced in the background with occasional noise from the street depending on the scene's location.

Criminal investigator don't work alone, they will usually work in pairs to analyze to analyze a crime scene, this is better when your goal is to obtain the maximum amount of evidence possible but the aim of the project is to evaluate an individual's performance when analyzing a crime scene. To increase the physical and psychological fidelity of the experience another officer will be added to the scene in the form of a NPC (non-playable character).

This addition will give more credibility to the scene as it will be used as a medium to give the player a debrief about the scene and the task, it could provide information about different devices and legislation, similiar to what DRoman's application does, it can give some hints to the player in the form of audio, speaking to the player, or text, on-screen tooltips and it can also be used as a medium to finalize the investigation, once the user considers all the evidence has been collected, he can interact with the NPC to finish the case and abandon the scene.

3.2.2 Make interactions as realistic as possible

This is a serious game that aims to be during the training of new criminal investigators so that they can do their job better. Virtual Reality offers a unique medium by mapping the users head and hands one-to-one inside the simulated scene, users expect their interactions to be as realistic as possible to not break that immersion feeling. Whilst creating "one-to-one" interaction mechanics in VR is impossible, we can maximize the fidelity of the in-game interactions to make the experience more realistic.

When playing a game in , one of the first things we identify is that a player can move its hands freely through space whilst their in-game hand-model moves trough a solid wall.In VR we can't physically limit the persons' movement, this raises a question about gameplay, what happens when the player is grabbing an object and passes his hands through a wall? One approach would be allowing the object attached to the hand to "ghost" through the wall and highlighting the players in-game hand and object outline so that the player is aware that he is still grabbing an object, alternatively, we can

make the object drop of the hand as soon as the hand moves through a wall. For our case, the latter makes more sense, feels less immersion-breaking and makes the player be more careful when handling potential evidence.

Now, what happens when the object the user is interacting with is attached to another object, i.e. a door handle, a drawer knob, a lever. These items usually only move around a pivot point in a single direction. We can make the player interact with it at a reasonable distance, highlighting both the hand-object and the other object, or otherwise we can stop the interaction if the hand moves away from the object. Again, the latter seems like a more realistic option but some play-testing will be needed to find a correct balance between realism and a user-friendly experience.

In addition to this, when playing a VR game, there is no sense of touch, the objects are virtual and the player cannot touch them and feel them, this handicaps the player in the search for evidence. Lets say that an SD card is taped below a desk in a room, usually an investigator would sweep their hand below a table looking for something that feels out of place, the taped SD card. To mimic this, if the player sweeps its in-game hand and touches something that's interactable he will receive feedback in the form of a vibration or a sound so that he is aware of an object being there.

To conclude, it has to be mentioned that due to the one-on-one mapping from the real world to the virtual scene means that different people with different heights will have different perspectives, this shouldn't suppose a problem when interacting with the scene, the scale of the assets will allow for the average adult to interact with objects in the game. A feature to adjust head-height can be included later on after some testing if time allows for it.

3.2.3 Evaluation of the serious game

To keep in line with Abt's definition of a serious game[2], some sort of evaluation on the player's run has to be done in order to produce feedback to the player. The initial idea was to introduce some sort of scoring system in the game such that users could set high scores when they finished investigating a scene like in the SGTAI[4]. Although this is fun and engaging for player, it seemed quite complicated in the sense that it is hard to judge which actions would give or deduct points from the player, so instead of this system a number of different options can be implemented in the system to gather data and provide the player with feedback about the investigation.

To deem an investigation as successful certain tasks have to be completed

such as preserving the scene, documenting it, investigation all objects in the room, finding evidence, securing evidence, etc., from this list of tasks we can make up a simple scoring system in which each task is worth 1 or 2 points and players can loose points if evidence is handled poorly. Parts of the list of tasks could be available for the player in game through the NPC or trough some text in the HUD or a toggle-able menu.

In addition to that, Bin Subahi's game, SGTAI logs the path a player follows during an investigation, a feature like this one would be interesting in order to identify trends that different investigators follow and can be used when reflecting about the player's run in the game to gain more knowledge about crime scene investigation. It can be expanded even more by logging the objects a player is looking at and the time they've spent looking at it too to give a more detailed representation of the run.

3.3 Requirements

Based on the project description given in section 3.1 and further analysis of the given requirements we can identify the features that the application needs to fulfill the clients requirements. The main focus of the project will be the player's interaction with the scene. From the previous analysis we can extract a series of requirements which can be found in table 3.1.

ID	Requirement	Importance
1	Create a room which the player can navigate	Mandatory
2	Provide a way of creating/editing levels	Desirable
3	Generate levels/layouts procedurally	Desirable
4	Include another officer as an NPC	Optional
5	Add a way to debrief user at the beginning of the investigation	Optional
6	Interact with NPC to finish investigating scene	Optional
7	Interact with NPC to view information about electrical devices and legislation	Optional
8	Allow grabbing/manipulation of objects in the scene	Mandatory
9	Allow interaction with furniture: drawers, doors, shelves	Mandatory
10	Allow moving some furniture around	Mandatory
11	Display splash-screen with health and safety tips	Mandatory
12	Make a list of actions to be carried out in the scene	Mandatory
13	Use the list to give points to the player when performing tasks successfully	Optional
14	Deduct points from the list if evidence is damaged	Optional
15	Record path followed by a user	Optional
16	Log what object a user has been looking at and for how long	Optional
17	Log total duration of investigation	Optional
18	Allow to adjust player's head height	Optional

Table 3.1: Table of Requirements

3.4 Health and Safety considerations

Health and safety has to be taken into consideration if the game is going to be used to train real people. It is in everyone's best interest to minimize risk at the workplace and to do this, a splash screen will be shown before the menu screen showing three different pieces of information. Firstly the user will be reminded to adjust the lenses in the headset to reduce eye strain accompanied by a pictorial description of how to adjust the interpupilary distance and the lens' distance. Secondly, the player will be told to ensure that allocated play-area is free of objects and to stay inside the *Chaperone* game area. Finally, the first couple of times a player utilizes VR they can experiences dizziness and fatigue, therefore the players will be reminded to take a break in case they are experiencing any of the formerly mentioned.

3.5 Testing and Evaluation

Testing and evaluation are necessary in order to produce a robust piece of software that meets the requirements. Testing will be done to find bugs and errors in the code, and the system as a whole will be evaluated to see how closely it meets the requirements. The testing strategies used will be black-box and user acceptance.

During the implementation of the system, when a new functionality is added into the system, black-box testing will be performed on that functionality. Black-box testing only takes into account the system's inputs and outputs, ignoring the inner workings of the component being tested. This testing is the most suitable given the nature of the application that will be created.

Finally, user testing will involve getting users to test out the system in order to gather feedback about the system.The idea would be to have two groups of users to test the system, namely groups A and B. This testing will be carried out halfway through development by group A, before the end of the development stage by groups A and B, and once the development is finalized by both groups. This testing will evaluate through the use of paper forms how the system feels, how realistic it is, how intuitive, the GUI and other aspects. By using two groups of people at different stages we can evaluate how much later stages of development have improved the final product.

3.6 Legal, Social and Ethical issues

When using the HTC Vive, or the Unity brand, I must ensure that the use I make of the brand is fair and in line with their usage policies. Usage of colour has to be taken into account to make sure that the game is usable by officers which migh suffer from colour blindness. User testing is required in the latter stages of the project, in order to get people to test the game, the ethical policies set by The University of Sheffield will be followed. The use of VR equipment has some risk adhered, the safety guide provided by HTC covers most of the risks related to the Vive's use.

3.7 Risk Assessment

The most common risk related the use of virtual reality is fatigue and eye tiredness, during long sessions of use or when using the system for the first time. In combination to that, in order to use a room-scale virtual reality experience, the user must ensure that there is enough space for the player to move and extend his arms fully, the chaperone play shouldn't be relied on for security. The play area shouldn't be used near heat sources, stairs, large windows or any object that could make the user trip. On start up the game will display a health and safety warning telling the user to restrain from using the Vive for long periods of time and to stop using it if they experience any symptoms of fatigue, additionally he will be reminded to make sure that the play are is clear from objects that could cause them to trip.

Chapter 4

Design

This chapter lays out the design of the features that have to be implemented in order to satisfy the requirements.

4.1 Game Overview

The game is going to be developed in Unity utilizing VRTK which is an open-source library for virtual reality development which extends the functionality provided by the Vive's SDK. Unity uses the C# language for its scripts, so I will be using this language to implement extra functionality based on my requirements. The assets used in the scene will be downloaded from either Unity's Asset Store or online 3D model marketplaces.

4.2 The Room

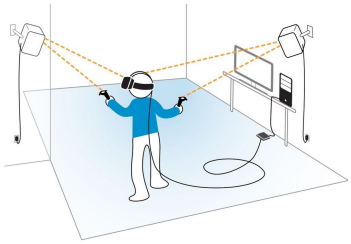

Figure 4.1: A typical Vive setup (Source: techradar.com)

The HTC Vive utilizes a 3D spatial laser-tracking system developed by Valve known as Lighthouse. By positioning two base stations opposite from each other the player can move around a space of up to 5x5 metres.

The game scene will simulate a crime scene based on a teenager's room, this room will be of a maximum size of 5x5 metres so that the Vive's Ligthouse can be used to navigate around the room by walking freely. The objects found in the room will be interactable for the player, by the means of grabbing, sliding, and rotating.

Figure 4.2: Left: The room layout. Right: Teleportation points in the room

Figure 4.2 shows the room's layout, the room has 4 areas of interest where evidence can be potentially hidden, the bed area, the table area, the drawer area and the rack area. On starting the game, the player will spawn in between the bed and the drawer, near the door.

If a 5x5 metre playarea isn't available, the player wouldn't be able to move from one corner of the room to the opposite one, to deal with this, three teleportation points have been added to the scene as shown in figure 4.2. To teletransport the play area to that position in space, the user will aim towards one of the green circles in the floor and press the trackpad, this will display a curved ray towards that point so that the user visualizes where he is going to teleport to.

Next to the door, the player will find a task list so that they know what their objective is. Below this task list there will be a space where the evidence

will be placed so that the player can keep track of their progress throughout the level

4.3 Grabbing

This project aims to make interactions as realistic as possible providing a high functional fidelity[3] to better the players immersion feeling. The main action performed by the player will be grabbing objects to pick them up, like books or evidence, sometimes they'll grab a handle to open a door or a drawer, sometimes they might push furniture around. Different objects will interact differently with the player inside the scene and most of the objects in the room shall be interactable.

4.4 Picking Up Objects

To pick up an object, a player would have to make the controller touch a GameObject and then press the grip button on that controller. From the analysis section, we concluded that when a GameObject grabbed by the player hits another collider from a wall or another object, this object would drop from the player's hand.

To achieve this the GameObject will connect to the controller using one of Unity's joints this will attach the object to the controller and move with it through space. A joint will brake when a force is applied to it making the grabbed GameObject fall to the ground.

4.5 Opening Drawers And Doors

In the scene, the player will have to open drawers and door to continue their search for evidence. To achieve this mechanic, the drawer object will have its movement limited to a single axis with a maximum displacement range, and its rotation locked on all axis. To open a drawer the player will have to grab a drawer's handle object to atach it to the controller and then pull away from the drawer.

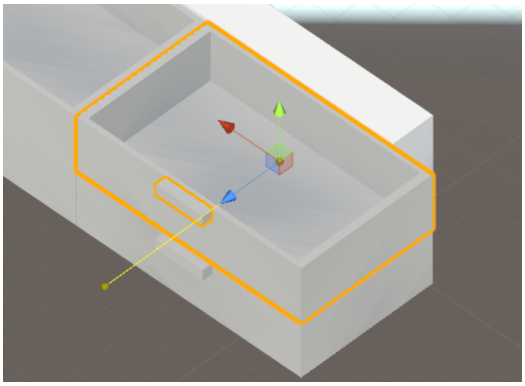

Figure 4.3: Visualization of a drawer

4.6 Finding Evidence

The evidence in the room can be either visible or hidden. Visible evidence will be placed in the room when the game starts and the player will be able to see the object a piece of evidence like an SD Card which they will then grab so that its placed in the evidence area. On the other hand, hidden evidence object will not be visible to the player at first, to find this object the user will first have to interact with other objects by picking them up or opening them, when this happens, an evidence object will spawn from the grabbed object. This encourages the player to search more thoroughly through the room.

When a piece of evidence is picked up, it will be automatically placed next to the door below the task list as a way of tracking a player's progress.

4.7 Touching Objects

When playing in VR, the player is holding a pair of controllers and has no real sense of feel so they might be unsure of being touching an object and won't be able to slide their hands around edges to feel for "miss-placed" objects. To resolve this, when an object that can be picked up is touched, the user will receive feedback in the form of a short vibration on the controller. A problem with VR is that a player can put his hands through objects, this means that they can receive that tactile feedback from an object which shouldn't be accessible to him, to work around this, the vibration script will

be deactivated if the player's hand is passing through a neighbouring object.

4.8 Moving Furniture

Most of the furniture in the room will be static although some of the furniture might have to be moved around. Initially the desk's chair and the bed will be the only two pieces of furniture that will be able to be moved around, the chair will be able to be pushed around with one hand whilst the bed will require the player to use both hands. To simulate the weight of both these objects, they will only be able to move in X and Z axis, this means that the player wont be able to lift them.

Chapter 5

Implementation And Testing

This chapter aims to describe how the individual components of the system are implemented. Firstly we analyze the recommended hardware needed to run the HTC Vive. Then we explore how using the *Virtual Reality Toolkit - VRTK* and some custom scripts we can fulfill the client's requirements.

5.1 Initial Setup

Processor	Intel™ Core™ i5-4590 or AMD FX™ 8350, equivalent or better
Graphics	NVIDIA GeForce™ GTX 1060 or AMD Radeon™ RX 480, equivalent or better. For additional graphics card options, view the complete list.
Memory	4 GB RAM or more
Video output	1x HDMI 1.4 port, or DisplayPort 1.2 or newer
USB	1x USB 2.0 port or newer
Operating system	Windows™ 7 SP1, Windows™ 8.1 or later or Windows™ 10

Figure 5.1: A screenshot of the final room

To play and develop in virtual reality, the computer used will have to meet the Vive's minimum requirements and both Steam and SteamVR have

to be installed. In figure 5.1 we can find the recommended hardware required to run virtual reality applicatins.

Setting up lighthouse is pretty straightforward and Steam guided the users quite well throughout the installation progress. The virtual reality equipment should work properly when set up at a correct height and they can physically see each other.

For development, we will be using the SteamVR SDK which can be found in the Unity Store for free has to be imported into our project as well as version 3.3 of VRTK, which can be found at VRTK's website.

5.2 The Room

The first requirement was to create a room which the user could navigate. Utilizing freely available models and textures a simple room was created following the concepts brought up in the design section. The size of the room is no bigger than 5x5 metres which can allow the user to navigate through the room in a natural way given the space to setup the lighthouse.

Figure 5.2: A screenshot of the final room

The room as seen in figure 5.2 has the typical things we would expect to find in a teenager's room, books, pictures, a laptopt, a wadrobe, etc...

5.3 The Player

To place the player inside the room when the game starts, we have to utilize some of the assets that we imported into the project previously. More specifically *VRTK_SDKManager* and *VRTK_SDKSetup* which handle the toolkit's setup, and the SteamVR *CameraRig* prefab. With these scripts and objects in the scene we now have the headset working in the scene.

We stated that when playing in VR, the player would be able to put his head through object and look through them due to there not being a physical limitation to their movement. To discourage players from doing this, when the players headsets collides with an object in the game, the player view fades to black until the headsets is not colliding with that object. To achieve this we add the *VRTK_HeadsetCollisionFade* script to a PlayAreaScripts GameObject. This fades the players view to a set colour when this happens.

5.3.1 Player Teleportation

To move around the scene there are different options for teleportation. There's free teleportation which allows the user to teleport anywhere in the scene and there's limited teleportation which allows teleportation to some pre-set points in the map. From play-testing during development It became clear that for new players the latter was more intuitive and easier to use. So we add the *VRTK_BasicTeleport* script to the PlayAreaScripts GameObject and we uncheck the "Headset Position Compensate" check-box as seen in figure 5.3, so that when the player teleports, the play area's centre moves to that destination point instead of the player moving to that point.

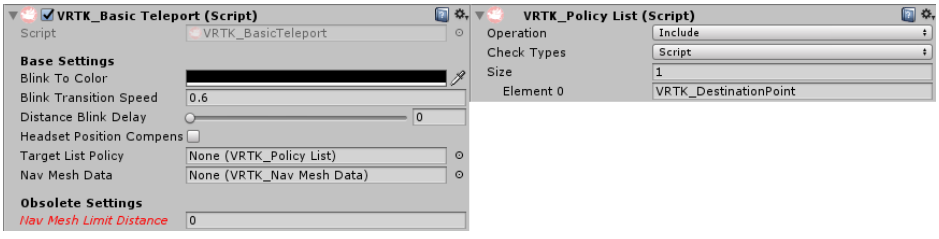

Figure 5.3: The teleportation scripts

To allow teleportation to certain destination points in the scene we also have to add the *VRTK_PolicyList* script to the PlayAreaScripts GameObject.

Policy lists allow to check for tags, scripts or layers to see if another operation is permitted. To allow teleportation we have to set the PolicyList to include scripts and we add the *VRTK_DestinationPoint* script to the array.

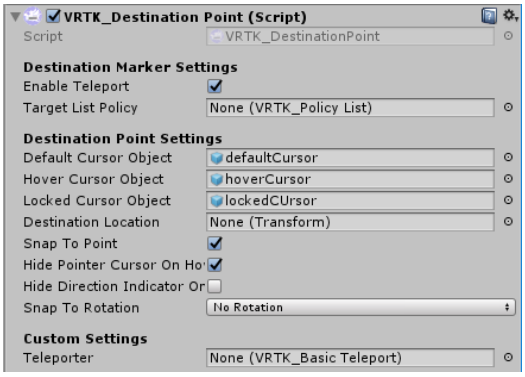

Figure 5.4: The destination script

To add teleportation destinations we have to create and empty GameObject and add the *VRTK_DestinationPoint* (figuer 5.4) script to the object. We will require to add a "Default Cursor Object" which will be the object representing the point in the play area that the player will be able to teleport to, and a "Hover Cursor Object" that be the object that the player sees when aiming at the teleport destination.

Finally, for players to visualize the teleportation movement, a script *VRTK_StraaightPointRendered* was added to the ControllerScripts, this script emits a coloured beam from the controller which determines where the user is pointing at.

5.4 Grabbing Objects

The objects in the scene are made interactable by attaching the *VRTK_InteractableObject* script to a GameObject. This script will add a RigidBody and a *VRTK_FixedJointGrabAttach* script to the GameObject when the game starts. To allow grabbing we have to enable the "Is Grabbable" check box as seen in figure 5.5. Now the players will be able to pickup objects in the scene by creating joints between objects and the controller. By default the joint is created from the origin point of the GameObject to the controller, to make the grabbing more realistic we

enables the "Precision Grab" check box in the joint's script as seen in figure 5.5 which will create the joint from the point in the object the player is touching to the controller.

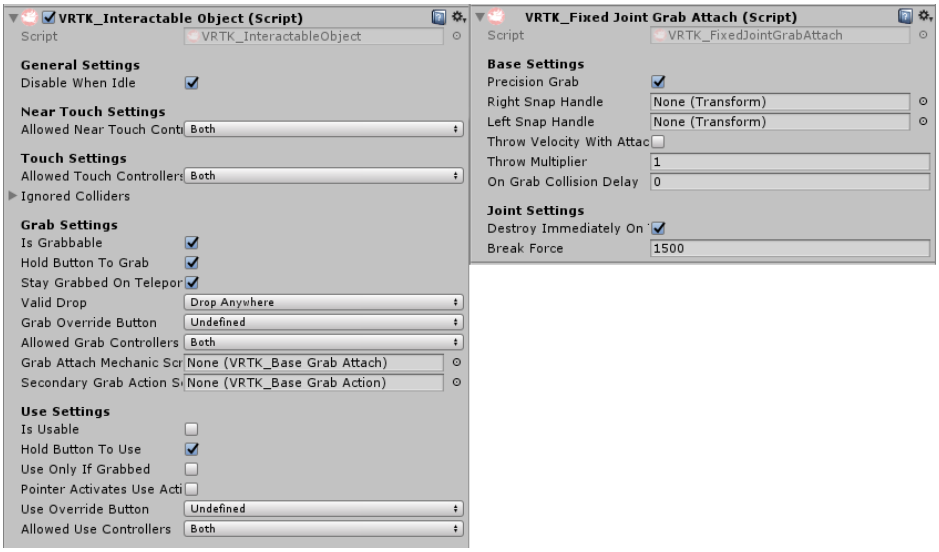

Figure 5.5: The InteractableObject and the FixedJoint for the grab

The *VRTK_FixedJointGrabAttach* connecting the object to the controller will brake if a force is applied to the object putting a force on the joint, thus disconnecting object and controller and making the object fall to the floor.

5.5 Moving Furniture

Some of the furniture in the room will be able to be moved a around like we would expect in a real room. In the game, both the chair and the bed in the room will be able to be moved around by the player. The player will be able to move the chair around with one hand, this is achieved making the chair a grabbable object and by restricting the movement and rotation axis on its RigidBody as seen in figure 5.6

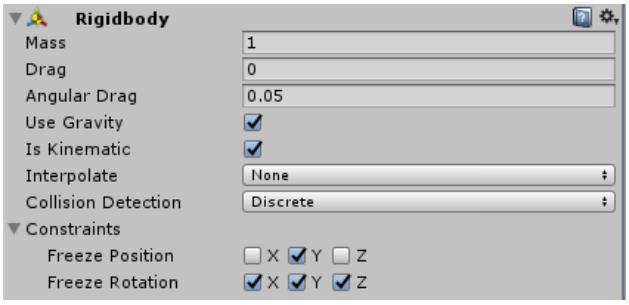

Figure 5.6: The chair's rigidbody constraints

This will allow the chair to move only in the XZ plane. The bed works in a similar way, but because its a larger object the player will need to use both controllers to move the object. The bed's implementation is similar to that one of the chair, first we made the bed a grabbable object with the displacement in the Y axis restricted. Finally to move the bed only when both controllers are touching the object, a script was made that locked all the movement axis of the object if both of the controller's colliders weren't touching the bed's collider.

5.6 Opening Doors and Drawers

To make drawers functional, VRTK offers two scripts to make an object slide through space, one is *VRTK_ArtificialSlider* and *VRTK_PhysicsSlider*, both scripts do the same thing but the latter is affected by physics which means it can be pushed by other objects, thus making it more realistic. For the drawer to work, a drawer-shaped collider has to be attached to the drawer object as seen in figure 5.7

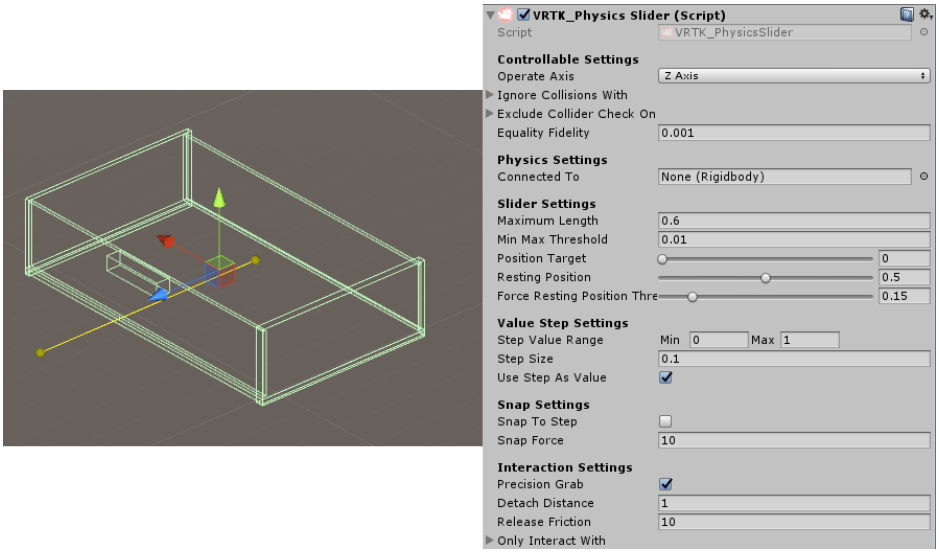

Figure 5.7: A drawer collider and the slider script

The *VRTK_PhysicsSlider* is added to an empty GameObject and the drawer is put as a child of that GameObject, we then set the operating axis of the object to the "Z-axis". The "Target position" and "Resting position" are set to 0 and 0.5 respectively for the drawer model used in the game as seen in figure 5.7

5.7 The Evidence

In the game the evidence will be found in the form of SD cards. The SD card is stored as a prefab because it will share the same components and scripts. The SD cards will be grabbable and will use the scripts described in section 5.4. On top of this, when the player touches the SD card they will feel a vibration on the controller. This is achieved using the *VRTK_InteractHaptics* script. For this script we set the "Strength on touch" to 0.15 which gives a subtle but still noticeable vibration, the "Duration on touch" and the "Interval on touch" are set to 0.6 and 0.15 respectively which makes the user feel 4 short vibrations on the controller and finally we ensure that the "Cancel on untouch" check box is active so that the vibration stops when the player stops touching the SD card. Figure 5.8 shows the mentioned parameters applied to the component.

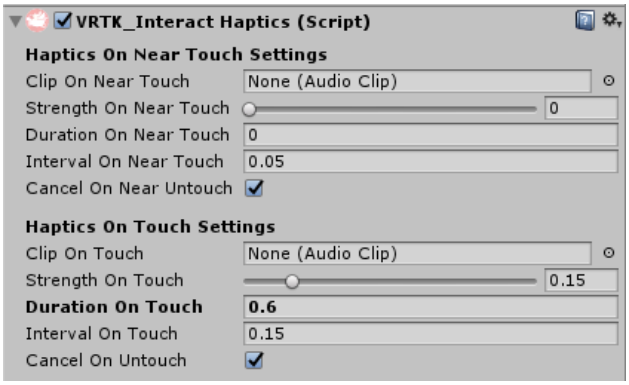

Figure 5.8: The InteractHaptics script parameters

In the design section it was mentioned that evidence could be visible or hidden. Hidden evidence will spawn in the room when the player picks up an object, this is done by applying the following script to the object that we want to spawn the piece of evidence.

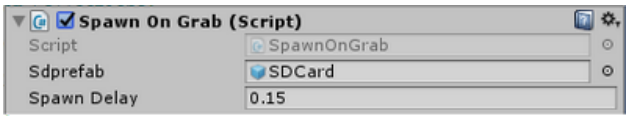

Figure 5.9: The spawn script parameters

Figure 5.9 shows the script and the editor component, on setup we have to specify the prefab we want to spawn and also a delay time so that it looks like the prefab fell of from the object.

When a piece of evidence is found by the player, when they grab it, the object will be automatically translated into the task list on the wall as seen in figure 5.10.

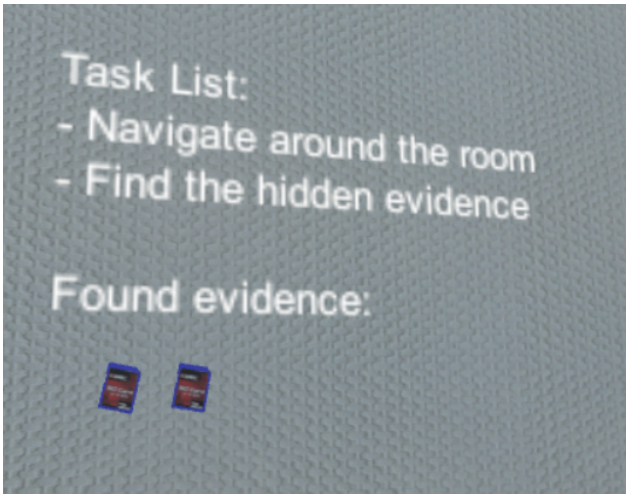

Figure 5.10: SD cards placed under the task list

5.8 Task List and UI

A task list was added to the game so that new players know what they have to do and can see how much evidence they've found. Figure 5.11 is a screenshot of the task list that appears on the wall for the player. Below that, in the area marked red, the evidence will be automatically placed when the player finds it so that they know how much of the evidence they've found.

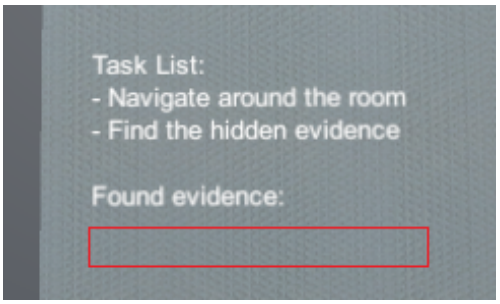

Figure 5.11: The player's task list

Figure 5.12: The level selection menu

The last thing that was implemented into the system was a Level Selection Menu and a Player Menu. Figure 5.12 show the Level Selection Menu, this is

an empty scene with a “start game” button which loads the crime scene and a “quit game” button to exit the game. Here the player can be run down through the controls before starting to search the crime scene.

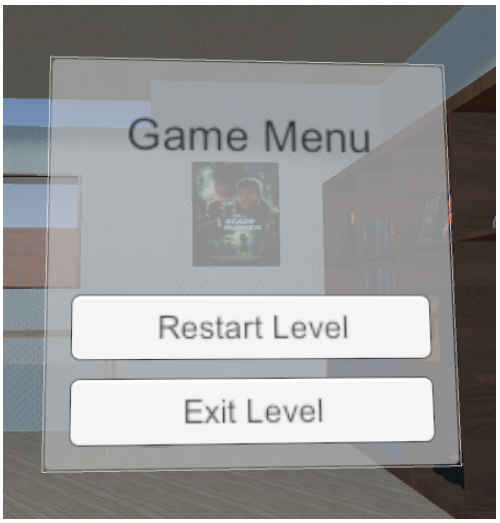

Figure 5.13: The in-game menu

Figure 5.14: The menu when all the evidence is found

Figure 5.13 shows the menu that is available to the player when playing the game. From this menu the player can go back to the Level Selection scene and also restart the current level.

When all the evidence is found by the players, the menu from figure 5.14 will open up so that the player knows that he has successfully found all the evidence hidden in the room.

5.9 Testing

Throughout this section the features described in the analysis stage were implemented in the system. Features were individually tested when they were implemented and once the system was complete they were tested again to make sure that everything was still working properly. Testing was done following the “Black Box” technique which examines the functionality of components ignoring their inner workings. The tests performed and their results can be found in table 5.1

id	Scenario	Expected Output	Actual Output
1	The player puts its head into an object	The players view fades to black	The players view fades to black
2	The player removes his head from an object	The black colour fades out and the user regains sight	The black colour fades out and the user regains sight
3	The player aims at a teleporting position and presses the touchpad	A ray is rendered from the controller pointing towards the teleportation point	A ray is rendered from the controller pointing towards the teleportation point
4	The player aims at a teleporting position and releases the touchpad	The player teleports to that position	The player teleports to that position
5	The player walks around in real life	The player walks around in game scene	The player walks around in the game scene
6	The player touches an object in the game and presses the grip button	The object gets attached to the controller	The object is attached to the controller
7	The player is grabbing an object and releases the grip button	The grabbed object drops to the floor	The grabbed object fell to the floor
8	The player grabs a drawer's handle and pulls away	The drawer slides open with the hand	The drawer slid open with the hand
9	The player grabs an open drawer's handle and slides it close	The drawer slides with the hand and closes	The drawer slides with the hand and closes
10	The player touches a piece of big furniture with two hands and presses the grip button	The furniture will be attached to his hands	The furniture is attached to his hands
11	The player touches a small piece of furniture with one hand and presses the grip button	The furniture will be attached to his hand	The furniture is attached to his hand
12	The player with furniture attached to its hands moves its hand around	The furniture moves with the hand	The furniture moved with the hand
13	The player picks up an object that spawns a piece of evidence	After the delay time, a piece of evidence is spawned from the object	After the delay time a piece of evidence was spawned from the object
14	The player touches a piece of evidence	The controller vibrates a little bit	The controller vibrated a little bit
15	The player grabs a piece of evidence	The evidence is translated below the task list	The evidence was translated below the task list
16	The player finds and grabs the last piece of evidence	The game menu appears with a congratulations message	The game menu appeared with a congratulation message
17	The player selects the "Start Game" option in the menu	The crime scene is loaded	The crime scene was loaded
18	The player selects the "Quit Game" option	The application closes	The application closed
19	The player selects the "Restart Level" option in the menu	The crime scene is reloaded	The crime scene was reloaded
20	The player selects the "Exit Level" option in the menu	The level selection scene is loaded	The level selection scene was loaded

Table 5.1: Results from the Black Box Testing

Chapter 6

Results And Discussion

In the previous chapter we demonstrated the implementation of the features into the application. Testing of these features was also carried out in the previous section. This chapter will evaluate the final solution in more detail. Furthermore data from participant testing will be analyzed and further work that can be done on the final solution will be considered

6.1 System Overview

The following section will illustrate the game setup and will analyze the game mechanics that were implemented.

Figure 6.1 shows the computer used to develop and to perform the user testings with one of the base stations behind it.

The system was demonstrated to investigators and members of the NCA at a NCA conference in the Kia Oval Centre, London on the 21st March 2018. The users got to experiment with the system and gave some feedback on the system.

In general feedback was positive, and the different users that got to test the game brought up new game mechanics that could be implemented and also different places where they've located evidence in real life crime scenes they've worked at.

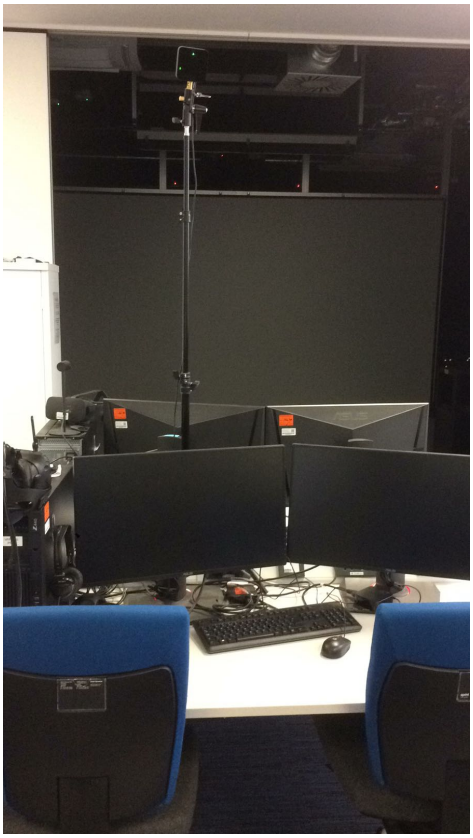

Figure 6.1: The room setup with the Vive's base station and the computer

6.2 Interactions

The main focus of this project was providing realistic interactions with the simulated scene utilizing the Vive's controllers. This section will evaluate the interaction mechanics in the game.

The game mechanic that players will use the most will be that of picking up objects to inspect them. The following sequence demonstrates picking up an object in the game.

Overall the picking up mechanic felt satisfying , a picked up object could rotate in the player's hand to be inspected. In the design section it was decided that picked up objects wouldn't 'ghost" through walls, this design choice makes it a bit tricky at times to pick up object. When picking up

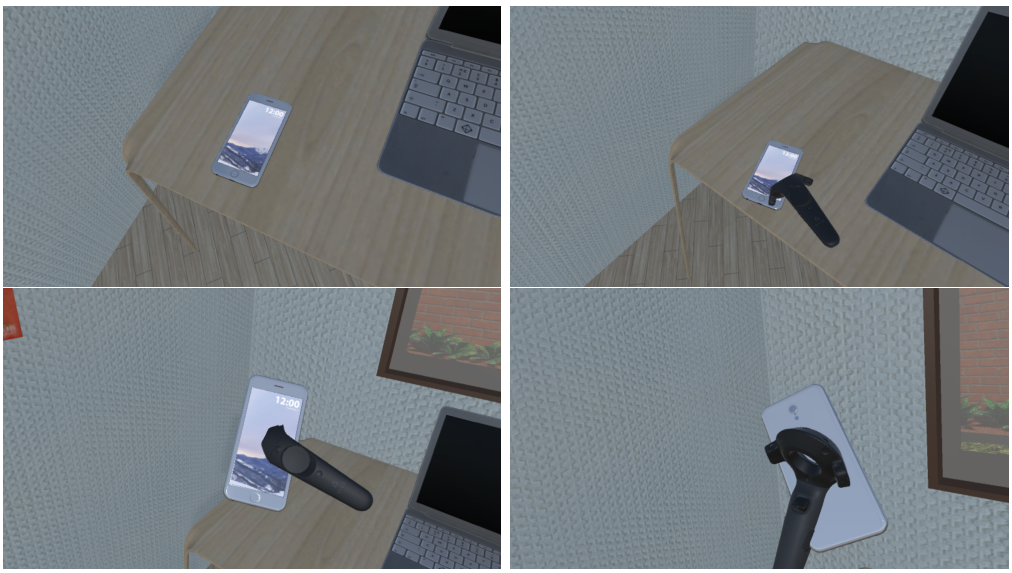

Figure 6.2: Picking up a phone in game

objects that were surrounded by walls or other objects the collision between the objects and its surrounding made the picked up object fall off the player's hand when they shouldn't.

During the search the players will have to open up drawers too in their search for evidence. To open a drawer the player must grab the handle and pull away from the wardrobe.

Figure 6.3: Opening a drawer

Opening drawers feels very good, the speed at which a drawer is open will make the objects inside that drawer shake and move around. In figure 6.3 some placeholder spheres were placed inside the drawer to observe how they were pushed by the back plate of the drawer.

Figure 6.4: Opening a door

Opening a door works as it does in real life, the player has to grab the door's handle and pull towards him so that the door rotates around its hinges as demonstrated in figure 6.4. A full motion isn't necessary to open the door, the player can also grab the handle and throw it away from the door to slam it open. Then to close the door, the player can push the actual door into the wardrobe.

This mechanic of a surface rotating about a hinge is also implemented into a laptop that can be found in the scene. Investigators might want to close down a laptop if they believe it is being accessed remotely or if they deem necessary. To replicate this a player would just have to grab the screen of the laptop and close it down gently.

Furniture can also be moved around by simple grabbing it and moving the controller around as illustrate in figure 6.5. This mechanic serves its purpose and allows to move furniture in the room to get them out of the way when investigating. Although objects can be moved around, they cannot be rotated around, so they will always point in the same direction. This doesn't suppose a problem to the mechanic but it does reduce a bit the functional fidelity of the system.

Figure 6.5: Moving a chair around

6.3 User Evaluation

User feedback is essential when evaluating a project such as this one. To obtain this feedback participants would have to use use the system and complete some tasks that will ensure that they explore all of the different mechanics the game has to offer.

Participants were 10 close friends and colleagues which I contacted personally over social media. All of the participant were invited to test the same version of the game with the same hardware to ensure the results were accurate and unbiased. Participants where given an information sheet (see Appendix A) which described the project and what their task was going to be. Participants then had to sign a consent form before getting to try the system (see Appendix B). Before playing the game they were asked their level of experience with VR. After this they were all briefed about game's controls and were tasked with investigating the room in the search for evidence at their own pace. After finding all the evidence in the room they were asked to fill in a short questionnaire (see Appendix C) related to the game, its design and its mechanics.

The first set of questions were about the user's previous experience with VR and the room they had investigated.

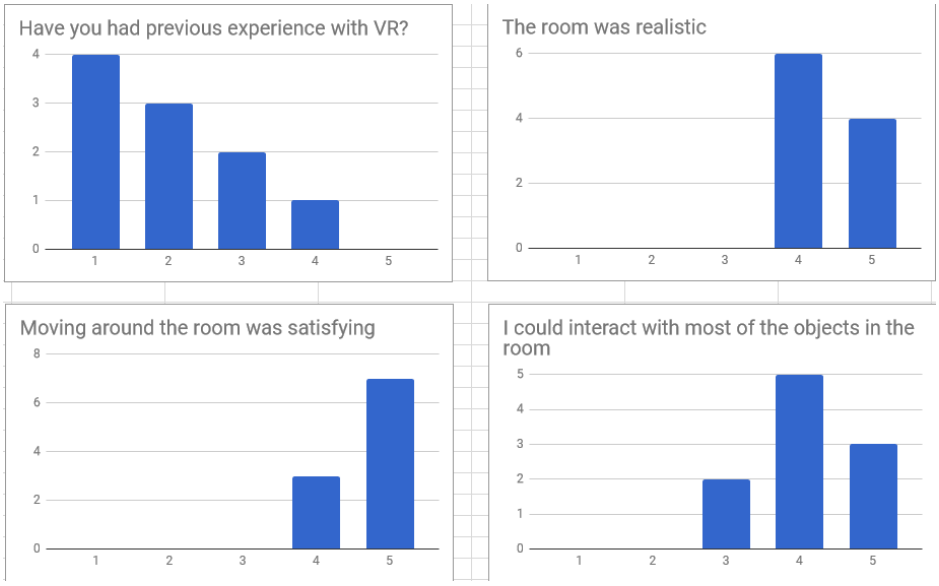

Figure 6.6: Results for the room (1:Strongly Disagree; 5:Strongly Agree)

From the data collected, we can see that the users that were involved with testing the system had different levels of experience using VR, whilst most of them had little to no experience, 3 of the users had some previous experience with VR. All of the participants agreed that the room was realistic and the movement and teleportation were satisfying. The last graph shows lower scores for the question "I could interact with most of the objects in the room", from the comments the user made when testing the system, this is because the clothes found inside the wardrobe were statics objects which the players couldn't interact with.

The next section of the survey was focused on the game mechanics and the player interactions.

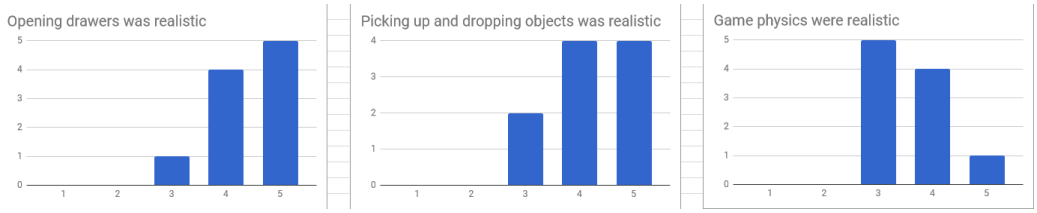

Figure 6.7: Results for the mechanics (1:Strongly Disagree; 5:Strongly Agree)

The results from this questions were mostly positive, for the first question, one of the testers response was a 3, this was probably because of a glitch with one of the wardrobe's door, which sometimes bounced from left to right when opening it too quick. The second question albeit showing good scores with exception of the single "3", most of the participants agreed that picking up books from the shelve was at first complicated, this was because of how the grabbing mechanic works, by creating a fixed joint between the controller and the object. When the participants picked up a book, if it wasn't taken out carefully and it collided with another book it would fall off the player's hand. The last of the three questions was related to the physics of the game, from the playtest users considered the physics to be correct but nothing special, this is probably because all of the object in the game have the same weight, some users also pointed out how they liked that objects could push other objects around, i.e. opening the drawers quickly would shake the objects inside it.

The final set of questions was related to the game in general.

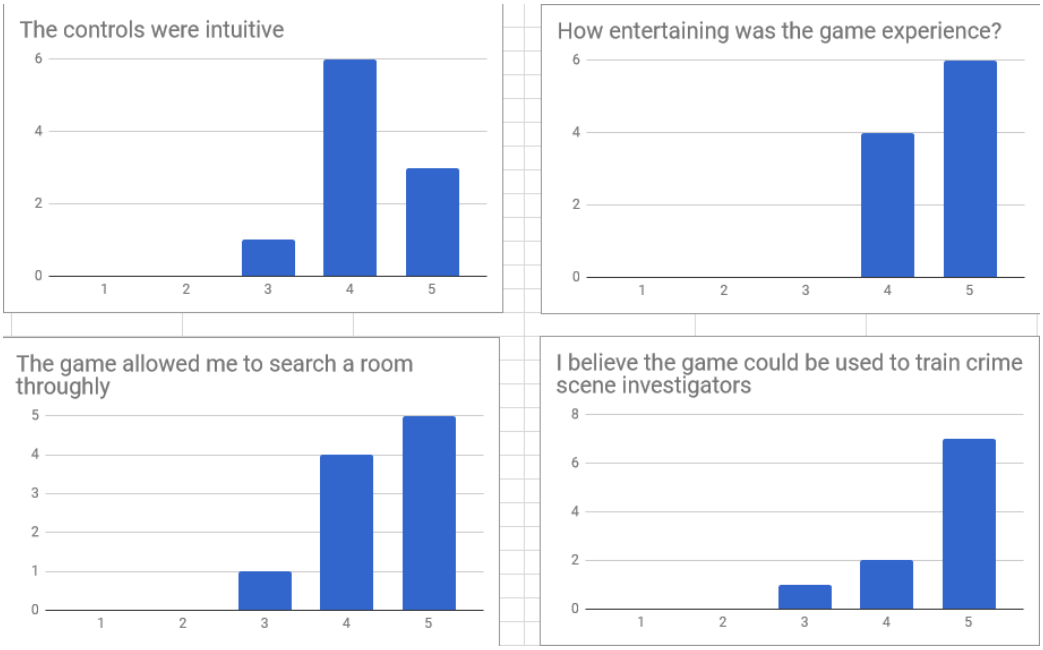

Figure 6.8: Results for the game (1:Strongly Disagree; 5:Strongly Agree)

From the first question we can observe that most of the testers believed

the controls were intuitive, albeit most of the users had little or no previous experience with VR although some users pointed out that the controllers were "a bit bulky" for their hands. The second questions shows that all of the users found the experience to be entertaining and some testers would've liked to play another level. The feedback for the last two questions was positive except for two scores of '3' which were given by the same user, unfortunately he didn't leave any further comments explaining this scores.

6.4 Discussion And Further Work

Overall the application provides an immersive experience with a good level of physical, functional and psychological fidelity[15]. In the end all of the mandatory requirements were implemented into the system and further improvements can be made based on the desired and optional requirements identified in section 3 and the feedback received from test participants and officers of the NCA.

The main focus of the project was providing realistic interactions with the scene in virtual reality this was overall achieved but wasn't a perfect solution. When designing the project, it was decided that we didn't want object to ghost though walls with the hands to not break the immersive feel of the game, this design choice made manipulating small objects like books in a shelve a bit tricky for new users. Further work could investigate if allowing items to ghost through objects would increase the accessibility at the expense of some realism. Aside from trying to allow user to ghost through walls, other types of joints could be used to allow the grabbing, i.e. using a spring joint which would allow collisions to happen for some time before dropping the object from the player hands.

The initial project proposal wanted the application to be used as a training tool for criminal investigators and from the feedback gathered all participants agreed that a tool such as this could be used to aid training a criminal investigator. To further fulfil this requirement some extra feature could be added to the system in the future. Features such as adding a way of viewing and analysing trends on how different users analyse and move around the crime scenes. This could be achieved by the means of heat maps that log what the users are looking at or what are the first objects that a user interacts with. Or even a feature that records the user's run through a level so that it can be review later by players and supervisors.

Further improvements can also be made to the way in which evidence is placed in the scene. In the final solution the evidence is always placed in the same places so after one run the user already knows where the evidence is hidden, a solution to this was being developed but due to time constraints it was unlikely that the feature was going to implemented and fully tested. The solution was to provide a setup panel in which a user could define where the evidences was placed or which objects were going to spawn a piece of evidence, this could also allow to have different amounts of evidence per crime scene and thus increase the variety of scenarios.

On top of further development of functionality, the 3D models used in the scene would also benefit from an upgrade. Making 3D models specifically for a scene would increase the physical fidelity of the room. For instance, one NCA officer pointed out that with the recent growth of cryptocurrencies he would like to see models of Bitcoin wallets being used as the models for evidence in the game to make investigator more familiar with this new objects. The assets used in the final solution all come from different authors and different asset bundles, they all have different styles, some model are low-poly models whilst others highly detailed models. Creating the 3D models for the scene would also allow to control the polygon count of objects in the scene so that more objects can be placed in the scene without having an impact in the game's performance.

In addition to this, creating the 3D models would allow to have more interactable objects in the scene, for instance, there is a blue box in the scene which the users can't interact with due to it being a textured cube instead of an actual box with a lid that can be removed.

From the demonstration at the NCA convention, some of the senior officers pointed out that evidence could be also hidden in window frames or the edges of furniture and that it would be nice to implement a way of investigating those. On top of this they mentioned that evidence is sometimes hidden behind sockets which have to be taken out or unscrewed from the wall to gain access to the evidence, so further game mechanics can be created based on this feedback.

Chapter 7

Conclusions

The aim of the project was to develop an application that would recreate a realistic crime scene in virtual reality. Players would then have to search through the room in the search for potential evidence of a cybercrime. This application would then be used to aide in the training of new crime scene investigators.

The main focus of this project was to provide realistic interactions with a objects in a scene utilizing virtual reality and the results from the user testing show that the application satisfies this. However the interaction mechanics whilst trying to be as realistic as possible sometimes made it tricky to interact with some of the objects due to the implementation of the grabbing mechanic. Further work can investigate if a trade off between realism and accessibility can be achieved without breaking the immersive feeling of the system.

In addition to this, whilst the amount of interaction mechanics was sufficient to meet the identified system's requirements and to please both participants and members of the NCA. This second group proposed different mechanics that could be implemented into the system based on their experience investigating real life crime scenes, such as an unscrewing mechanic.

The application was created to be used as another training tool for crime scene investigators. From the user feedback we can observe that all the users believed an application such as this could be used for that purpose. But this application in its current state is just a starting point. More work can be done to gather data from a users investigation so that the data can be presented and stored in a meaningful way. This would allow the users to later review their performance and see if they've improved at investigation crime scenes over time when using this application.

Overall this project was successful in creating a believable crime scene which users can explore and interact with in the search for hidden objects whilst making the experience enjoyable for users.

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Appendix A

Information Sheet

Information Sheet

Title of Research Project: Virtual Reality and Crime Scenes: Forensic Investigation of a Crime Scene
You are being invited to participate in a research project as part of the researcher's undergraduate dissertation project. Before you make a decision it is important that you understand what the motives are behind the research and what your participation would involve. Please take time to read the following information carefully. Please ask if there is anything you find not clear or if you would like more information and take time to decide whether or not you wish to participate.

What is the project's purpose?
Virtual reality has become more accessible than ever before and the technology is finally capable of delivering compelling experiences. With the rise of processing power and the new VR technologies new types of experiences can be delivered to users that could not have been achieved before.
Virtual Reality reproduces 3D scene and places the user inside of them, making them feel like they are actually in that place.

This project is a game which aims to use the HTC Vive to place the user inside a crime scene which they will have to forensically investigate in the search for pieces of evidence of a crime. The project aims to create an immersive VR experience with realistic interactions with the objects in the scene.

Do I have to participate?
Participation is completely voluntary. By agreeing to participate you will be asked to sign a consent form. You are free to withdraw from the research project at any time without providing any reason. By withdrawing, all data obtained from your participation will be destroyed.

What will happen to me if I participate?
To begin with the users are asked if they've had previous VR experience. After this they will will be taken through the controls and game mechanics. When the users are ready they will load the simulated crime scene and start investigating it in the search for evidence. The evidence is small objects (SD cards) that are hidden in the scene.
Once they find all the evidence they will quit the game and will be asked to fill in a short survey to give feedback on the scene, the game and the interact

How long will the research process last?
Testing the software should take around 10 minutes and completing the survey should take around 5 minutes.

What are the possible disadvantages and risks of participating?
Motion sickness is a potential for those unfamiliar with VR. If you find yourself feeling unwell please do say and you can stop the experiment.

What are the possible benefits of participating?
It is likely that the quality of the software will be improved with your participation.

Will my taking part in this project be kept confidential?
Your personal data will not be recorded. Instead a unique identification number will be used to refer to you and the answers you give to the questions after using the software. Anonymised results will be presented in the final report for the project and the surveys will then be destroyed.

What will happen to the results of the research project?
The results of this project will be analysed and discussed in the researcher's undergraduate dissertation project at the University of Sheffield. Summarized results may be used in subsequent research publications, research talks and for teaching.

Who is organising and funding the research?
None.

Who has ethically reviewed the project?
The project has been reviewed by University Research Ethics Committee of the Department of Computer Science at the University of Sheffield.

What if something goes wrong?
If you have any complaints or concerns, please contact the project researcher or supervisor using the contact details given below.

Contact for further information
If you require any further information, please contact:

Fernando Montero Perez, Student of Software Engineering, The University of Sheffield,
Email: fmonteroperez1@sheffield.ac.uk , Mobile: +34 600 014 789

Dr Steve Maddock (Supervisor), Senior Lecturer in Computer Science, The University of Sheffield, Regent Court, 211 Portobello St, Sheffield, S1 4DP
Email: S.Maddock@dcs.shef.ac.uk Telephone: *0114-2221830*

Appendix B

Consent Form

Participant Consent Form

Title of Project:
Virtual Reality and Crime Scenes: Forensic Investigation of a Crime Scene

Name of Researcher: Fernando Montero Pérez

Participant Identification Number for this project:

Please tick the boxes below to confirm your consent for the following:

1. I confirm that I have read and understand the information sheet explaining the above research project and I have had the opportunity to ask questions about the project. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐
3. I give permission for the researcher to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐
4. I give permission for my anonymised results to be released to relevant researchers for research or teaching uses, provided they agree to only use those results in such work, and not to redistribute them. ☐
5. I agree to take part in the above research project. ☐

_____	_____	_____
Name of Participant (*or legal representative*)	Date	Signature

_____	_____	_____
Lead Researcher	Date	Signature

To be signed and dated in presence of the participant

Appendix C

Questionnaire

Virtual Reality and Crime Scenes: Forensic Investigation of a Crime Scene

1. **Have you had previous experiences with VR?**
   Mark only one oval.

	1	2	3	4	5	
No experience	◯	◯	◯	◯	◯	A lot of experience

The Scene

2. **The room was realistic**
   Mark only one oval.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

3. **I could interact with most of the objects in the room**
   Mark only one oval.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

4. **Moving around the room was satisfying**
   Mark only one oval.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

The Mechanics

5. **Picking up and dropping objects was realistic**
   Mark only one oval.

	1	2	3	4	5	
not realistic	◯	◯	◯	◯	◯	very realistic

6. **Opening drawers was realistic**
Mark only one oval.

	1	2	3	4	5	
not realistic	◯	◯	◯	◯	◯	very realistic

7. **Game physics were realistic**
Mark only one oval.

	1	2	3	4	5	
not realistic	◯	◯	◯	◯	◯	very realistic

The Game

8. **How entertaining was the game experience?**
Mark only one oval.

	1	2	3	4	5	
Not entertaining at all	◯	◯	◯	◯	◯	Very entertaining

9. **The controls were intuitive**
Mark only one oval.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agreee

10. **The game allowed me to search a room throughly**
Mark only one oval.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agreee

11. **I believe the game could be used to train crime scene investigators**
Mark only one oval.

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agreee

12. **Further comments**