# Mixed Reality in Education

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**B.Sc. Computer Science with Artificial Intelligence**

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# Abstract

Mixed Reality (MR) is an emerging immersive technology that has the potential to assist and support the teaching and learning process in the field of education. MR has seen its uses in fields such as engineering and architecture to assist in visualising complex models and run simulations directly on the real world. However, MR has yet to see a widespread usage in the field of education and training. In a campus setting, one of the most common type of education and training that is available to everyone regardless of their background is the fire safety education, thus this project aimed at investigating the use of Mixed Reality technology in the field of education and training through the Fire Safety Training (FST) application.

The project has produced an MR FST application that can be used in a Microsoft HoloLens2 headset. To achieve the aim of the project, a formal study was conducted with volunteer participants. This study has investigated how MR-based learning could offer more benefits for learners when compared to a traditional learning setting. Additionally, user experience (UX) were also investigated to obtain insights regarding how users view and perceive the FST MR application. The findings from this study were then used to provide recommendations on the implementation of MR in Education.

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# List of Acronyms

| | |
|---|---|
| **MR** | Mixed Reality |
| **VR** | Virtual Reality |
| **AR** | Augmented Reality |
| **XR** | Extended Reality |
| **STEM** | Science, Technology, Engineering, and Mathematics |
| **UNNC** | University of Nottingham Ningbo China |
| **FoSE** | Faculty of Science and Engineering |
| **FHSS** | Faculty of Humanities and Social Sciences |
| **NUBS** | Nottingham University Business School |
| **CELE** | Centre for English Language and Education |
| **SDK** | Software Development Kit |
| **MRTK** | Mixed Reality Toolkit |
| **Hololens** | Microsoft Hololens 2 |
| **FST** | Fire Safety Training |
| **UI** | User Interface |
| **UX** | User Experience |
| **SRS** | Software Requirements Specifications |

| | |
|---|---|
| **VS19** | Visual Studio 2019 |
| **IDE** | Integrated Development Environment |
| **Y1** | Preliminary Year |
| **Y2** | Qualifying Year |
| **Y3** | Part 1 Year |
| **Y4** | Part 2 Year |
| **PhD** | Postgraduate |
| **UEQ** | User Experience Questionnaire |

# Chapter 1

# Introduction

In the post COVID-19 pandemic era, the education sector transitioned from traditional classroom-based teaching towards online learning. However, based on a survey by Serhan (2020), students are generally unhappy with using an online-based conferencing platform, citing the lack of engagement, low quality sessions, and large number of distractions as some of the reasons [1]. Thus immersive technologies in education could prove to be indispensable in promoting engagement in learning [2].

## 1.1 Background

The applications of immersive technologies, *i.e.,* Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has taken place in many educational fields, including medical sciences [3], architecture [4], and the humanities [5] amongst many others. VR and AR, in particular, has started to become commonplace in the field of education since they offer a digital reality that blends our reality and virtuality through digital simulations [6]–[9]. This being said, VR and AR still have their challenges, such as motion sickness, lack of real-world spatial relation in VR, and the separation of the real and augmented world in AR [10]–[12]. MR tries to address these issues by providing a mixture of the best from each of the digital realities.

MR through Microsoft Hololens, in particular, has seen its uses in the Science, Technology, Engineering, and Mathematics (STEM) field, especially in regards to practical sessions like training and labs [13], [14]. The use of holograms to replace real equipment minimises all risk involved regarding safety, such as when using heavy machinery where there are risk of injury or Fire Safety Training (FST) with the risk of getting burn.

## 1.2 Motivation

Using Microsoft Hololens 2 (Hololens), one would be able to simulate a scenario, such as a fire, and apply that scenario virtually, but directly on the real world through the use of holograms. This project will look into the applications of MR using the Microsoft HoloLens 2 in education in the University of Nottingham Ningbo China (UNNC) campus environment. Since MR is best used to simulate practical tasks, the FST has been chosen as the scenario for the app to be developed. This decision was based on several reasons, including (1) fire safety equipment may not be available for everyone on campus to try using; (2) real fire safety training does not include the real experience in real fire because it is dangerous and impractical; and (3) fire safety equipment are limited in number and in some cases quite costly.

By using MR to address this, the challenges are virtually mitigated through the use of 3D models and simulations, no additional cost of procuring fire equipment is needed. Fire simulation is also entirely virtual, thus the danger aspect of fire is also nullified. Lastly, using MR would allow anyone with access to the device to experience first-hand, real-time fire safety training.

## 1.3 Aims and Objectives

This project aims to investigate the application of MR using the Hololens headset for FST simulation in a university environment. This project will try to address the strengths of using MR in the training when compared to traditional methods and the effectiveness of such application for such application for learning from the training. The objectives are listed below:

1. Design and build the FST simulation application for Hololens.
2. Collect data about the use of MR for training in a formal study by recruiting participants to try the app.
3. Analysis and comparison of data between identified groups and to traditional training.

## 1.4 Dissertation Outline

Chapter 1 has summarised various types of digital realities platform (*i.e.*, VR, AR, and MR), provided brief background of their real-world applications, and stated the aims and objectives of this project.

Chapter 2 will describe existing MR applications specifically in education and how it could be geared towards providing a safer training as compared to traditional methods.

Chapter 3 will describe the methodologies used in the project, including development and study methodology, along with the Software Requirements Specifications (SRS), risk analysis and mitigation strategies, and a brief description of adjustments made since the interim period.

Chapter 4 will describe the various design decisions regarding the MR application development as well as the data collection session. It will be followed by a detailed walk-through over the implementation steps from prototyping to deploying a working application in the Hololens device.

Chapter 5 will first present the obtained data from the formal study session and analyse them using various statistical methods. The results of data analysis will then be discussed and interpreted in context of MR in Education.

Chapter 6 will provide a description of what has been done and conclude both the formal study findings and the project. Some recommendations will also be given for consideration in future works.

Chapter 7 will discuss about the project management as well as look into a reflection of what went right and wrong in the project and what can be improved. Additionally, some future work considerations will also be given and briefly discussed.

# Chapter 2

# Background & Related Work

This chapter will first outline various studies that have been done on the applications of MR on education, especially on training programmes, and using it as a safer alternative to real-life training. It will then discuss about the latest breakthroughs and innovations specific to the MR field. Finally, this chapter will look into how MR has been applied and used as an educational platform in real-life scenarios.

## 2.1 MR in Education and Training

Mixed Reality has seen it uses in the field of education and training, with some claims that it improves learning outcomes and is transforming how learning is done. This section will discuss the background of the use of MR in this particular field.

### 2.1.1 Application in Education

Although MR could be deemed still an emerging immersive technology, there have been instances where it has been used in the education industry. According to Microsoft, there is a 22% improvement in test scores, and a 35% increase in engagement and retention when using the technology [15].

A study done by Hughes et al. in 2005 [16] has seen that using MR technology in a *Sea Creatures experience* (viewing and learning about various marine life) in the Orlando Science Center's DinoDigs exhibition hall encourages longer and more repeated visits to the exhibit. Furthermore, 88% of the respondent of the study noted that they agree that using MR increases entertainment value, that allowed them to learn in an entertaining way.

A more recent finding by Leonard & Fitzgerald in 2018 showed that students in a secondary school setting feel that using HoloLens in education increases the content engagement and overall could have a positive impact on learning [17]. This study also found teachers in the same setting are increasingly able to identify ways to redesign learning environments and try to connect their students with the new technology. Bacca et al. [18] and Radu [19] both further validates the study by finding that AR and MR technologies were both found to be positively impacting learning and motivation, amongst other benefits.

### 2.1.2 Towards Safer Training

According to a review by Hamilton et al. [8], the use of immersive technologies are mostly concentrated in the field of Science (45%), while the use in Safety Education is the lowest (3%). Furthermore, Hamilton et al. cited that "the ability to repeatedly practice a procedure in a safe environment whilst expending little resources" is possible one of the best benefit of using immersive education.

The United States CDC has reported that between 2001 and 2014, approximately 11% of fire fighter fatalities were related to training and drills [20]. Equipment drills was reported to be one of the three leading type of activity associated with the fatalities [21]. Thus it is important to find a safer fire training method, which MR might be the answer.

## 2.2 Existing Applications

There have been several existing MR applications in education. This section will describe some of them.

### 2.2.1 Lifeliqe

Lifeliqe [22] is a HoloLens-based education platform that provides classroom MR solutions, including interactive 3D models and lesson plans available directly on the Hololens device.

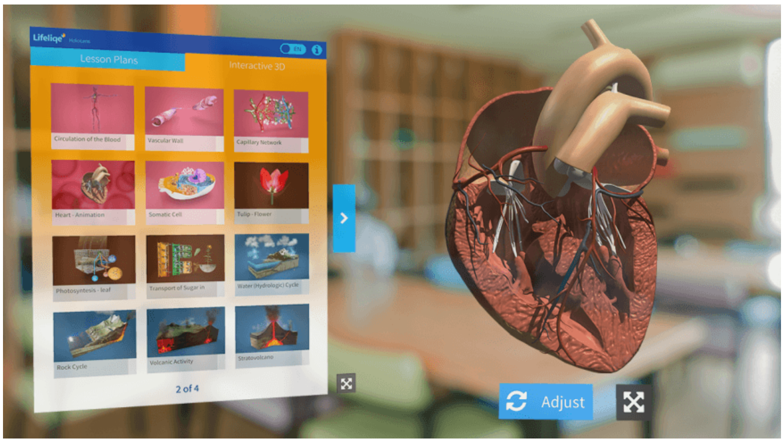


Figure 2.1: Lifeliqe: Holographic view of Human Heart (also showing UI)

### 2.2.2 Lumilo

Lumilo [23] is a pair of glasses based on the Hololens that allows teachers to see real-time analytics about the class being taught by combining MR and Artificial Intelligence technologies [24].


Figure 2.2: Lumilo: an AI-powered MR solution for teachers

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**Chapter Summary:**

Chapter 2 has summarised the project background, referencing to related works and existing real-world applications.

Next chapter will introduce the methodologies along with the Software Requirements Specifications (SRS) of the project.

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# Chapter 3

# Methodologies & Project Specifications

This chapter describes the methodologies used in the project as well as the specifications of the project. The overall project methodology will be discussed first, detailing about the workflow of the whole dissertation project. The second section will then describe the SRS with risk assessment and mitigation strategies. The final section will describe in detail about the methodology for the formal study, including participants recruitment and study design.

## 3.1 Project Methodology

The overall project plan includes preliminary stage (proposal and ethical review), followed by the project stage where application development and literature review progressed in parallel. The next stage involves the formal study and data collection session where participants were recruited to try the FST app and feedback their experience through surveys. Post-study stage includes data analysis and dissertation writing. These processes are described in detail in the flowchart presented in figure 3.1.

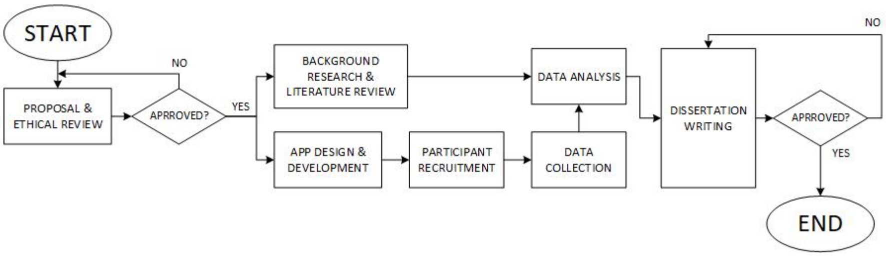


Figure 3.1: Overall Project Flowchart

## 3.2 Project Specifications

This section states the two types of requirements of the project: (1) Functional Requirements; and (2) Non-Functional Requirements. Project risk was also assessed in terms of the identified requirements and given at the end of this section.

### 3.2.1 Functional Requirements

The following list of functional requirements was identified and has been implemented in the FST app.

1. Users should be able to start the FST application and use it almost readily.
2. The FST application must be supported on the Windows 10 Holographic.
3. The FST application must have a menu screen to choose between "learning" and "training" mode (Main Menu).
4. "Learning" mode should teach users about firefighting equipment and their usage.
5. "Training" mode should allow users to extinguish fire simulation using holographic firefighting equipment.
6. Users should be able to manipulate holograms via hand gestures.
7. The FST application should show usage safety tips and prompt for "I understand“.
8. Users should be able to return to Main Menu from any scene.
9. Users should be able to quit the app from the Main Menu.
10. The FST application should not store nor record any user data.
11. In the case where certain assets copyright and usage right is not owned by the author, proper attribution and licensing should be shown either in the app or in the code.
12. The FST app should be in the English language.
13. Proper documentation should be present for all code used in the app, including methods and classes description and functionalities.

### 3.2.2 Non-Functional Requirements

In addition to the functional requirements, the following non-functional requirements were also identified and incorporated into the FST app.

#### Usability

The User Interface (UI) should be as intuitive as possible, where any elements containing text should be readable and clear. Text and button should be sized appropriately and uses color that will not cause discomfort for users and visible in the MR environment. Interactable elements, such as buttons, should be self-explanatory and leads to the corresponding intended functionality.

**Performance**

The FST application should load within 10 seconds of opening the app on Hololens. Scene loading time should be within 5 seconds of the start of each scene. Freezing should not happen mid-scene. The application should run on the Hololens. If there are any bugs or errors in the application, they should be removed with a patch or a fix in the next application update.

**Security**

The FST application should not ask for nor store any personal data; it should only allow users to use the intended functionalities. No parts of the application should have access to user personal data, unless consent is explicitly given by the user.

**Safety**

The FST application should display safety and comfort tips for users to ensure in-app safety and good User Experience (UX).

### 3.2.3 Risk Assessment

Risk assessment and task prioritisation were done to determine which task(s) should be prioritised or implemented first. There is always a risk related to a requirement regardless. Thus it is important to determine the priority of each requirement.

In this project, most of the risk of failure comes from the implementation of the technical features, such as adding proper behaviour to a fire extinguisher object. As such, Table 3.1 specifies which tasks are to be prioritised and carries higher risk.

Table 3.1: Functional Requirements Priorities and Risks

| ID | Name | Priority | Loss Risk |
|---|---|---|---|
| FR01 | App Startup | 3 | Low |
| FR02 | Support for Hololens | 3 | Low |
| FR03 | Menu Screen | 2 | Medium |
| FR04 | Learning Mode | 3 | High |
| FR05 | Training Mode | 3 | High |
| FR06 | Hologram Manipulation | 2 | Medium |
| FR07 | Health & Safety Notice | 3 | Low |
| FR08 | Return to Menu | 2 | Low |
| FR09 | Quit App | 1 | Low |
| FR10 | Data Collection and Storage | 3 | Low |
| FR11 | Copyright and Attributions | 3 | Low |
| FR12 | Language | 3 | Low |
| FR13 | Documentation | 3 | Medium |

Both priority and functionality loss risk are rated in three scale of importance: low (1), medium (2), and high (3). These scale was adjusted from the previous version described in the interim report to be more simplified and allow the author to quickly and easily review the list. The three-level scale are also more intuitive since all functionalities always have a risk of failing, therefore describing them in words would allow for easy understanding. These risks were minimised and mitigated through allocating sufficient resources and doing comprehensive testing.

### 3.2.4 Adjustments to Requirements

Some requirements were adjusted and modified as the project progressed. In particular, four requirements (FR10 - FR13) were added in, since they were overseen and not considered in the previous plan. FR10 was added after getting more familiarised with the university's code of research ethics, and thus it was decided to explicitly specify that no user data or information should be collected through the FST application. FR11 was added because the author had received assitance in the 3D modeling of some fire safety equipment. FR12 was added due to the usage context of the FST app, which is in an English-speaking environment. Lastly, FR13 was included due to it being overlooked previously.

Additionally, no changes were made to the Non-Functional Requirements as they were deemed sufficient and standard to be followed while developing the software application.

## 3.3 Study Methodology

The formal study section of this project aims to provide preliminary understanding of how is MR-based learning being received by the participants compared to traditional learning methods and obtain feedback about the FST application and UX. The study has been reviewed and approved by the University's Research Ethics Subcommittee, following the process for ethical review governed by the University's Code of Research Conduct and Research Ethics [25]. The process for the formal study session is shown in figure 3.2. Relevant ethical review documents are attached in Appendix B (Participant Information Sheet) and Appendix C (Participant Consent Form).

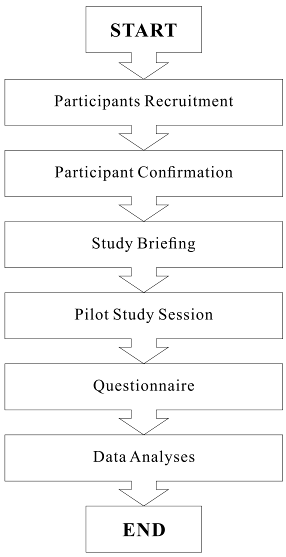


Figure 3.2: Data Collection Session Flowchart

### 3.3.1 Sampling Method

The volunteer sampling method, which could be considered a subset of the convenience sampling method, was used to recruit participants to join the study. This sampling method was chosen due to it being the least time-consuming and least expensive compared to other methods, such as simple random sampling or structured sampling [26]. This however, may increase the bias in the participants, since depending on how the recruitment was conducted, certain types of individuals may be favored more than other resulting in a skewed sample pool.

To address the possible bias, the volunteer sampling method used in this study was tweaked from the convenience sampling to include a larger proportion of stranger, instead of acquaintances (*i.e.*, friends, colleague, and family) of the author. This was done through sending recruitment email to the whole student population in UNNC, which was hoped to increase the randomness and give an equal probability for each individual to be selected as a sample.

### 3.3.2 Participants

A total of 59 participants were recruited from various study background in UNNC using the volunteer sampling method through e-mail and direct recruitment. The participant gender distribution is roughly equal between male ($n = 28$) and female ($n = 31$), with no one identifying as non-binary.

Amongst these participants, 15 came from the Centre for English Language and Education (CELE), 26 from the Faculty of Science and Engineering (FoSE), 6 from the Faculty of Humanities and Social Sciences (FHSS), and 12 from the Nottingham University Business School (NUBS). These include, 15 students from Preliminary Year (Y1), 17 from Qualifying Year (Y2), 9 from Part 1 Year (Y3), 15 from Part 2 Year (Y4), and 3 from Postgraduate (PhD) level. Table 3.2 below summarised the demography of the participants as described above.

| **Study Background** | Year 01 | Year 02 | Year 03 | Year 04 | PhD | Total $n$ |
|---|---|---|---|---|---|---|
| CELE | 15 | - | - | - | - | 15 |
| FoSE | - | 7 | 6 | 10 | 3 | 26 |
| FHSS | - | 2 | 1 | 3 | - | 6 |
| NUBS | - | 8 | 2 | 2 | - | 12 |
| Total $n$ | 15 | 17 | 9 | 15 | 3 | **59** |

Table 3.2: Participants Study Background

It is worthwhile to note that amongst the participants pool, about 77.96% (46 out of 59) of the participants voted "yes" to having previous experience of using either of the three immersive technology platforms (*i.e.*, VR, AR, and/or MR).

Originally, university staff members were also planned to be recruited alongside students. However, due to time constraints and unforeseen COVID-19 pandemic situation and restrictions during the data collection phase, it was impractical to recruit staff members due to the strict campus entry-exit restrictions as most staff lives off-campus.

In accordance to the University's research ethics requirements, each participant was informed that their participation in the study was entirely voluntary and that they are able to withdraw their participation at any time. This information was iterated to the participant at multiple occasions, including email recruitment and verbally during the formal study session. All information collected are kept strictly confidential following the requirements for data storage as outlined in the University's Code of Research Conduct.

### 3.3.3 Learning Session Design

The study is divided into two parts, namely the traditional learning and MR-based learning sessions. Both sessions were set to have similar duration, with the MR-based session taking about five minutes longer to allow time for participants to adjust to the Hololens hand gesture operations.

#### Traditional Learning Session

The traditional learning session was designed to mimic a short lecture-style fire safety briefing. This session includes verbal instructions, a set of presentation slides, and a brief video demonstrating how to use a fire extinguisher, as well as other elements found in a traditional learning setting.

The short presentation introduced participants to different classes of fire, fire safety equipment, and types of fire extinguisher, including which type is effective for which fire class. The short video was retrieved from YouTube, under the Creative Common Attribution License (CC BY) [27], [28].

The related presentation slide is available under Appendix E. The video used is available online on YouTube [29].

#### MR-based Learning Session

The MR-based learning presents similar content as the traditional learning session, with immersive elements being incorporated through MR. These elements include animations of the 3D models and fire training simulation, in which participants can attempt to use the virtual equipment to extinguish virtual fires.

### 3.3.4 Pilot Study Design

Participants who volunteered to join the study were asked to indicate their available timeslot and if their registration was valid, a confirmation email was sent detailing their session arrangement. Each session was arranged in groups of five participants with a duration of approximately 45 minutes. This was done to save time and include as many participants in the study as possible.

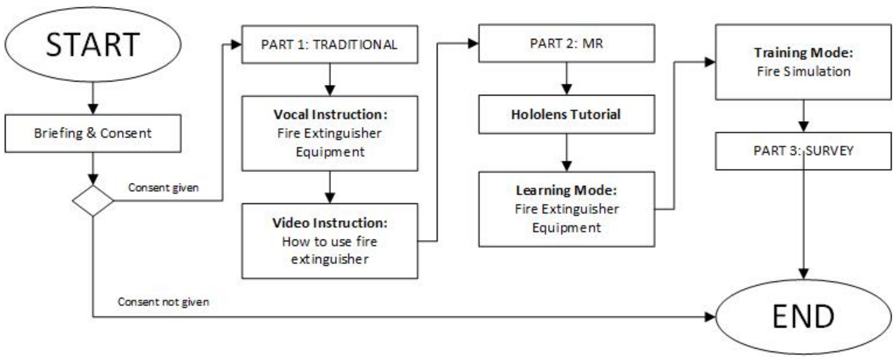


Figure 3.3: Pilot Study Detailed Process Flowchart

At the start of the each study session, all participants are briefed with the project information and asked to give their consent. The voluntary nature of the project was also reiterated. In the case where a participant wish to withdraw at this point, they were asked to leave the venue and all related data and information was deleted and omitted from being used. Otherwise, participant information collection was done to collect basic demographic information, such as gender, age, and study background.

Figure 3.4: Participant using hand gesture

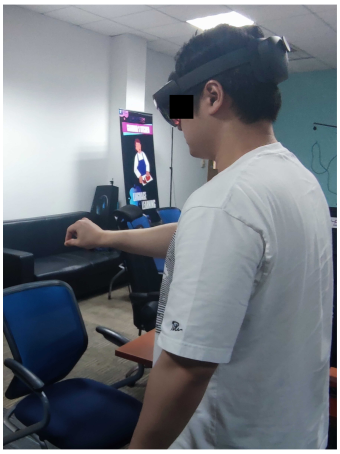

Figure 3.5: Using virtual extinguisher

After briefing and consent section was completed, participants were then invited to join the traditional learning session described previously, after which they were asked to fill the first quiz. Participants then continued on to the MR-based session, where they were first taught about the hand gesture operations of the Hololens device, before starting the FST application experience. The MR experience is depicted in figures 3.4 and 3.5, which shows participants using the Hololens and interacting with the virtual content. The latter figure shows the participant pinching motion, which correspond to activating the pressure handle of the virtual extinguisher, although not illustrated. After they finish the MR session, they were asked to fill a second questionnaire which included another short quiz, along with additional questions regarding their experience and feedback.

Each session, on average lasted about 45-50 minutes per participants. The author was always present during any sessions to assist participants at any time. The entire process has been summarised in the flowchart in Figure 3.3.

### 3.3.5 Questionnaire

After the study session, participants were asked to fill-out the data collection questionnaire, that includes two five-questions quizzes (one for after each, traditional and MR-based learning) and questions that look into various aspects of the FST application UX, overall experience, and possible cybersickness. These questionnaire were available through Microsoft Forms and the complete questionnaire is available under Appendices F.1 - F.2.

#### Quiz Design

The quizzes were designed to be five multiple choice questions that look into the knowledge retained after each learning sessions. The difficulty of these questions were set to be roughly the same, since both the traditional and MR-based learning sessions present very similar learning content.

#### User Experience Questionnaire

The User Experience Questionnaire (UEQ) used in this study was adapted from the UEQ+ [30], [31], a standardised framework to measure UX. This framework was chosen because of the completeness of the resources provided, as well as that the framework is supported by relevant study and research papers [32], [33].

The most basic UEQ measures the following six UX impressions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. However, for the purpose of gaining more meaningful and insightful data, the UEQ+ modular extension was used instead, adding four more scales: acoustics, usefulness, quality of content, and clarity. These scale measures are described in table 3.3 below in the context of the FST application.

| **Scale** | **Description** |
|---|---|
| Attractiveness | Overall impression of the FST app |
| Perspicuity | How easy to learn or get familiar with is the app |
| Efficiency | How much effort does user need to achieve the task |
| Dependability | How much control does user feel while interacting with the app and does the interactions provide a robust and predictable experience |
| Stimulation | How exciting and motivating is the FST app for users |
| Novelty | Is the FST app interesting and creatively designed |
| Acoustics | Impact of the sound effects used in the app towards user experience |
| Usefulness | Do users find advantages in using FST app |
| Quality of Content | How good and updated is the information provided in the FST app |
| Clarity | User impression on the UI order, structure, and visual complexity |

Table 3.3: Descriptions of UEQ scales

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**Chapter Summary:**

Chapter 3 has described the methodologies used in the project, including overall methodology and study methodology. This chapter has also described the SRS for the FST application and discussed the identified risks and mitigation strategies, in addition to mentioning the changes made in the requirements.

Next chapter will introduce the design stage of the FST application and how it is implemented for the Hololens 2 device.

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# Chapter 4

# Design & Implementation

This chapter will discuss the FST application design and includes the prototyping process and specifications of the development environment, *i.e.*, software and hardware specifications. It will then detail the implementation of the MR FST application in the Hololens device, along with a description of the testings done on the app.

## 4.1 Design

This section describes the FST application design process from its conceptual stage until its functional stage. Since the project revolves around mixed reality and considering that the Hololens device is readily available, it was decided to create the application specifically for Hololens.

### 4.1.1 Application Design

This project aims to create one application for Fire Safety Training that is usable in the Hololens 2 device. At the conception stage, the FST application was planned to be split into two major parts: **Learning** and **Training** modes, as mentioned in section 3.2. A brief description of the two modes is provided below.

- **Learning Mode**
  Allows user to get to know fire safety equipment and how to use them interactively. This mode will present the user with holographic fire safety equipment, which they would be able to view and learn about the specifics. The holographic equipment would be shown in a "showcase"-like fashion, where they can be rotated and switched into an exploded view to show how the equipment looks like when disassembled.
- **Training mode**
  Allows user to use holographic fire safety equipment to extinguish fire simulation. This mode would have users use holographic fire safety equipment to extinguish simulated fire. Users should be able to interact with the holographic equipment similarly to how their real-life counterpart would be, adjusted for the hand gestures.

Based on the project requirements, the following functionalities were designed to be included in the final working application, in addition to the two modes described above.

- **Health and Safety Warning** – displays health and safety notice regarding the use of the Hololens headset, which informs user of potential cybersickness that they may experience and what to do if they indeed experience it. User must confirm that they have read and understood the notice before continuing to the main app content.
- **Main Menu** – contains four buttons with the following functions: (1) Switch to Learning mode scene; (2) Switch to Training mode scene; (3) Toggle visibility of CPU and performance console; and (4) Exit the application. Additionally, the main menu panel should be able to follow the user, if they wish, to allow ease of navigation without having to travel around the room/space.

Additionally, a fire simulation system was also designed. The fire was planned to have variable health property, *i.e.*, it would take different amount of extinguishing agent and different time duration to extinguish individual fire sources. This was done to simulate how real fire behave, since not every fire would take the exact same resource to extinguish. There was also plan to extend this simulation system to allow for different types of fire, *e.g.*, liquid flammable fire, electrical equipment fire, *etc.*, that requires specific type of fire extinguisher to extinguish. This was, however, not implemented due to time constraint.

### 4.1.2 Prototyping

Prototyping was done using both low-fidelity (*i.e.*, paper sketches) and high-fidelity prototypes (*i.e.*, working application).

#### Low-Fidelity Prototypes

Low-fidelity prototypes of the FST application were created by drawing on paper. These prototypes includes the initial look and feel of various part of the application and descriptions of functionalities as described in section 3.2 previously. Two examples of the low-fidelity prototype is shown in figures 4.1 and 4.2, respectively showing the learning and training modes.

These prototypes were used as the starting point for the implementation stage. Most of the looks and feel from the low-fidelity prototypes were kept in the final working application.

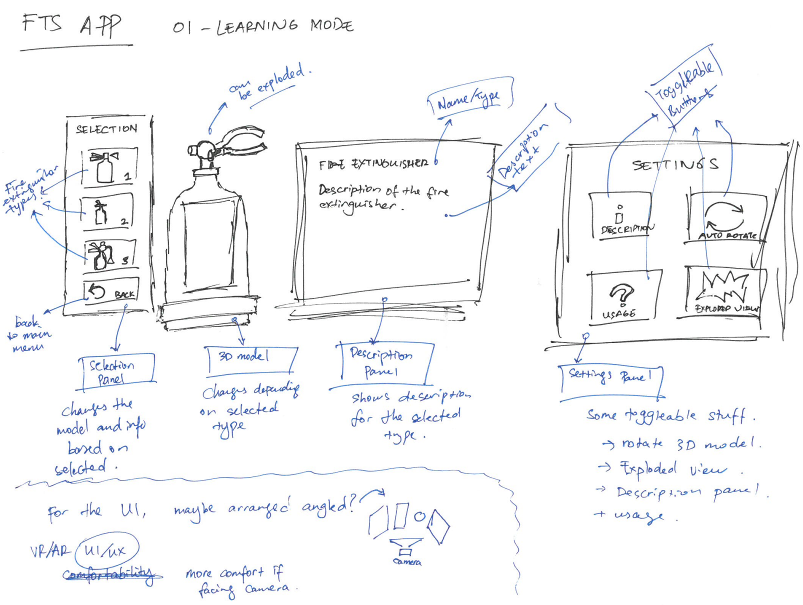


Figure 4.1: Learning mode prototype

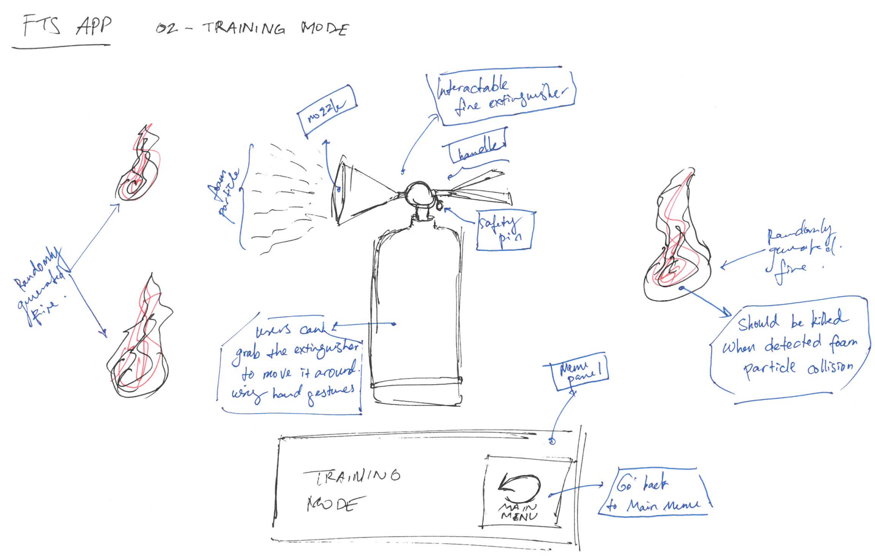


Figure 4.2: Training mode prototype

### High-Fidelity Prototype

Several versions of high-fidelity prototypes were produced in the process of developing the application. Rapid prototyping strategy was implemented to quickly produce working prototypes for functionality testing purposes. Figure 4.3 shows an example of the early learning mode prototype, based on the low-fidelity prototype. Most of the high-fidelity prototypes were made using Unity and tested directly in the editor. Some major prototypes were tested on the Hololens to ensure important features, such as hand gesture and fire simulation, were working properly outside of the development environment.

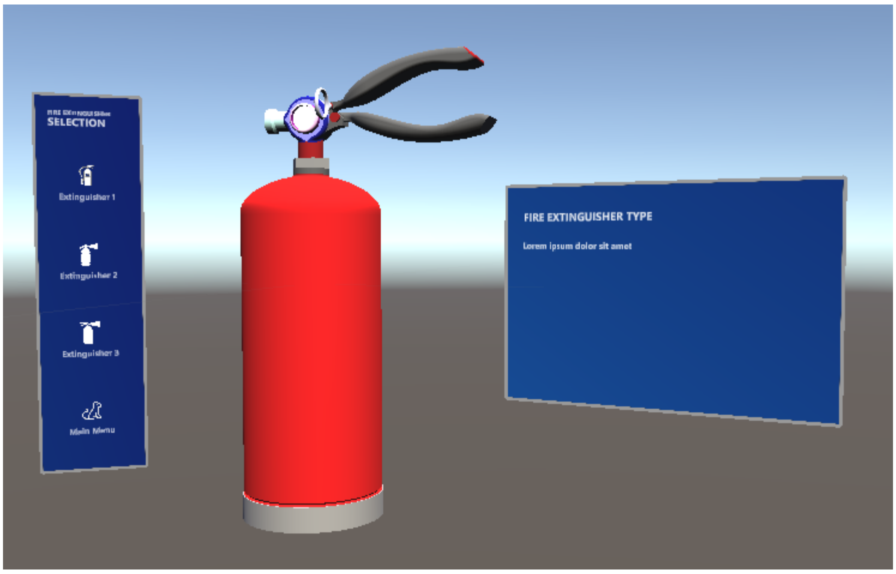


Figure 4.3: Learning mode high-fidelity prototype (in Unity Editor)

## 4.1.3 Development Environment Specification

The following Hardware and Software tools have been selected as the development environment based on the availability and the author's relevant experience and skills.

### A. Hardware

The following hardware was chosen as the target device for the project.

**Microsoft HoloLens 2** [34] – an MR smart glasses developed by Microsoft that features see-through holographic lenses, hand tracking, eye tracking, and spatial tracking, amongst other things.

**ASUS Notebook (GL753VD)** — the author's laptop notebook, using Windows 10 operating system. This device is used to run all the software tools used in the development.

### B. Software Tools

The following software tools were selected to be used in the project and content development.

**Unity** [35] — a cross-platform game development engine. Unity has support for major platforms, such as Mobile (Android & iOS), Desktop (Windows, MacOS, and Linux), Web-based (WebGL), Console (PlayStation, Xbox, Nintendo Switch), and Extended Reality (XR) (Windows Mixed Reality / Hololens, Oculus, SteamVR).

Unity was chosen as the main Integrated Development Environment (IDE) for the application development due to having a large user base and comprehensive documentations, thus various supports are available through the documentations site and Unity forums. Unity primarily uses C Sharp (C♯) programming language as its scripting language. The advantage of using Unity including rapid prototyping and the large user community.

**Mixed Reality Toolkit (MRTK)** [36] — a cross-platform app solution for MR development. Available as a plugin for Unity that supports direct development and building to the Microsoft HoloLens 2. This toolkit allows for various built-in MR features, such as solver functions to track head or hand movements, to be implemented quickly with relative ease.

**Visual Studio 2019 (VS19)** [37] — an IDE by Microsoft that supports major scripting languages and is integrated with natively to Unity. VS19 provides, amongst other, syntax highlighting and smart recommendations for Unity-specific C♯ classes, functions, and data types, thus improving coding efficiency by reducing the amount of time needed to refer to the online Unity documentations.

**C. Priorly Considered Tools**

These tools were originally used in the earlier stage of the project, however was removed due to various reasons described in each.

**Vuforia Engine** [38] — an Software Development Kit (SDK) for object recognition through the use of computer vision technology. Vuforia provides integration with Unity through a plugin.

**Removal reason:** This SDK was removed from the project because the object recognition process was too complicated, including getting a development token, linking to their website, and complex configurations. Additionally, when object scanning was attempted, the resulting object recognition was not consistent.

**GitHub** [39] — a version-control solution for archiving and storing project data and documentations. GitHub also provides static web page hosting, which will be used for hosting documentations and project progress. The project site is still available at **GitHub Pages** at the time of the writing.

**Removal reason:** Unity project files typically can reach up to gigabytes in size, with the FST application reaching to nearly 6 gigabytes at one point of the development. The recommended repository size was up to 1 gigabyte, thus it was decided that this version control system may not be the best option to be used.

### 4.1.4 Formal Study Tools

In addition to the software development tools, the following tools were used in the pilot study phase of the project, including for participant recruitment and questionnaire.

**Doodle** [40] — a meeting time and scheduling assistant that allows users to select their best available time slots. This tool was very useful when scheduling the pilot study session as they allow multiple date and time to be set, in addition to setting a quota for each timeslot. Participants were asked to select one date/time slot for the study session.

**Microsoft Forms** [41] — an online forms creator that supports creating surveys, questionnaires, quizzes, and polls. Microsoft Forms was used to host the questionnaire in the study. The responses gathered were then exported as a spreadsheet for further data analysis.

**YouTube** [42] — a popular video sharing platform that contains all types of videos, including fire extinguisher usage tutorial. As described in brief previously (Section 3.3.3), YouTube serve their content under the CC BY license by default, in addition to having a "fair use" clause in their terms of service [43].

## 4.2 Implementation

This section describes the process of implementing the FST Mixed Reality application based on the software requirements specified (Section 3.2) and design details (Section 4.1). This section will also cover more specific details regarding the MR FST application, including its features and UI design.

### 4.2.1 Hardware & Software


Figure 4.4: Hardware for Development, showing Laptop Notebook with Unity and HoloLens 2 with its charging and data cable.

As detailed in the design (Section 4.1), it was decided to implement the mixed reality fire safety training app on the Microsoft HoloLens 2 headset. Figure 4.4 shows the hardware equipment used to implement the FST application, including the ASUS laptop notebook as the primary development machine for scene building, scripting, and application compiling and the Hololens with a data transfer cable and charger. Note that the Hololens is not needed per se for building the application, it is only used when a build version is ready to be deployed and tested on the headset. Most of the application testings were done directly on Unity as it has a built-in Windows Holographic emulator (through MRTK plugin). However, some functionalities, such as rotating objects using hand gestures, were not available since the emulator utilises mouse and keyboard to simulate inputs. For testing on the Hololens, the built application could be deployed using either the data cable or through wireless connection (WiFi).

In terms of software, Unity was used alongside the MRTK plugin because of extensive documentations and active community, on top of the author's previous experience with these tools. VS19 was used to script since it is already integrated with Unity, and is available for free (through the Community edition).

Additional details for both hardware and software specifications are available under Appendix A.

### 4.2.2 MR FST Application

Referring to the specifications and description of the FST application in Sections 3.2 and 4.1, the application has two major features: Learning and Training modes, in which users should be able to do tasks related to each mode. It was expected that all interactions with the MR content should be done through specific hand gestures (*e.g.*, swiping, "air tap", pinching, two-hands stretching, grabbing, *etc.*). Figures 4.5 — 4.8 shows the initial implementation of the FST app with some gestures being demonstrated.

Figure 4.5: Fire Extinguisher Hologram

Figure 4.6: Pinch Gesture

Figure 4.7: Two-hands Enlarge Gesture

Figure 4.8: Grab Gesture

#### Main menu implementation

The subsequent implementation of the app saw various improvements on many aspects, including user interface and application stability. The main menu was also implemented as the first scene in the app (Figures 4.9 and 4.10). Once a user starts the FST application, they will have four options to choose from: (1) Learning Mode; (2) Training Mode; (3) Options; and (4) Exit. Options (1) and (2) will take users to the specific scenes, while (3) will toggle the CPU performance display on/off and (4) quits the app. There is also an additional pin button, which toggles whether the main menu panel is following the user or staying still in space. Any button that appears in the FST app is linked to a C♯ script related to the specific functionalities that that button should exhibit.

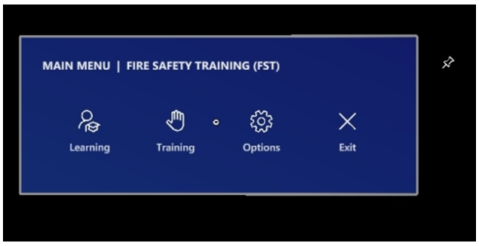


Figure 4.9: Main Menu on emulator

Figure 4.10: Main menu on Hololens

#### Learning mode: default view

The learning mode scene (Figure 4.11) was designed to be more complex with a significantly more number of functions, such as 3D model rotation, 3D model exploded view, toggling panels on/off, and showing extinguisher usage steps that includes animations. In this view, users are able to select different types of fire extinguisher and learn about them.


Figure 4.11: Learning mode scene on Unity (emulator), showing the toggleable panel, selection panel, 3D extinguisher model, description panel, and fire classes panel

### Learning mode: usage view

When the user toggled the "usage", the view of learning mode scene will change and shows four buttons that corresponds to the steps to use a fire extinguisher, *i.e.*, **P**ull safety pin, **A**im at fire, **S**queeze the handle, **S**weep the base of the fire (Figure 4.12). Each of the steps shows an animation that moves the virtual extinguisher to the appropriate position for that step, in addition to a simulated fire (Figure 4.13).

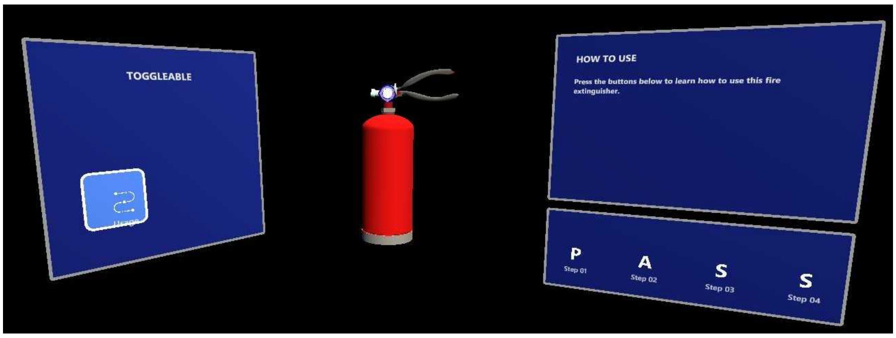


Figure 4.12: Learning scene when "usage" is toggled

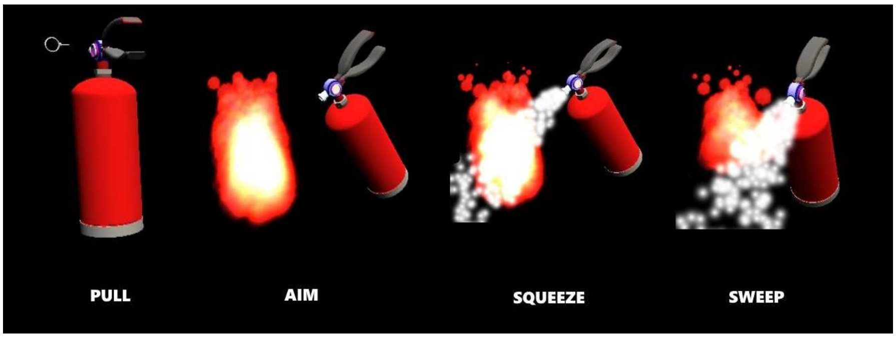


Figure 4.13: Different extinguisher and fire state on different steps

The animation was created directly using the *Animation*, *Animator*, and *Controller* components provided by Unity. These components enabled various types of animations, from simple coordinate transformation and rotation to activating/deactivating multiple objects. Each animation is controlled through keyframes that define what changes were applied to the object (Figure 4.14).

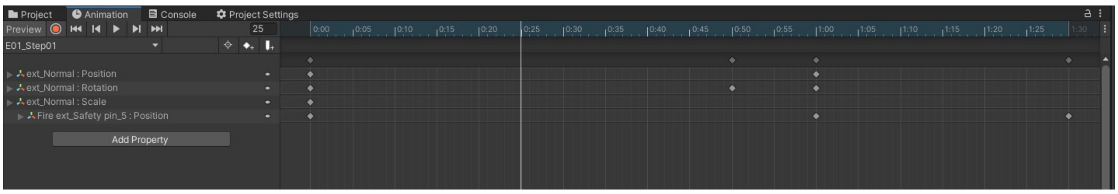


Figure 4.14: Keyframe example for rotating extinguisher model and pulling safety pin in Step 01

### Training mode

The training mode scene simpler in terms of the functionalities present (Figure 4.15). In this scene, user are able to interact with the holographic fire extinguisher using hand gestures and perform operations such as pulling the safety pin (Figure 4.16), squeezing the handle (Figure 4.17), and moving the holographic extinguisher around in space. The various animations in this scene were made with the same keyframing method described previously. However, the animation is only tiggered when user interacts with the related part of the holographic object, *e.g.*, pinching the safety pin will play the pulling out animation.


Figure 4.15: Training mode scene on emulator

Figure 4.16: Safety pin pulled out

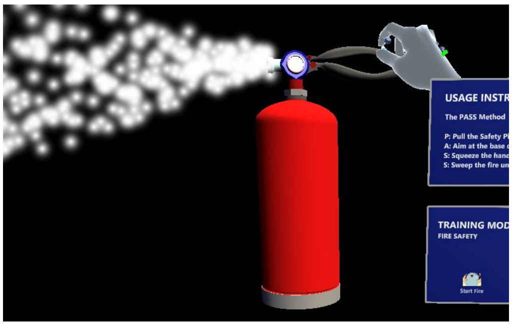


Figure 4.17: Emulated squeeze to dispense particle

The menu panel in this scene contains summarised extinguisher usage steps, and two buttons, start fire and main menu. The “start fire” button would trigger the fire simulation to start, while main menu button will simply bring user back to the main menu scene.

### Training mode: fire simulation

The fire simulation starts with a fire alarm sound effect that is audible to the user through the Hololens built-in speaker. It is then followed by the instantiation of five fire source objects in random x and z-coordinates offsets centered at the original spawn point of the holographic extinguisher, while the y-coordinate is kept constant near the ground level (Figure 4.18). The fire was created using Unity particle system, which allows simulating fluid and particle mechanics.

Figure 4.18: Fire source spawned randomly at ground level

Each fire source was attached to a specific *fire behaviour* script, which adds a "health" property to the fire (Figure 4.19). The health is calculated randomly with values within a user-defined range. Once the health value reaches zero, the fire will be disabled, causing the remaining particles to finish their lives, which creates an effect of fire going out as each particle moves upwards and fades out. This health point could be reduced by hitting the fire source object with the extinguishing particle from the holographic fire extinguisher (Figure 4.20).

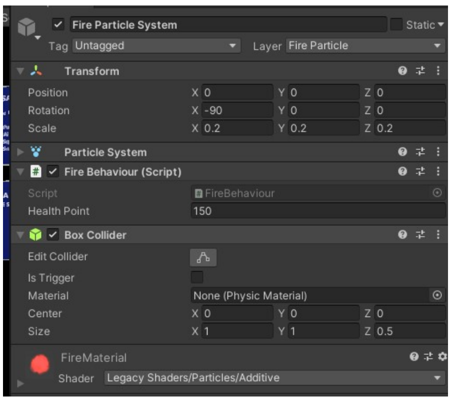


Figure 4.19: Properties of a fire source

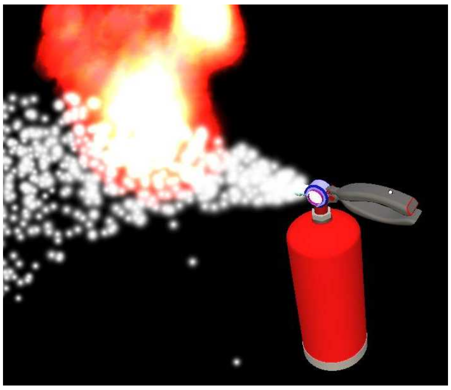

Figure 4.20: Hitting fire using extinguisher particle

The extinguishing process was implemented using a particle colliding event, where each extinguishing particle carry a user-defined "fire killing factor". This value in the factor is reduced from the health of the fire for every extinguishing particle that hits the fire source.

### Health & Safety Warning

The last part that was implemented in the FST app was the health and safety warning panel (Figure 4.21). This was left at the end because considering it only contained text and a "I understood" button, which did not take a considerable amount of time to implement. This panel was put before showing the main menu, and the button is linked to a script that changes the scene to the main menu scene

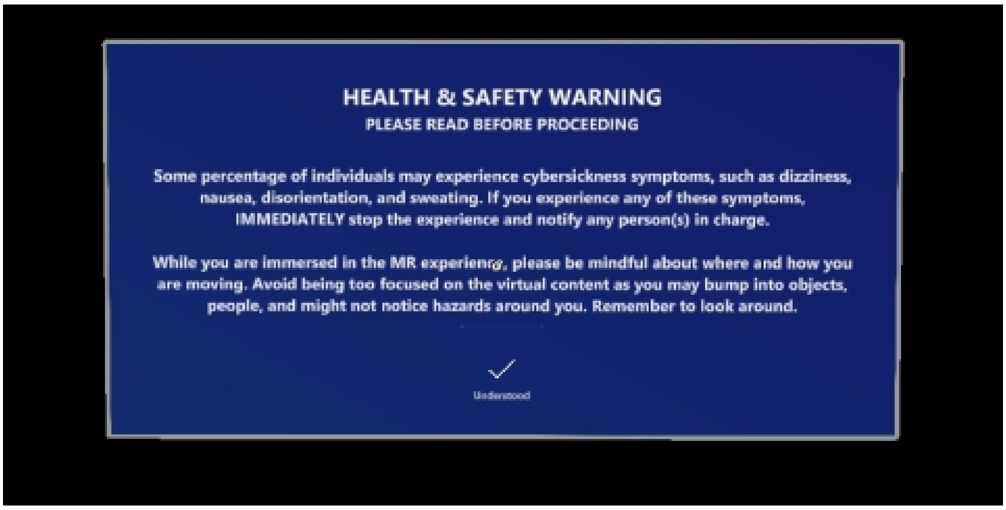


Figure 4.21: Health & safety warning panel with button shown

During testing, however, it was noticed that the warning panel may appear either too far or near the user, thus they would need to move to see it in full. This was addressed by applying the same function as the main menu pinning, *i.e.*, the panel would follow the user's movement and stay a certain distance from the user's view. This behaviour was achieved using MRTK's solver methods, which allow complex calculation to be done automatically to save time.

### Deploying on the Hololens

After every parts of the FST application were developed and tested on the emulator, major deploy-ready versions were built and deployed on the Hololens for further testing. The deploying process involves building the Hololens application solution, building the solution into an APPX package (the installation package for Windows Holographic platform) using VS19, and deploying the package to the Hololens either using wireless or wired connection. The deployment step is typically also done in VS19, since it can interface directly with Hololens via WiFi connection after specifying the headset IP address. This process is summarised in figure 4.22.

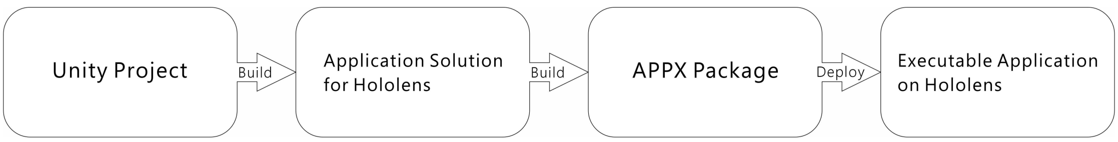


Figure 4.22: MR Application Building and Deploy Flowchart

Once deployed in the Hololens, the application was then ready to be tested. Extra attention was given specifically on the hand gesture and fire simulation features, since the emulator was not able to simulate it perfectly. The figures 4.23 - 4.29 shows the FST application being tested on the Hololens; the images were taken from the latest prototype of the application.


Figure 4.23: Main menu

Figure 4.24: Learning mode, exploded view


Figure 4.25: Training default view

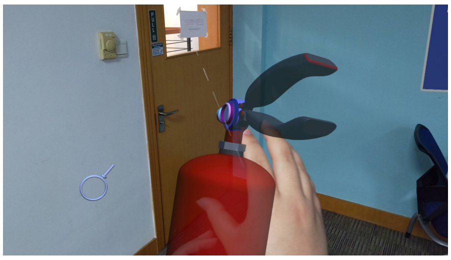

Figure 4.26: Pin pulling interaction

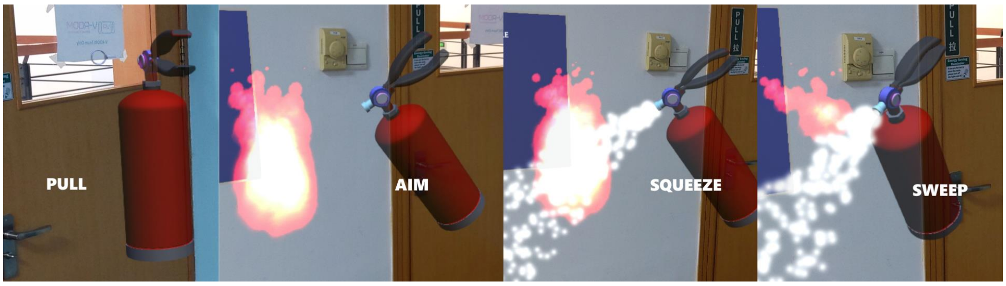


Figure 4.27: Usage steps animation

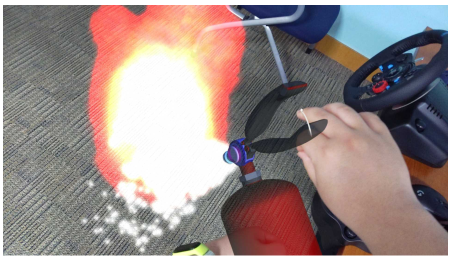

Figure 4.28: Fire simulation

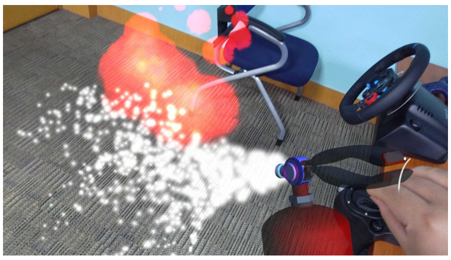

Figure 4.29: Fire extinguished

### 4.2.3 Testing

The FST application was tested extensively both on the emulator and Hololens to ensure that each parameter matches the specified requirements. Since to the best of the author's knowledge, there is no framework to test a mixed reality application, testings were done manually by walking through every aspects of the application. The testing results are as follow.

- All functional requirements were successfully implemented without any loss of functionalities.
- All non-functional requirements were fulfilled
  - Usability — all UI elements, such as text and buttons, were clear, sized appropriately, and self-explanatory. Colors used did not cause any discomfort.
  - Performance — the application took on average 6 to 7 seconds to start. Scene loading is almost instantaneous once buttons are pressed. No freezing occured at all, both during testing and formal study.
  - Security — the FST application does not store any information or data from user.
  - Safety — health and safety warning was shown to the user

### 4.2.4 Challenges

Despite having implemented all the requirements, some challenges still remains. The following describes some of the challenges.

- **User Interface** — the native UI package provided by the MRTK package is very *clunky* and difficult to configure. There were also issues with text being pixelated in the Hololens build, which was resolved by changing from default text to using Unity's TextMeshPro component (a package that provides better and greater control over UI elements, such as fonts and typesetting).
- **Custom Hand Gestures** — based on initial feedback, the default hand gesture provided by MRTK and Hololens were difficult to perform (*e.g.*, pinching on safety pin to pull it out, compared to actually pulling). There were attempts at trying to define custom gestures, which were not successful. This is perhaps due to the author's lack of skill in more technical aspect of mixed reality application development.
- **Object Recognition** — although outside of the scope, there was an attempt to implement object recognition using Vuforia SDK. However, it was not successful and thus were abandoned in favor for developing other integral aspects of the FST application, as described in section 4.1.3.

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**Chapter Summary:**

Chapter 4 has discussed in detail about the design of the application, including prototypes produced. This chapter has also described the process of implementing the FST MR application from the emulator on Unity to the working application on the Hololens, as well as the testing done and challenges faced.

Next chapter will provide a discussion and analysis of the data obtained from the formal study session.

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# Chapter 5

# Data Analysis & Discussion

This chapter presents the data that was obtained from the formal study and provides an analysis and discussion about any findings. The data will be analysed with statistical analysis methods and the results summarised in charts and graphs. The analysis will be conducted from a variety of perspectives to investigate whether factors such as gender or academic background influence their attitudes toward using MR in education. In addition, some discussions about motion sickness in MR will be offered to bring more insights toward adopting MR in an education setting.

## 5.1 Overview

The obtained data were initially pre-processed in order to link replies from the same person in the two questionnaires. After that, the pre-processed data were anonymised, with only non-identifiable information retained.

Through the responses obtained in the questionnaires, the participants demographic data were obtained as previously presented in Section 3.3.2. As can be seen in Figure 5.1, a majority of participants came from FoSE (44.1%) followed by CELE (25.4%), NUBS (20.3%), and finally FHSS (10.2%). Amongst these, Y2 students made up the most number and PhD students the least as shown in Figure 5.2.

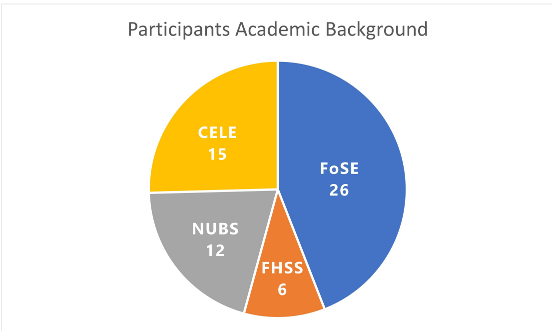


Figure 5.1: Participant proportions

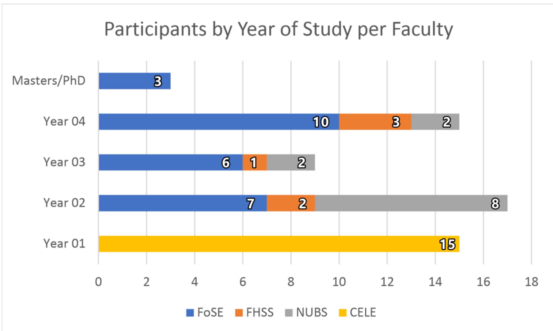


Figure 5.2: Participants by year of study

During the study, participants were asked to rate various aspects of their learning experience using the MR FST application, *i.e.*, learning motivation, engagement, attraction, comfort, and their overall experience. The rating were scaled from 1 to 5, where 1 means the lowest and 5 the highest. The responses were summarised and the average, mode, median, along with the minimum and maximum values presented in Table 5.1.

| ***Learning Aspects*** | **Average** | **Mode** | **Median** | **Min** | **Max** |
|---|---|---|---|---|---|
| Motivation | 4.59 | 5 | 5 | 3 | 5 |
| Engagement | 4.39 | 5 | 5 | 3 | 5 |
| Attraction | 4.49 | 5 | 5 | 2 | 5 |
| Comfort | 3.69 | 4 | 5 | 2 | 5 |
| Overall | 4.32 | 5 | 4 | 3 | 5 |

Table 5.1: Summary of Data

As evidenced by the average overall rating of 4.32 out of 5, participants regarded the MR FST application to be valuable to their learning, particularly in the context of a fire safety training. This was further reinforced by the mean ratings for motivation (4.59), engagement (4.39), and attraction (4.49); all of which indicate that participants are more motivated to learn, more engaged with the content offered, and more attracted to the learning experience. These findings are consistent with an earlier study published in 2005 by Hughes et al., in which they used MR technologies in a Sea Creatures experience (viewing and learning about marine life) in the Orlando Science Center's DinoDigs exhibition hall [16]. According to the study, 88 percent of those surveyed believe that MR adds an entertainment factor to the learning process, and 83 percent agree or strongly agree that they learned more about the subject supplied when compared to when they did not use MR.

Despite the high overall rating, several participants found that using the Hololens were not particularly comfortable as indicated by the comfort rating of 3.69 out of 5. One participant noted on their response that "*the headset was a little uncomfortable*", and a verbal follow up attributed the discomfort to the weight of the headset and that the Hololens would become warmer during long sessions. Another user commented "*... I always feel the* [Hololens] *device falling down*", alluding to how the device may have possibly been misadjusted and was too loose.

**MR Learning vs. Gender**

| ***Learning Aspects*** | ***Average*** | |
|---|---|---|
| | **Male** | **Female** |
| Motivation | 4.61 | 4.58 |
| Engagement | 4.39 | 4.39 |
| Attraction | 4.54 | 4.45 |
| Comfort | 3.71 | 3.68 |
| Overall | 4.29 | 4.35 |

Table 5.2: Summary of Data based on Gender

The responses were also analysed based on how different genders perceive the MR-based learning experience, with both male and female giving almost identical overall (respectively 4.29 and

4.35 out of 5). Table 5.2 provides the average ratings from the two gender perspectives. When examining each component, it is also worth noting that there is very little difference in how each gender perceives them, with the major variance being in the attraction rating (0.08), where male participants found the app slightly more interesting then their female counterparts.

#### MR Learning vs. Study Background

| *Learning Aspects* | *Average* | | | |
|---|---|---|---|---|
| | **FoSE** | **FHSS** | **NUBS** | **CELE** |
| Motivation | 4.54 | 4.67 | 4.67 | 4.60 |
| Engagement | 4.35 | 4.50 | 4.58 | 4.27 |
| Attraction | 4.31 | 4.50 | 4.67 | 4.67 |
| Comfort | 3.50 | 3.17 | 4.08 | 3.93 |
| Overall | 4.23 | 3.83 | 4.67 | 4.40 |

Table 5.3: Summary of Data based on Gender

Apart from gender, it was also decided to look into the data from the perspectives of study background, grouped by the participants' faculties of study in the university. Amongst the four faculties, participants from NUBS rated the overall experience with the highest rating (4.67), followed by CELE (4.40), FoSE (4.23), and lastly FHSS (3.83).

#### Participants Comments

During the study, participants were asked about which aspect of the MR FST application surprised them the most. Their responses to this question, in general, agrees that hologram interaction is one of the most surprising aspects, with some participants commenting such as "*I can catch the fire extinguisher to put out the fire!*", "*How real the interaction was*", and "*We can use our fingers to click the buttons ...*". Some participants also praised aspects of the fire simulation and extinguishing mechanics, demonstrated by comments such as "the fire looks hot" and "... training session is useful ...".

However, there were also some aspects of the MR FST app that participants disliked. A large proportion of participants (13 out of 59) noted that they disliked the safety pin pulling mechanics, due to the pin being "*... hard to click*". This has explicitly identified one area where the application could be improved by perhaps changing the mechanism for pulling the pin. Some participants (6 out of 59) noted that they found that the Hololens screen resolution and field of view limiting, with one person commenting explicitly "*Narrow field of view*". Since this issue was a hardware limitation, perhaps it may be worth in the future to look into different alternative hardware and not only limiting the study to the Microsoft HoloLens 2 device. Other comments regarding disliked aspect includes issues with the screen being too dim/transparent and that some people find wearing the headset uncomfortable.

In terms of the perceived advantage, many users (> 15 participants) noted that the MR app is interesting and engaging, partly due to it offering an immersive learning experience where they can interact directly with virtual contents in the real world. However, participants have also identified disadvantages with using MR in education, including the expensive price of the Hololens equipment, possible increased distraction in MR environment, and the many technical issues that may arise during a learning session.

## 5.2 Traditional vs MR-based Learning

This section will look at how participants performed in the two quizzes for each learning session, as one of the goals of this study is to compare traditional and MR-based learning. Both quizzes contains five multiple-choice questions with only one correct answer for each question.

### 5.2.1 Statistical analysis of quiz results using t-Test

Table 5.4 and 5.5 present the proportion of people who get the correct and wrong answer per question. At a glance, it can be seen that in general the participants did worse in the second quiz (*i.e.*, after the MR-based learning session).

| | **Correct** | | **Wrong** | |
|---|---|---|---|---|
| | ***n*** | ***%*** | ***n*** | ***%*** |
| Question 1 | 53 | 91.4% | 5 | 8.6 % |
| Question 2 | 43 | 74.1% | 15 | 25.9% |
| Question 3 | 55 | 94.8% | 3 | 5.2 % |
| Question 4 | 50 | 86.2% | 8 | 13.8% |
| Question 5 | 56 | 96.6% | 2 | 3.4 % |

Table 5.4: Quiz 1 Result

| | **Correct** | | **Wrong** | |
|---|---|---|---|---|
| | ***n*** | ***%*** | ***n*** | ***%*** |
| Question 1 | 48 | 81.4% | 11 | 18.6% |
| Question 2 | 52 | 88.1% | 7 | 11.9% |
| Question 3 | 52 | 88.1% | 7 | 11.9% |
| Question 4 | 57 | 96.6% | 2 | 3.4 % |
| Question 5 | 44 | 74.6% | 15 | 25.4% |

Table 5.5: Quiz 2 Result

| Changes | -3 | -2 | -1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|---|
| *n* | 0 | 5 | 16 | 23 | 12 | 1 | 2 |

Table 5.6: Number of people with specific marks change

Since both quizzes have a full mark of 5 points, the data was processed to calculate each person's change in marks between the two quizzes. Table 5.6 summarises the number of people with certain marks changes. A change of -1 means that the person did worse by 1 mark in the second quiz, and a +1 means that the person answered one more question correctly compared to the first quiz. A change of 0 means that the person answered exactly the same number of questions correctly.

The average performance change was calculated to be $-0.10$, showing a general worsening of their quiz results, which may be attributed to a range of factors including, but not limited to, information retention, attention span, and a possible increase in distracting components in an MR setting. This being said, the value of $-0.10$ corresponds to a 2% drop in the average marks, which is not bad per se and could have also happened by chance. The Student's t-test was done to verify whether there is a statistical significance between the two quiz results, the result is shown in Table 5.7.

| Mean | Std.Deviation | t | df | Sig. (2-tailed) |
|---|---|---|---|---|
| $-.102$ | 1.094 | .714 | 58 | .478 |

Table 5.7: t-Test Result

Taking $\alpha = 0.05$ and the hypotheses,
$H_0 : \mu_d = 0$
$H_1 : \mu_d \neq 0$

We can conclude that since the $p$ value of $0.478 > \alpha$, there is ***not*** enough evidence to support rejecting the null hypothesis ($H_0$). This means that there is insufficient evidence to confirm that there is indeed a statistical significance in the quiz results differences, and the difference may have occurred purely by chance.

## 5.3 UX Feedback

Participants were also asked to rate their user experience using a series of question adopted from the UEQ+ framework described in Section 3.3.5.

### 5.3.1 UEQ Results

The processed responses from the UEQ is summarised in Table 5.8. Note that the means for the scales were transformed from a scale of 1–7 into a $-3$ to $+3$ range.

If a particular scale has a mean value $< 0$, it indicates that the participants view the FST application unfavorably for that scale, while a mean value $> 0$ indicates a favorable view, and a mean value of $= 0$ means that the app is neither viewed favorably nor negatively for that particular scale. For example an *Attractive* mean value of $-3.00$ would indicate that participants do not find the app as attractive at all, and a *Usefulness* mean value of 3.00 indicates that participants found the app to be very useful in context.

| **Scale** | **Mean** | **Variance** | **Std.dev.** | **N** | **Confidence** | **C.Interval** | |
|---|---|---|---|---|---|---|---|
| Attractiveness | 1.81 | 1.50 | 1.22 | 59 | 0.31 | 1.50 | 2.12 |
| Efficiency | 1.61 | 1.92 | 1.38 | 59 | 0.35 | 1.26 | 1.96 |
| Perspicuity | 1.94 | 1.36 | 1.16 | 59 | 0.30 | 1.65 | 2.24 |
| Dependability | 1.80 | 1.76 | 1.32 | 59 | 0.34 | 1.46 | 2.14 |
| Stimulation | 2.16 | 1.27 | 1.13 | 59 | 0.29 | 1.87 | 2.44 |
| Novelty | 1.99 | 1.36 | 1.16 | 59 | 0.30 | 1.69 | 2.29 |
| Acoustics | 1.58 | 1.88 | 1.37 | 59 | 0.35 | 1.23 | 1.93 |
| Usefulness | 2.04 | 1.40 | 1.18 | 59 | 0.30 | 1.74 | 2.34 |
| Quality of Content | 2.08 | 1.16 | 1.07 | 59 | 0.27 | 1.81 | 2.35 |
| Clarity | 2.15 | 1.05 | 1.02 | 59 | 0.26 | 1.89 | 2.41 |

Table 5.8: User Experience Questionnaire Data

Based on the result presented, it could be seen that for all scales provided, all of the mean values are $> 0$. This indicates that in general, the study participants viewed the FST application favorably for all scales. This is illustrated in Figure 5.3, showing all scales are well above the 0 line.

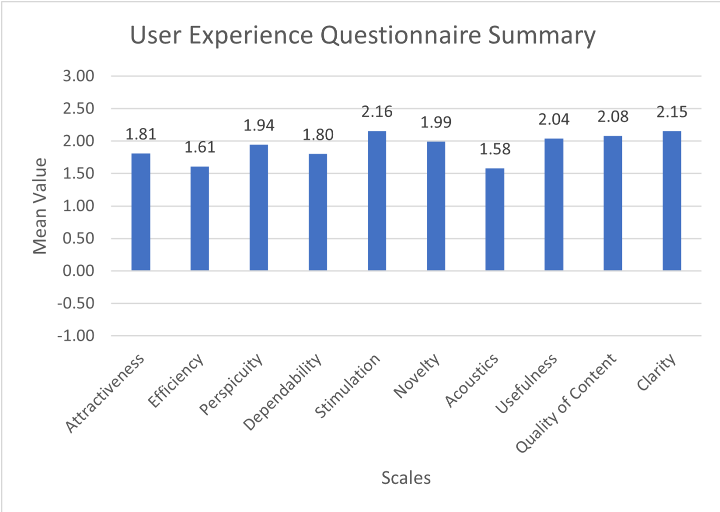


Figure 5.3: Summary of UEQ Results

It could be seen that the top three aspects for users of the application were: 1. Stimulation (2.16); 2. Clarity (2.15); and 3. Content Quality (2.08). In this sense, it could be concluded that users feel that the FST application is especially motivating and exciting to use, on top of being well structured and having a good and updated learning content. Furthermore, the *Usefulness* scale mean score was found to be 2.04, indicating that the application was judged to be beneficial and useful for assisting in learning, particularly in the context of fire safety.

### 5.3.2 Scale Consistency

It is also important to see if the scales and components used in the UEQ are consistent, *i.e.*, participants did not interpret any scales or components in an unexpected way thus causing part of the data inconsistent with the rest. For this purpose, the Cronbach Alpha value - formally known as the Alpha-Coefficient - was calculated. A target value of 0.70 was selected due to the general consensus that the value is a sufficient threshold value [44]–[46]. An $\alpha$ value $> 0.70$ is interpreted as a scale being "sufficiently consistent" and any $\alpha < 0.70$ would indicate that there is possibly some inconsistencies in the scale used.

| **Scale** | **Average Corr.** | **Cronbach Alpha** |
|---|---|---|
| Attractiveness | 0.54 | **0.82** |
| Efficiency | 0.51 | **0.81** |
| Perspicuity | 0.49 | **0.80** |
| Dependability | 0.44 | **0.76** |
| Stimulation | 0.69 | **0.90** |
| Novelty | 0.69 | **0.90** |
| Acoustics | 0.62 | **0.87** |
| Usefulness | 0.69 | **0.90** |
| Quality of Content | 0.52 | **0.81** |
| Clarity | 0.71 | **0.91** |

Table 5.9: Scale Consistency (Cronbach Alpha)

As Table 5.9 shows, the Cronbach Alpha value for every scale are > 0.70. This has proven that every scale that were used in the UEQ for the FST application study were sufficiently consistent, and the likelihood of having data inconsistencies is low. Therefore, the UEQ data could and should be used as a reference for further development of the MR FST application.

## 5.4 Cybersickness

Cybersickness is a subset of motion sickness best defined as occurring when a person starts exhibiting motion sickness symptoms in an immersive virtual environment [47]–[49]. In this study, 4 out of 59 participants have identified themselves as having experienced cybersickness symptoms during the MR session. Amongst these, three participants started exhibiting symptoms roughly between 10 to 15 minutes into the MR session and only one started feeling cybersick after 15 minutes.

| ***Symptoms*** | **Avg** | **Min** | **Max** |
|---|---|---|---|
| Headache | 1.50 | 1.00 | 2.00 |
| Fatigue | 1.00 | 1.00 | 1.00 |
| Eye Strain | 2.25 | 1.00 | 4.00 |
| Loss of Balance | 2.00 | 1.00 | 3.00 |
| Nausea | 2.25 | 1.00 | 4.00 |
| Dizziness | 2.50 | 1.00 | 4.00 |
| Sweating | 1.50 | 1.00 | 3.00 |
| Disorientation | 2.00 | 1.00 | 4.00 |
| General Discomfort | 2.00 | 1.00 | 4.00 |
| Stomache awareness / ache | 1.00 | 1.00 | 1.00 |
| Vomitting | 1.50 | 1.00 | 3.00 |

Table 5.10: Cybersickness symptoms rating

Participants were asked to rate the severity of their symptoms, which result is summarised in Table 5.10. Based on the ratings, it could be seen that in terms of severity, *dizziness, nausea, eye strain, loss of balance, disorientation* and *general discomfort* are amongst the most severe symptoms, with most of them having a maximum rating of 4. On the other hand, participants reported *fatigue* and *stomach awareness/ache* as the two non-severe, perhaps even non-existent, symptoms based on the highest rating for these two at 1.

When asked about what could possibly cause their cybersickness symptoms, all four participants that experienced cybersickness symptoms provided differing reasons. One of them attributed their symptoms to visual/graphics quality, based on their comment "*Blurry image?*". Another mentioned that "*the scene ... are not very clear, ... moving from time to time*," suggesting that there might be some issue or bug in the FST application that may have caused instability of holograms and scenes such that they may not anchor properly in space. The third noted that they felt sick because "*cannot move the things in the first click*," also possibly relating to a possible bug in the hand gesture interaction system. The last participant who experienced the symptoms was not able to identify any specific potential cause and simply commented "*nothing*".

Although the proportion of participants who experienced cybersickness symptoms is low (6.8%), it is still important to address the issue and possibly minimise and mitigate the occurence of cybersickness in future MR learning experiences.

### 5.4.1 Summary of Discussions

To reiterate the points of discussions in this chapter, the participants perception of the MR FST application has been favorable indicated by their ratings on how motivated, engaged, attracted, and comfortable they felt while using the app, in addition to a relatively high overall rating value. A brief analysis of the data from gender and study background perspective has provided further insights on how different groups may have perceived the MR application differently.

A comparative analysis using the Student's t-Test statistical method has also been conducted to investigate whether MR-based learning is more beneficial towards students classroom performance, measured by their scores on two short quizzes. The result of this has been inconclusive as there is not enough evidence to support that the two learning sessions had affected students learning performance.

An investigation into user experience using UEQ was also done to see how users feel while using the FST application. In general, the result has been very favorable with the mean value of all scales being in the positive range ($> 0$). The scales were also found to be sufficiently consistent on an Alpha-Coefficient value analysis.

Lastly, a minority of participants reported cybersickness symptoms and therefore an investigation was done to look into possible causes and how severe these symptoms were. Some possible causes that were identified include graphics quality and unstable holographic elements.

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**Chapter Summary:**

Chapter 5 has presented and analysed the data obtained from the study, as well as provide in depth discussions to the meaning of these data and importance towards further considerations when developing an MR application for educational purposes.

Next chapter will provide a conclusion to the

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# Chapter 6

# Conclusion

The MR in Education project aimed to develop and build a mixed reality application for the Hololens, which content was decided to be based on the fire safety training. The MR application was developed successfully based on the software requirements specified and has been deployed and tested using the Hololens 2 headset.

The FST app was then used in a formal study that aimed to compare conventional and MR-based learning and investigate further aspects of human-computer interaction between the user and the FST app on the Hololens. The formal study session was joined by a total of 59 participants from varying background. The study concluded that in general, the FST app has been received rather favorably by participants as shown in the discussions in Chapter 5. However, despite the favorable reception, various problematic aspects and point for improvements have also been identified, such as bugs and issues regarding holographic content interactions. These have been noted and should be referred to in future development of educational mixed reality applications.

In terms of the comparative investigation between the two learning models, the result has been inconclusive due to the lack of evidence to support that MR-assisted learning have any statistically significant impact on student's performance that were measured through their score on the quizzes. In the future, it may be worth expanding the study to include a more comprehensive and detailed investigation to compare between the two learning models.

In general, the project has shown that mixed reality technology has a very broad potential to be a breakthrough solution towards improving teaching and learning model by introducing an immersive setting where learners are able to interact and experience first-hand supported by holographic elements in the real world. Since this project has explored the topic more through a computer science-oriented perspective, an interdisciplinary investigation may result in even more comprehensive and impactful insights being discovered.

At the current stage, it might be premature still to implement mixed reality technology in a classroom setting. This could be attributed to the problems highlighted in the study and how participants perceive the technology. There are still many aspects of mixed reality application that should be explored fully for the technology to be completely relevant in education. That being said, the potential of using immersive technology in the education field is limitless, crediting the potential benefits that have been investigated and demonstrated through this project.

Next chapter will look into the author's reflection and future work.

# Chapter 7

# Evaluation and Reflection

This chapter will outline the author's reflection on aspects of the project, what went right and wrong, points of improvements, and possible future plans for the project.

## 7.1 Project Management

The project started by the submission of proposal, which signified the start of Phase 0, which were followed with an ethical review since this project requires human participants. Once this was completed, procurement of necessary hardware and software was done as described in Chapter 4, signifying the end of Phase 0.

Phase 1 started late October 2021 as per the project plan, which includes the start of app development and literature review. While the interim report has increased the duration for app development, it was not nearly sufficient. App development finally concluded late March 2022, citing the lack of relevant development skills for mixed reality platform and possibly poor time management. Due to this, Phase 1 were still ongoing at the point where Phase 2 and Phase 3 were supposed to have started, and thus it was decided to run the phases in parallel despite making the project plan more complicated.

Phase 2 was done concurrent with Phase 1, starting with low-fidelity prototyping on paper and initial implementation for a high-fidelity working prototype. A small scale pilot study were done to get an initial feedback from several select users, which influenced some aspects of the final application design.

Due to Phase 1 being completed a good several weeks after its original plan, Phase 3 schedule for data collection was postponed to the end of March 2022. Additionally, during mid of March 2022, the campus was on a state of high alert due to confirmed positive COVID cases in Ningbo city, resulting in a *lockdown* of the campus. This caused some concern over participant recruitment because it was very near to the end of the final year project timeline. However, the recruitment and subsequent formal study sessions were successfully conducted with relative ease. It was decided not to include staff member because of the COVID campus entry-exit restriction, considering most staff live off-campus.

Phase 4 was decided to be cut by more than half its initial duration. Dissertation writing started concurrent to the start of participant recruitment. Sections that do not require study data were

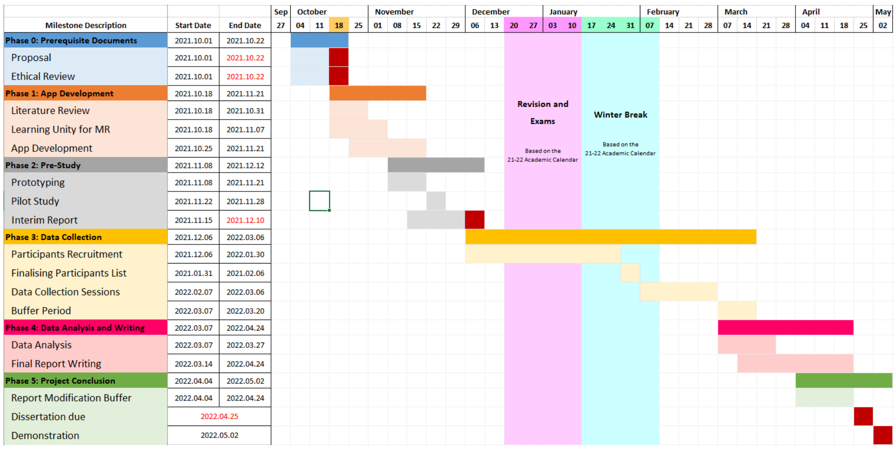


Figure 7.1: Original Project Gantt Chart

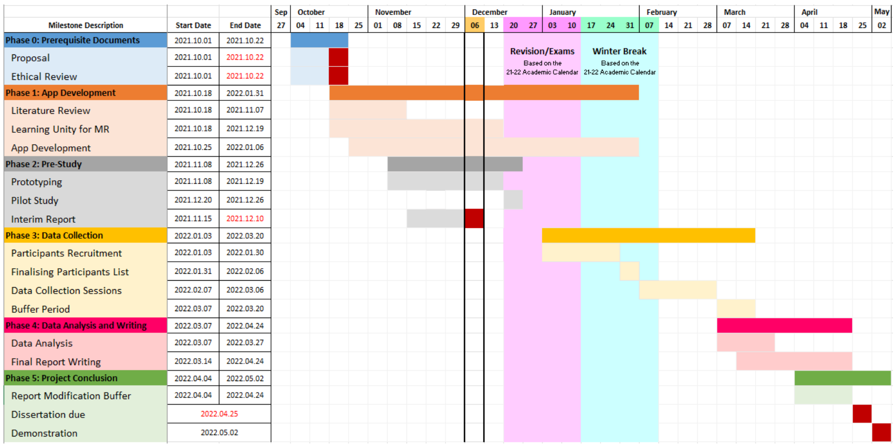


Figure 7.2: Interim Project Gantt Chart

written first so that there will be less outstanding work by the time data was finished being collected.

Due to the major changes in the project plan last minute, Phase 5 was effectively non-existent except for the submission deadline. The following Figure 7.1 - 7.2 shows the original Gantt chart created, respectively, at the start of the project and after evaluation in the interim period. The latest Gantt chart was not produced due to lack of time.

## 7.2 Reflections

The project has had a clear goal and direction since the beginning. However, due to mostly lack of relevant knowledge about mixed reality app development, various issues have arisen in the course of the project. Many of these issues were resolved either partly or fully by more research and literature review, which provided the know-how on MR app development.

One major issue that was faced was during the interim period where the Hololens headset inexplicably stopped working due to an underlying hardware fault. This pushed the project back by several weeks to complete a new Hololens device exchange order with Microsoft Support.

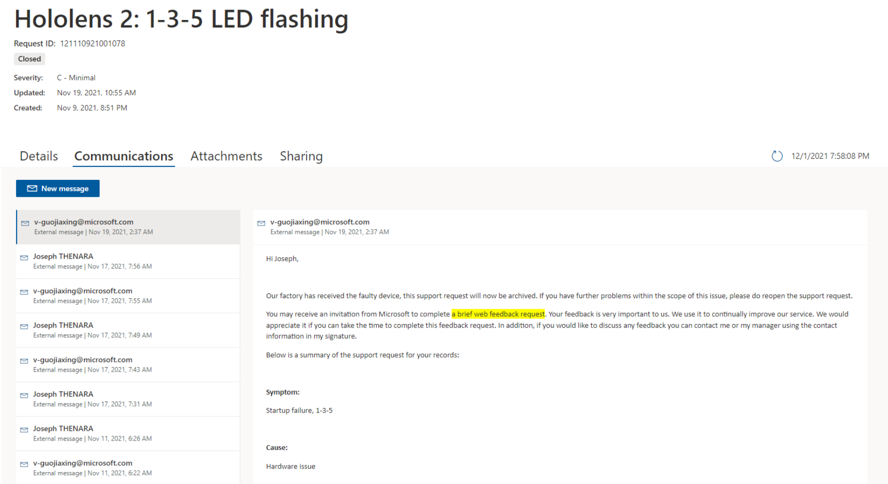


Figure 7.3: Exchange order support ticket for the faulty Hololens device

By the second semester, there were not many changes done to the scope of the project, however the project lagged behind schedule due to issues related to technical aspects of the app development, such as version incompatibility between MRTK plugin with the Unity. This led to the Unity project being remade from almost scratch. Additionally, since it was not possible to learn modelling, initially free-to-use assets were obtained as a placeholder until an original asset has been produced. Fortunately, two friends agreed to help with simple modelling of the fire extinguisher and gave me the right to use the asset in my project. However, since this was a favor between friends, it was decided to only ask for the minimum number of assets as possible, which led to only having two *explodable* extinguisher models being implemented in the final working app.

Nevertheless, the project went considerably well despite many major changes in the timeline. All deadlines were met on time and initial research and literature review done in the first semester helped in many aspects in the second semester, which allowed for a decent progress speed in the second part of the project.

At the current stage, the FST MR application were implemented on time for the formal study and data relating to user perception were able to be collected duly. All requirements were successfully implemented as well. In the future, the most important aspect to be worked on is the improvements of the existing system and mechanics in the app, such as improving the fire simulation as well as possibly implementing custom hand gestures.

This project has been able to investigate the possible application of MR technology in the field of education, particulary in fire safety training scenarios. Although not perfect, the project has demonstrated the massive potential for using MR in various educational settings to improve the teaching and learning pedagogy and methods.

## 7.3 Future Work

This section describes and proposes some considerations of things that could be added to the project and improved.

### 7.3.1 Interfacing with Additional Hardware

There were several discussions about integrating a custom-built fire extinguisher that is equipped with sensors to the FST MR application, such that users instead of using hand gestures to interact with holographic extinguisher, they would be able to use a real extinguisher to extinguish virtual fires. This could be achieved in theory by equipping a communication module and several sensors that detects changes in pressure of the handle and possibly a gyroscope to detect changes in position and orientation of the extinguisher. These data could then be communicated to the FST application via perhaps Bluetooth wireless connection, or cabled connection to the Hololens. In this way, when users press on the real fire extinguisher handle, a holographic foam would be produced in the FST app and will be able to extinguish holographic fire in the virtual fire simulation.

### 7.3.2 Interdisciplinary Investigation

As was discussed in Chapter 6, it may be worth to conduct a further investigation using an interdisciplinary framework, such as combining computer science with an explicit education pedagogy. In this way, effects of MR technology on the teaching and learning process could be investigated in more detail and may yield insightful data regarding the implementation of MR in a classroom setting.

### 7.3.3 Expanding Scope Outside of Education in an Institution

The current project has looked into implementing mixed reality in a university context. However, in the future, immersive technologies including MR would be indispensable to the society. Therefore it is important to look beyond an institution setting and to create an immersive education solution that could be used universally by anyone with access to the equipment regardless.

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# Appendix A

# Hardware & Software Specifications

The following list of specifications refers to the hardware and software tools described in Section 4.1.3.

| Item | Type | Version used | Cost | Remark(s) |
|---|---|---|---|---|
| Microsoft HoloLens 2 | Hardware | Windows Holographic 21H1 | USD 3,500 basic version | One unit provided for free for this project; 4 additional units provided courtesy of V-ROOM Project. |
| ASUS GL753VD Notebook | Hardware | Windows 10 build 19043.1645 | free | Author's personal notebook |
| Unity | Software | 2019.4.31f1 | free | Free for personal and non-commercial use |
| Visual Studio | Software | 2019 | free | Community edition |
| Mixed Reality Toolkit (MRTK) | Software | 2.7.0 | free | |

Table A.1: Project Tools Specifications

Regarding the Unity version, 2019.4.31f1 was chosen because from experience, versions above and below 2019.X contains various bugs related to XR platform development. The MRTK version was provided through the MR Feature Tool [50] by Microsoft and was the most updated version during the development stage, although by the time of writing, a newer version (2.7.3) is available.

# Appendix B

# Participant Information Sheet

**Participant Information Sheet** — *Mixed Reality in Education* Dear Participant,

Thank you for agreeing to participate in the study in connection with my Undergraduate dissertation at the University of Nottingham Ningbo. The project is a study of the application of Mixed Reality (MR) in Education. This project aims to investigate the application of MR using the Microsoft Hololens headset for fire safety training simulation in a university environment and its strengths and weaknesses, as well as the effectiveness when compared to traditional learning methods.

Your participation in this study is entirely voluntary. You are able to withdraw from the study at any point in time at and to request that the information you have provided not be used in the project. Any information you have provided will be kept confidential in accordance with the UNNC Code of Research Conduct. Your identity will not be disclosed in any use of the information you have supplied in the study.

The research project has been reviewed according to the ethical review processes in place in the University of Nottingham Ningbo. These processes are governed by the University's Code of Research Conduct and Research Ethics. Should you have any question now or in the future, please contact me or my supervisor. Should you have concerns related to my conduct of the survey or research ethics, please contact my supervisor or the University's Ethics Committee.

Yours truly,
Joseph M. THENARA

**Contact details:**
Student Researcher: Joseph M. Thenara (scyjt1@nottingham.edu.cn)
Supervisor: Dr Boon Giin Lee (Boon-Giin.Lee@nottingham.edu.cn)

**University Research Ethics Committee Coordinator,**
Ms Joanna Huang (Joanna.Huang@nottingham.edu.cn)

---

*The content above has been provided verbatim.*

# Appendix C

# Participant Consent Form

**PARTICIPANT CONSENT FORM**

**Project title** Mixed Reality in Education

**Researcher's name** Joseph M. THENARA

**Supervisor's name** Dr Boon Giin Lee

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified, and my personal information and results will remain confidential.
- I understand that data will be stored in accordance with data protection laws.
- I understand that I may contact the researcher or supervisor if I require more information about the research, and that I may contact the Research Ethics Sub-Committee of the University of Nottingham, Ningbo if I wish to make a complaint related to my involvement in the research.

**Signed** (participant)

**Print name** **Date**

**Contact details**

Researcher: Joseph Thenara (scyjt1@nottingham.edu.cn)

Supervisor: Dr Boon Giin Lee (boon-giin.lee@nottingham.edu.cn)

UNNC Research Ethics Sub-Committee Coordinator:
Joanna.Huang@nottingham.edu.cn

---

*The content above has been provided verbatim.*

# Appendix D

# Code Samples

## D.1 Fire Extinguisher Behaviour Script

The following code controls how virtual fire extinguisher behaves, including various animation controls.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class FireExtinguisher_Behaviour : MonoBehaviour
{
    public GameObject _mockParticle;
    public ParticleSystem _foamParticleSystem;

    public bool _debugMode = false;

    [Header("Handle Animation")]
    public Animator m_handleAnimator;
    public string releasedState = "Released";
    public string pressedState = "Pressed";
    public string lockedDownState = "HandleLockedDown";
    public string lockedUpState = "HandleLockedUp";

    [Header("Safety Pin Animation")]
    public GameObject safetyPin;
    public Animator m_pinAnimator;
    public string engagedState = "Engaged";        // Safety pin off.
    public string disengagedState = "Disengaged";   // Unused for now
    private bool isPinOff = false;

    private string baseLayer = "Base Layer.";

    private float minimum = 0.0f;
    private float maximum = 500f;
    private static float t = 0.0f;

    public void ShowParticle()
    {
        if (_debugMode)
        {
            Debug.Log("ShowParticle");
            _mockParticle.SetActive(true);
        }

        if (isPinOff)
        {
```

```
            var emission = _foamParticleSystem.emission;
            emission.enabled = true;
        }
    }

    public void HideParticle()
    {
        if (_debugMode)
        {
            Debug.Log("HideParticle");
            _mockParticle.SetActive(false);
        }

        if (isPinOff)
        {
            var emission = _foamParticleSystem.emission;
            emission.enabled = false;
        }
    }

    public void PullSafetyPin()
    {
        if (!isPinOff)
        {
            StartCoroutine("PullingSafetyPinAnimation");
            isPinOff = true;
        }
    }

    IEnumerator PullingSafetyPinAnimation()
    {
        m_pinAnimator.Play(engagedState);
        yield return new WaitForSeconds(1);
        DisableSafetyPin();
    }

    public void DisableSafetyPin()
    {
        safetyPin.SetActive(false);
    }

    public void PressHandle()
    {
        if (isPinOff)
        {
            m_handleAnimator.Play(pressedState);
        }
        else
        {
            m_handleAnimator.Play(lockedDownState);
        }
    }

    public void ReleaseHandle()
    {
        if (isPinOff)
        {
            m_handleAnimator.Play(releasedState);
        }
        else
        {
            m_handleAnimator.Play(lockedUpState);
```

```
        }
    }


    // Start is called before the first frame update
    void Start()
    {
        // ParticleSystem should not play at the scene start
    var emission =_foamParticleSystem.emission;
    emission.enabled = false;

        // Rename animation state
        releasedState = baseLayer + releasedState;
        pressedState = baseLayer + pressedState;
        engagedState = baseLayer + engagedState;

    }


    void DebugMode(string msg)
    {
        if (_debugMode)
        {
            Debug.Log(msg);
        }
    }

    // Update is called once per frame
    void Update()
    {

    }
}
```

## D.2 Instantiate Fire Script

This script controls the instantiation (spawning) of holographic fire during training mode.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class InstantiateFire : MonoBehaviour
{
    public int quantity = 5;
    public float yPos = -.5f;
    public float spawnRange = 2.5f;
    public GameObject fireObject;


    [Header("Global Variable")]
    public int numberOfActiveFire = 0;
    public int fireKilled = 0;

    public void PutFire()
    {
        for (int i = 0; i < quantity; ++i)
        {
            StartCoroutine("PlayAlarm");
```

```
            var position = new Vector3(Random.Range(-spawnRange, spawnRange),
                yPos, Random.Range(-spawnRange, spawnRange));
            Instantiate(fireObject, position, Quaternion.identity);
            numberOfActiveFire += 1;
        }
    }

    IEnumerator PlayAlarm()
    {
        AudioSource audioSource = GetComponent<AudioSource>();
        audioSource.Play();

        yield return null;
    }
}
```

## D.3 Fire Behaviour Script

This script controls the behaviour of each fire object, including its health point.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class FireBehaviour : MonoBehaviour
{
    public float healthPoint;

    private ParticleSystem fireSystem;

    // Start is called before the first frame update
    void Start()
    {
        fireSystem = GetComponent<ParticleSystem>();
        healthPoint = Random.Range(100.0f, 200.0f);
    }

    // Update is called once per frame
    void Update()
    {
        if (healthPoint <= 0)
        {
            StartCoroutine("FireDeath");
            Debug.Log("Killing fire");
        }
    }

    IEnumerator FireDeath()
    {
        fireSystem.Stop();
        yield return new WaitForSeconds(4.0f);
        gameObject.SetActive(false);

        yield return null;
    }

    private void OnParticleCollision(GameObject other)
    {
```

```
            Debug.Log("Collision: " + other);
        }

}
```

## D.4 Particle Collision Detection Script

This script detects when a particle collide with another object. This is used to reduce the health point of fire based on the number of particles that collide with the fire object.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class ParticleCollisionDetection : MonoBehaviour
{
    private void OnParticleCollision(GameObject other)
    {
        //Debug.Log("Collision: " + other);
        FireBehaviour fb = other.GetComponent<FireBehaviour>();

        fb.healthPoint -= 1.0f;
    }
}
```

## D.5 Back to Main Menu Script

This script originally contains various system-related scripts, but was streamlined to only having the back to main menu function.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Microsoft.MixedReality.Toolkit;
using Microsoft.MixedReality.Toolkit.SceneSystem;
using UnityEngine.SceneManagement;

public class SystemFunctions : MonoBehaviour
{
    IMixedRealitySceneSystem sceneSystem;

    public Object _mainMenuScene;

    private Scene currentScene;

    void Start()
    {
        sceneSystem = MixedRealityToolkit.Instance.GetService<
            IMixedRealitySceneSystem>();
        currentScene = gameObject.scene;

    }

    async public void ReturnToMainMenu()
    {

```

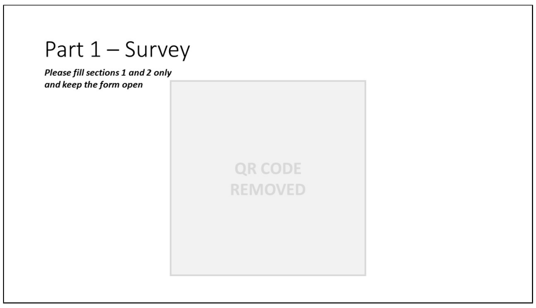
```
        await sceneSystem.LoadContent("00_MainMenu");
        await sceneSystem.UnloadContent(currentScene.name);
    }
}
```

# Appendix E

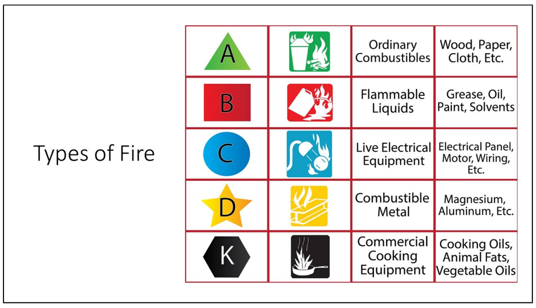
# Fire Safety Training Presentation Slides

The following set of presentation slides were used in the “traditional learning” section of the formal study and data collection session. Note that this set of slides were delivered verbally by the author.


Slide 01

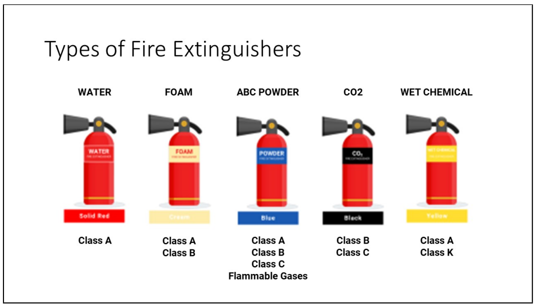



Slide 02

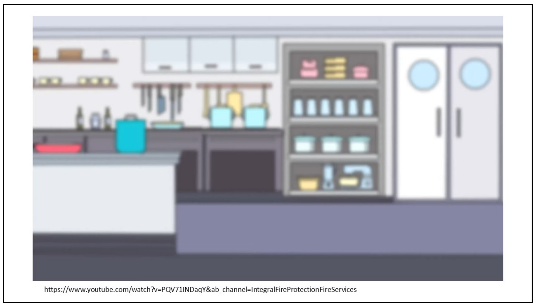



Slide 03

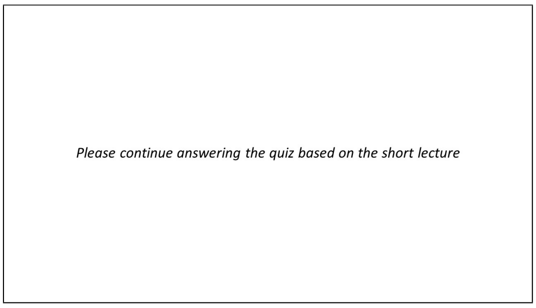

Slide 04




Slide 05




Slide 06




Slide 07


Slide 08

Slide 02 and 08 contains QR codes that takes user to the respective questionnaires. For the purpose of this document, the QR code have been removed to prevent scanning.

Slide 06 contains a brief video about how to use a fire extinguisher. The video is available on YouTube [29].

# Appendix F

# Questionnaires

This section contains the two questionnaires used for the data collection.

## F.1 Questionnaire 1

# Mixed Reality (MR) in Education: Information Collection and Part 1 - Traditional Learning

Thank you for joining the study. This survey will take approximately 5-10 minutes.

This questionnaire will collect your information for analysis purpose and a quiz to measure your learning using traditional teaching method (direct and video instruction)

I have tried making it as simple and straightforward as possible but these are data required for my project, thank you for understanding :)

Please fill up this form honestly, there is no correct or wrong answer (except quiz part)!

Section 1 ...

### Participant Consent

Project Title: Mixed Reality in Education

Researcher's Name: Joseph M. THENARA

Supervisor's Name: Dr Boon Giin Lee

Please give your consent to the following:

1. I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part in the study.

2. I understand the purpose of the research project and my involvement in it.

3. I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.

4. I understand that while information gained during the study may be published, I will not be identified and my personal information will remain confidential.

5. I understand that this study will involve data collection and documentation.

6. I understand that data collected will be stored in accordance with data protection laws.

7. I understand that I may contact the researcher or supervisor if I require more information about the research, and that I may contact the Research Ethics Sub-Committee of the University of Nottingham, Ningbo if I wish to make a complaint related to my involvement in the research.

---
Contact details:

Researcher:
Joseph THENARA (scyjt1@nottingham.edu.cn)

Supervisor:
Dr Boon Giin Lee (boon-giin.lee@nottingham.edu.cn)

University Research Ethics Committee Coordinator:
Ms Joanna Huang (Joanna.Huang@nottingham.edu.cn)

1. By selecting this option, you agree to give consent to the aforementioned *

- ○ Agree

2. Do you consent to having your picture used in my dissertation, if needed? *

If you consent to this, I will take one or two pictures that may be used in my dissertation to illustrate user experience. Don't worry, your face and other identifying features will be removed (blurred/censored).

You can say "NO" to this! :)

- ○ Yes
- ○ No

Section 2 ···

## Participant Information Collection

This information is collected for confirmation and analysis purpose only. Your personal information and sensitive data will, under no circumstances, be released/publicised nor given to any unauthorised parties.

3. Campus ID number *

For confirmation purpose only, e.g. 20219999

Enter your answer

4. Gender *

- Male
- Female
- Prefer not to say

5. Age *

Participants under 18 years of age is not eligible to join this study.

Number must be between 18 ~ 99

6. Year of Study / Status *

- UG Year 01
- UG Year 02
- UG Year 03
- UG Year 04
- Masters/PhD
- Staff Member

7. Faculty *

- Faculty of Science and Engineering (FoSE)
- Faculty of Humanities and Social Sciences (FHSS)
- Nottingham University Business School (NUBS)
- Centre for English Language Education (CELE)

8. Programme *

e.g., "Computer Science with Artificial Intelligence" / "CSAI"

Enter your answer

Section 3 ···

## Quiz: Fire Safety Knowledge (Tr)

Answer these 5 questions based on the knowledge you gained from the traditional teaching session.

9. How many classes of fire are there? *

- 3
- 4
- 5
- 6

10. Which of the following is Step 03 in the PASS method? *

- Squeeze the handle
- Sweep the fire
- Stop the fire
- Squeeze the safety pin

11. Which of the following is **not classified** as a **Class A** fire? *

- Scrap paper
- Wood
- Clothing
- Gasoline

12. The ABC Powder Fire Extinguisher is effective for which classes of fire? *

- Class A, B, and C
- Class A, and B only
- Class A, B, C, and D
- Class B only

13. Carbon dioxide is used in which type of fire extinguisher? *

- CO2 Extinguisher
- ABC Extinguisher
- Foam Extinguisher
- Portable Extinguisher

## F.2 Questionnaire 2

# MR in Education: Part 2 - FTS App Experience Survey

Thank you for joining the study. This survey will take approximately 15-30 minutes.

I have tried making it as simple and straightforward as possible but these are data required for my project, thank you for understanding :)

Please fill up this form honestly, there is no correct or wrong answer (except quiz part)!

Section 1 ...

1

Campus ID number *

For confirmation purpose only, e.g. 20219999

Enter your answer

Section 2 ···

Prior Experiences

This section will ask if you have already use VR/AR/MR devices in the past, and if so, what activities have you done on the platform.

2

Have you experienced any VR / AR / MR devices in the past? *

- Yes
- No

3

If yes, which platforms have you used before? *

Select all that applies;

- Virtual Reality (VR) -- e.g. Oculus or HTC Vive Headsets
- Augmented Reality (AR) -- e.g. phone-based AR
- Mixed Reality (MR) -- e.g. Microsoft HoloLens

4

Which of the following have you tried in VR / AR / MR? *

Select all that applies; If there are any experience outside the stated, please fill up in "Other".

- Education (e.g. Lectures, Human Anatomy, etc.)
- Gaming (e.g. Beat Saber, Half Life Alyx, etc.)
- Entertainment (e.g. 360 Video, Virtual Tour, etc.)
- Training (e.g. Lab equipment training, etc.)
- Simulation (e.g. Surgery simulation, Driving simulation, etc.)
- Other

Section 3 ···

Quiz: Fire Safety Knowledge (MR)

Answer these 5 questions based on the knowledge you gained from the MR-assisted teaching session.

5

Which class is **Flammable Liquid** Fire? *

- Class A
- Class B
- Class C
- Class D
- Class K

6

Which type of fire extinguisher is effective **against Class A, B, and C** fire? *

- ABC Powder Fire Extinguisher
- CO2 Fire Extinguisher
- Foam Fire Extinguisher
- Portable Fire Extinguisher

7

Choose the correct steps for putting out fire. *

- Pull safety pin > Squeeze handle > Aim at the fire > Sweep the fire
- Pull safety pin > Aim at the fire > Squeeze handle > Sweep the fire
- Aim at the fire > Pull safety pin > Sweep the fire > Squeeze handle
- Squeeze handle > Pull safety pin > Sweep the fire > Aim at the fire

8

The CO2 Fire Extinguisher uses which of the following substance? *

- Carbon Dioxide
- Carbon Monoxide
- Nitrogen Oxide
- Hydrogen

9

Which one of these is the cleanest type of extinguisher? *

- ABC Powder Fire Extinguisher
- Foam Fire Extinguisher
- CO2 Fire Extinguisher
- Portable Fire Extinguisher

Section 4 ...

## Overall Experience

This section will look into you overall experience after the experience. It includes your experience along with the experience of using MR (via the HoloLens 2) in the context of Fire Safety Education using the FST App on HoloLens.

10

Please rate your learning motivation by using MR *

Not motivated at all 1 2 3 4 5 Very motivated to learn

11

Please rate your engagement towards the learning content provided *

Not engaging at all 1 2 3 4 5 Very engaging

12

Please rate your attraction towards using MR in education and training *

Not attracted at all 1 2 3 4 5 Very attrracted

13

Please rate how comfortable did you feel while using the HoloLens *

Not comfortable at all 1 2 3 4 5 Very comfortable

14

Please rate your overall satisfaction of the MR learning experience in this study *

Not satisfied at all 1 2 3 4 5 Very satisfied

15

Which aspect of the FST App surprised you the most?

Enter your answer



16

Any other comments regarding your rating, please write below.

Enter your answer

Section 5 ...

## FST App Feedback

This section will look into your specific feedbacks to various aspects to the Fire Safety Training app.

**17**

Attractiveness *

In my opinion, the FST app is generally

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Annoying \| Enjoyable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Bad \| Good | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Unpleasant \| Pleasant | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Unfriendly \| Friendly | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**18**

Efficiency *

To achieve my goals, I consider the product as

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Slow \| Fast | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Inefficient \| Efficient | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Impractical \| Practical | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Cluttered \| Organised | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

19

Perspicuity *

In my opinion, handling and using the FST app are

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Not understandable \| Understandable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Difficult \| Easy to learn | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Complicated \| Easy | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Confusing \| Clear | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

20

Dependability *

In my opinion, the reactions of the FST app to my input and command are

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Unpredictable \| Predictable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Obstructive \| Supportive | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Insecure \| Secure | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Does not meet expectations \| Meet Expectations | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

21

Stimulation *

In my opinion, handling and working with the FST app is

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Not interesting \| Interesting | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Boring \| Exciting | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Inferior \| Valuable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Demotivating \| Motivating | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

22

Novelty *

In my opinion , the idea behind and design of the FST app is

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Dull \| Creative | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Conventional \| Inventive | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Usual \| Leading Edge | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Conservative \| Innovative | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

23

Trust *

Regarding the use of my personal data and information , the FST app is:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Insecure \| Secure | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Untrustworty \| Trustworthy | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Unreliable \| Reliable | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Non transparent \| Transparent | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

24

Acoustics *

The noise during the use is

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Loud \| Quiet | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Dissonant \| Melodic | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Booming \| Dampened | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Piercing \| Soft | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

25

Usefulness *

I consider the possibility of using the product as

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Useless \| Useful | | | | | | | |
| Not Helpful \| Helpful | | | | | | | |
| Not Beneficial \| Beneficial | | | | | | | |
| Not Rewarding \| Rewarding | | | | | | | |

26

Quality of Content *

In my opinion, the information provided in the app are

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Obsolete \| Up to date | | | | | | | |
| Not interesting \| Interesting | | | | | | | |
| Poorly Prepared \| Well Prepared | | | | | | | |
| Incomprehensible \| Comprehensible | | | | | | | |

27

Clarity *

In my opinion, the UI of the product looks

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Poorly \| Well Grouped | | | | | | | |
| Unstructured \| Structured | | | | | | | |
| Disordered \| Ordered | | | | | | | |
| Disorganised \| Organised | | | | | | | |

28

Which feature do you like the most? *

Enter your answer

29

Which feature do you dislike the most? *

Enter your answer

30

What advantage do you find from using MR for education and training? *

Enter your answer

31

What disadvantage do you find from using MR for education and training? *

Enter your answer

32

Other issues, suggestions, or comments?

Enter your answer

Section 6 ...

## Motion Sickness

33

Did you experience Motion Sickness in the session? *

- Yes
- No

34

Approximately how long after using do you start getting motion sickness *

- Less than 1 minute
- Between 1 - 5 minutes
- Between 5 - 15 minutes
- After 15 minutes

35

Please rate your symptoms *

1 = Light discomfort; 5 = Severe discomfort
Please choose N/A if you did not experience the particular symptom

| | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| Headache | | | | | |
| Fatigue | | | | | |
| Eye Strain | | | | | |
| Loss of Balance | | | | | |
| Nausea | | | | | |
| Dizziness | | | | | |
| Sweating | | | | | |
| Disorientation | | | | | |
| General Discomfort | | | | | |
| Stomache awareness / ache | | | | | |
| Vomitting | | | | | |

36

Please mention what may have caused you to feel motion sickness. *

Enter your answer

# Appendix G

# User Manual

This document will provide a guide on how to setup the MR FST application.

## G.1 Prerequisite

This project was developed on the Unity game engine for a Windows Holographic MR platform. Please refer to Appendix A for the hardware and software requirements.

## G.2 Loading the Project

Due to the limitations imposed by Moodle and Microsoft Forms, the project file has been submitted split into parts.

Please download the project files from Microsoft forms. It should contain two files:

- scyjt1.zip.pdf
- scyjt1.z01.pdf

These two files **must** be saved in the same directory.

Once downloaded, please rename the file extension from **.zip.pdf** or **.z01.pdf** into only either **.zip** or **.z01**.

- scyjt1.zip
- scyjt1.z01

If you have succesfully changed the extension, open **scyjt1.zip** and extract the folder named **FTS_220302** into the directory you prefer. This is the Unity project directory and will be loaded into the Unity Editor for building into a solution file.

(Refer to Figure 4.22 for the deployment process into Hololens)

Assuming you have Unity Hub and an appropriate version of Unity Editor installed, open Unity Hub and click on **Add** button on the top.

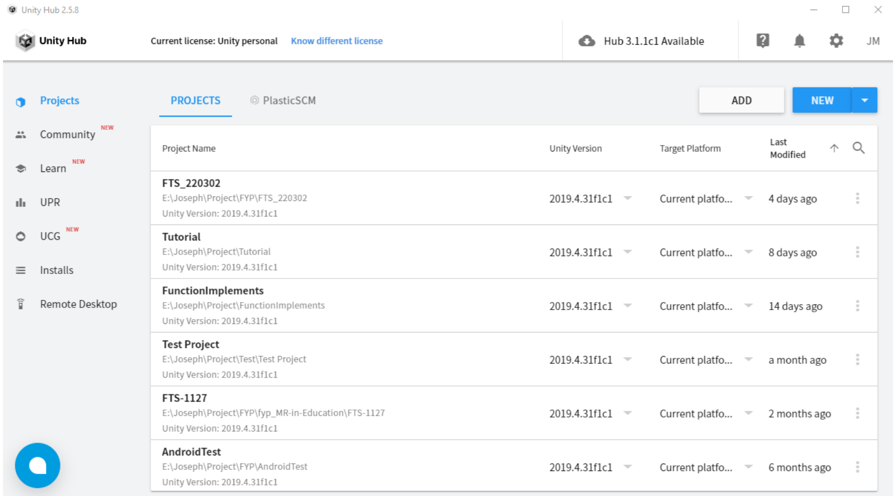



Figure G.1: Unity Hub

(You will need a Unity account and a Unity Personal License to do anything in Unity, please make sure you have done so, if not please check the official Unity documentations online).

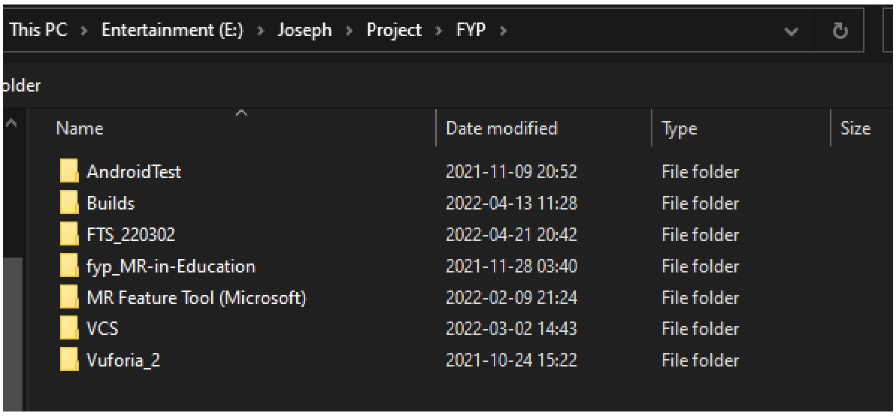



Figure G.2: Select the project directory

Select the **FTS_220302** directory and click on **Select Folder**. The project folder should now be added and is shown in Unity Hub. Open the project in the Unity Editor by clicking on the project name. First time opening a Unity project may take some time, please be patient.

Once loaded, please ensure the following settings are correct.

- File > Build Settings — Platform is set to **Universal Windows Platform**

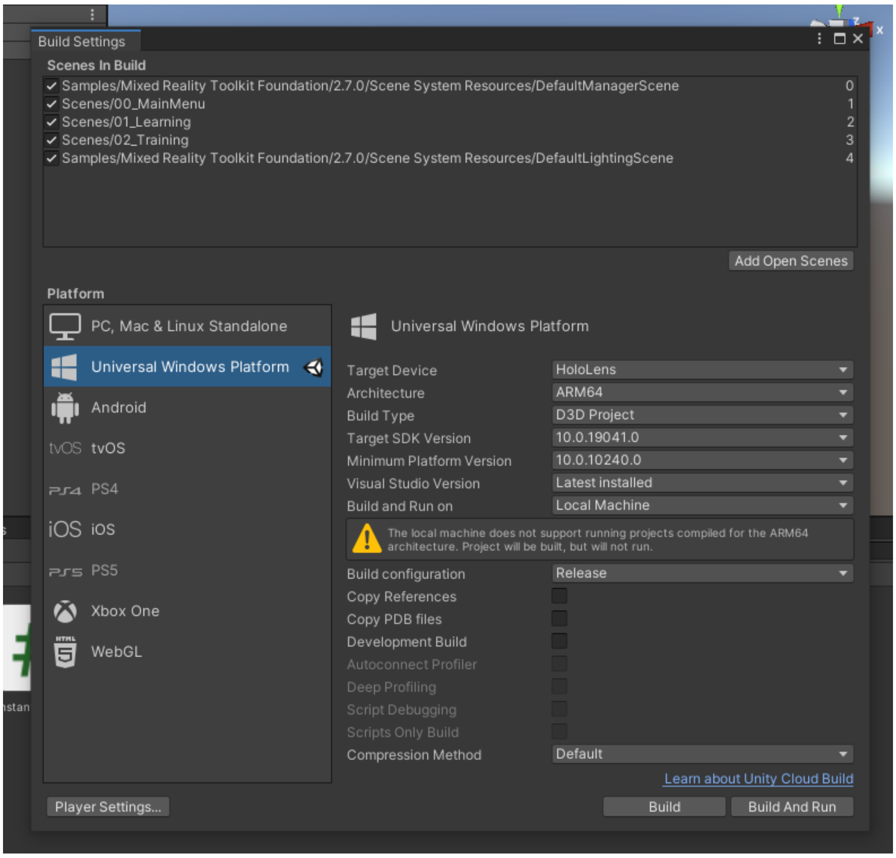



Figure G.3: Build Settings window on Unity

Once confirmed, we are now ready to build the Visual Studio Solution!

## G.3 Building Visual Studio Solution

When you are ready to build, go to **Build Settings** from the previous step. There make sure everything looks the same with Figure G.3. Once ensured, click on **Build** and select a directory where you want the built solution to be. The building should start and may take several minutes.

Once the building is complete, the directory window should appear. If not you can manually navigate to the directory where you built the solution file. Select the filename ending with **.sln**.

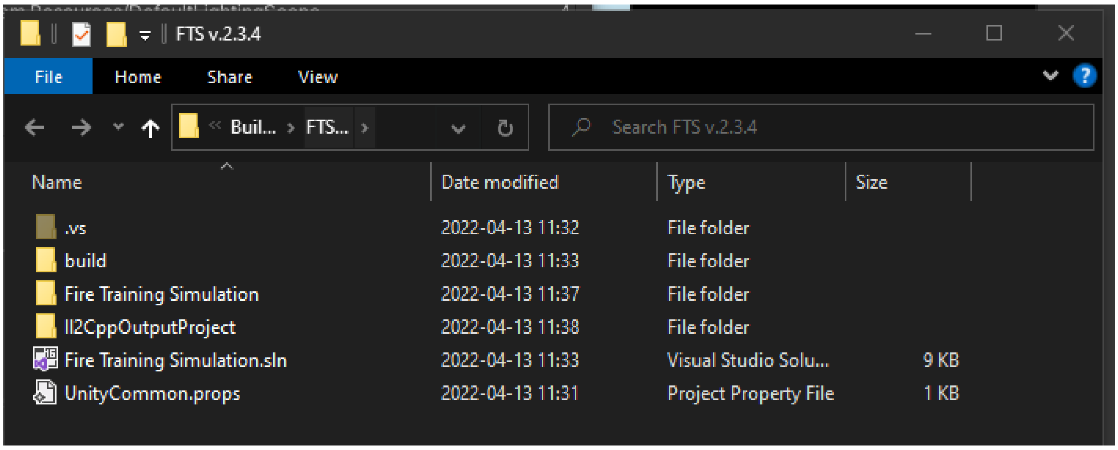



Figure G.4: Solution directory

If you have visual studio installed, it should load up the solution file. Once it opened, the screen may seem blank, which is expected. Ensure that on the top bar of Visual Studio, the setting is set to **Release** and **ARM64**.

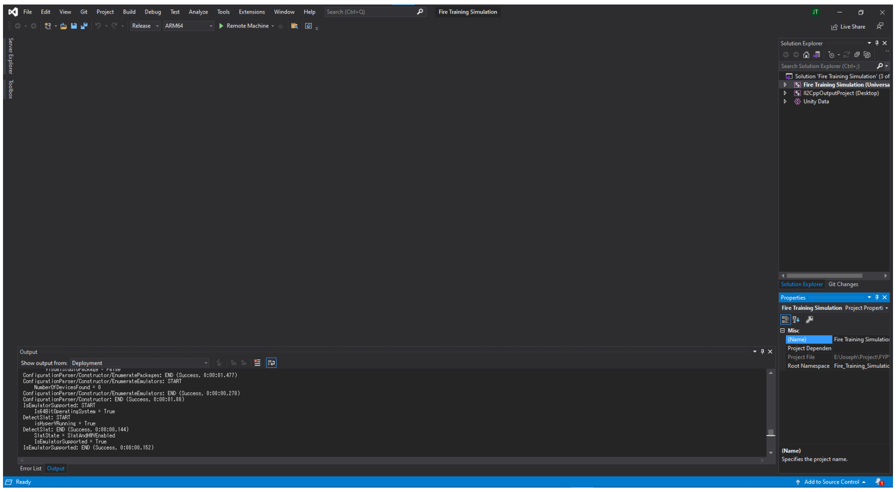


Figure G.5: Solution directory

Now go to **Debug** > *project name* **Debug Properties**.

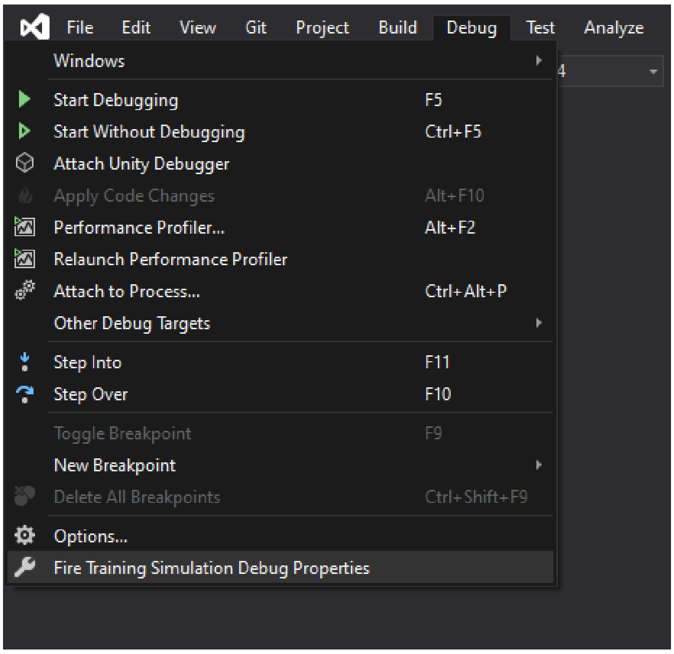



Figure G.6: Solution directory

Go to **Debugging** and enter the Hololens IP Address on the field. Note that the Hololens need to be on the same network with your computer.

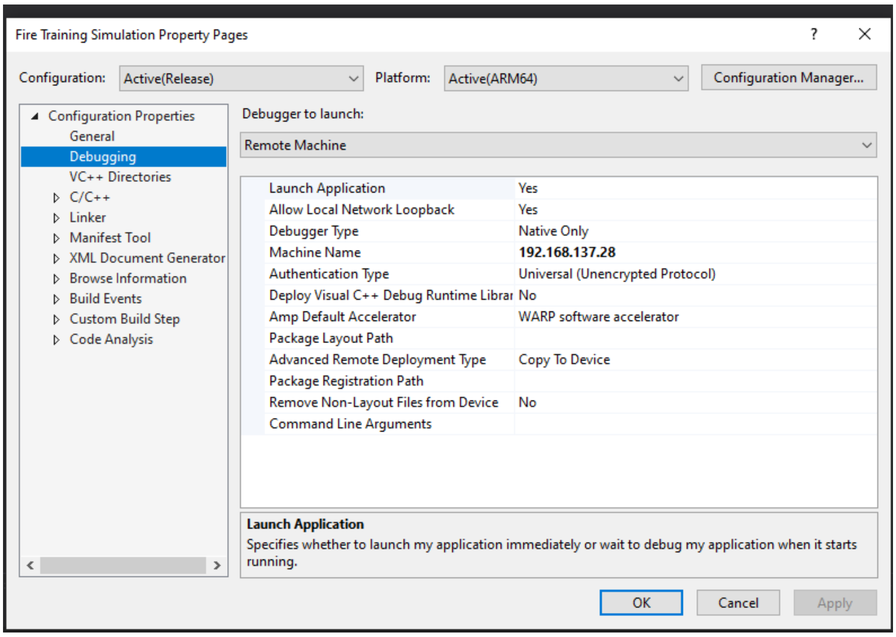



Figure G.7: Solution directory

Once done, if there are no problems, you should be able to deploy the app on hololens by going to **Build** > **Deploy Solution**.

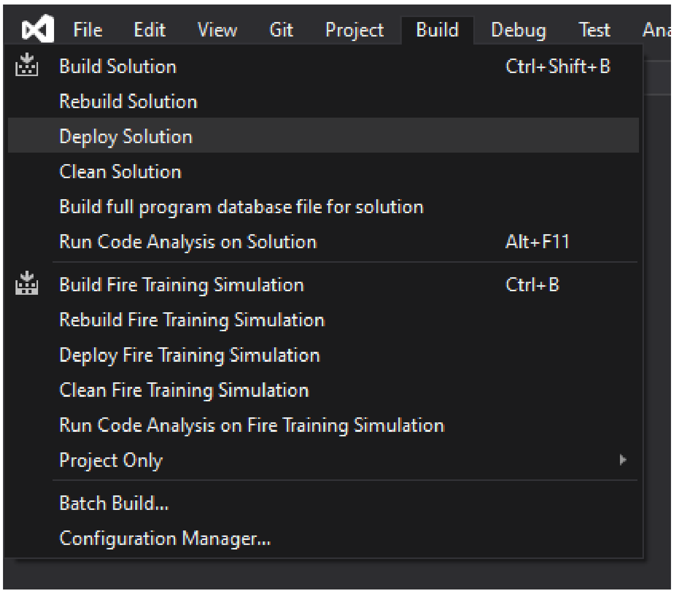



Figure G.8: Solution directory