AR LEARNING APPLICATION OF PARTS OF HUMAN DIGESTIVE SYSTEM BASED ON 3D RECONSTRUCTION OF CT IMAGES

BY

LIM HUI YING

A REPORT

SUBMITTED TO

Universiti Tunku Abdul Rahman

in partial fulfillment of the requirements

for the degree of

BACHELOR OF COMPUTER SCIENCE (HONOURS)

Faculty of Information and Communication Technology

(Kampar Campus)

JAN 2022

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UNIVERSITI TUNKU ABDUL RAHMAN

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FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

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Date: 22/4/2022

SUBMISSION OF FINAL YEAR PROJECT

It is hereby certified that ***Lim Hui Ying*** (ID No: ***18ACB04180***) has completed this final year project entitled "*AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images*" under the supervision of Dr Sayed Ahmad Zikri bin Sayed Aluwee (Supervisor) from the Department of Computer Science, Faculty of Information and Communication Technology.

I understand that University will upload softcopy of my final year project in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

Yours truly,

(*Lim Hui Ying*)

DECLARATION OF ORIGINALITY

I declare that this report entitled **"AR LEARNING APPLICATION OF PARTS OF HUMAN DIGESTIVE SYSTEM BASED ON 3D RECONSTRUCTION OF CT IMAGES"** is my own work except as cited in the references. The report has not been accepted for any degree and is not being submitted concurrently in candidature for any degree or other award.

Signature : 

Name : Lim Hui Ying

Date : 22/4/2022

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and appreciation to my supervisor, Dr Sayed Ahmad Zikri bin Sayed Aluwee for his patient guidance and help in accomplishing my final year project. He is the one who gives me the opportunity to learn and engage in a project of Augmented Reality (AR) Application.

I also wish to thank my friends, who give me a lot of encouragement. Finally, I would like to express my thanks to my parents for their love and support throughout the course.

ABSTRACT

Human anatomy is the study of human body structures and the relationship between them. Anatomy education is crucial in medical and healthcare sectors. However, the traditional anatomy learning method is not efficient and has a lot of limitations. The main problem with traditional learning method is the difficulty of visualising 3D anatomy from 2D images on textbook, and limited access to learning materials. In this proposed project, an effective anatomy learning application using AR technique will be developed. The application is a hybrid mobile application, which supports both iOS and Android devices. The methodology used for developing the application is Rapid Application Development (RAD) based methodology. The three main modules in the application are the AR module, learn anatomy module, and anatomy puzzle game module. The focus of this project is the middle part of the human digestive system, which are the liver, pancreas, stomach, and gall bladder. The project aims to enhance the learning process of undergraduate students on the human digestive system, through visualizing the 3D organs using AR technique. Besides, the application also aims to provide a more realistic-looking and detailed 3D representation of the human digestive system by reconstructing the 3D model based on CT images. Thus, the students can get precise information of the anatomy structures and learn the exact position of each structure of the organs.

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LIST OF ABBREVIATIONS

AR	Augmented Reality
CW	Cognitive Walkthrough
CT	Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
IDE	Integrated Development Environment
MRI	Magnetic Resonance Imaging
MAR	Mobile Augmented Reality
PET	Positron Emission Tomography
RAD	Rapid Application Development
SDK	Software Development Kit
TAR	Tangible Augmented Reality
TUI	Tangible User Interface
3D	Three-Dimensional
2D	Two-Dimensional
VR	Virtual Reality

CHAPTER 1 INTRODUCTION

1.1 Background Information

Human anatomy is the study of human body structures and the relationship between them. It is a fundamental subject in the medical and healthcare sector to understand the human body structures. There are two main types of anatomy, which are macroscopic anatomy and microscopic anatomy. Macroscopic anatomy, also known as gross anatomy, is the study of anatomical structures that are visible to naked eyes. For example, external organs and internal organs. Microscopic anatomy is the study of tissues or cells, which cannot be seen by naked eyes. Conventional anatomy education has a lot of limitation such as difficulties in imagining the 3D anatomy from 2D pictures, lack of interactive element, and difficulties in accessing the learning materials. Augmented reality technology, which is a technology of augmenting the real scene with additional virtual object, can help in anatomy education by overcoming the limitation of the conventional anatomy education.

1.2 Problem Statement and Motivation

Conventional anatomy education has many limitations and weaknesses. Students are facing difficulties when learning the complex anatomy of the human body, especially the human digestive system. They need an alternative learning method that can help them to achieve better learning outcome and increase the efficiency of learning. The following are the major problems that the proposed application will solve and why they need to be solved.

- Difficulty of learning human anatomy through traditional learning methods

  The anatomy of the human body is very complex and difficult to understand. Furthermore, many students are having difficulty visualising the 3D organ from the 2D pictures [1]. This makes learning process slower and inefficient.

- Lack of accuracy and realistic looking of the 3D human anatomy

  Most anatomy learning application is lacking accurate details of the anatomy and does not look realistic because the 3D model is usually created through normal 3D modelling software, without the use of medical image technology. The accuracy of details is important so that the students can get precise

information of the anatomical knowledge and learn the exact position of each part of the organs.

- Lack of interaction in traditional learning methods, which leads to lack of interest in studying human anatomy

  Students lose interest in studying human anatomy when it is difficult for them. Traditional ways of using textbooks are often boring and lack fun. Interaction in learning process is the key to effective learning [1]. However, the traditional teaching methods often lack interaction.

1.3 Project Objectives

The main objective of the proposed project is to develop an educational AR-based application which enhances the learning process of university students in science faculty on human digestive system, by visualizing the 3D organs using AR technique. The 3D organs model will be reconstructed using medical image technology to create an accurate and realistic 3D model. Students are able to learn more effectively when they can interact with the virtual 3D organs while learning the human digestive system. The main objective can be further divided into several sub-objectives as shown below:

- To enhance the learning process and increase learning outcome about the human digestive system through the augmented 3D model

  The application helps students to learn and understand the human digestive system faster and easier, by providing the students with a 3D visualization of the digestive organs in AR mode. The students can view the virtual model at various angles and zoom in and out to observe the anatomy.

- To provide a more realistic-looking 3D representation of the human digestive system

  The 3D model of liver, pancreas, stomach, and gall bladder will be created through 3D reconstruction of CT images. This will create a more realistic-looking and detailed 3D representation of the organs. Therefore, the students can learn the anatomy structures more accurately.

- To provide a more engaging and interactive method of learning human digestive system

The proposed application will stimulate the motivation and interest of students to learn this difficult subject, by providing an interactive learning method. The students can interact with the augmented 3D model to learn the anatomy structures.

1.4 Project Scope and Direction

The proposed project aims to solve the problems faced by undergraduate students in faculty of science when learning human anatomy. The solution proposed to overcome the problems is by developing an effective learning application using AR technique based on the 3D reconstruction of CT datasets. The application developed is a hybrid mobile application, which supports both iOS and Android devices. In this project, the proposed application only focuses on the middle part of the human digestive anatomy, which are the liver, pancreas, stomach, and gall bladder. The project will be further combined with other parts of the human digestive system in the future, to produce a complete human digestive system.

The three main modules in the application are:

- AR module
- Learn anatomy module
- Anatomy puzzle game module

Before using the AR function, the user needs to download the marker from the application. Then, the user can scan the marker and view the AR model to learn the structure of the organs. Then, the user can view the detailed description, play around with the AR model by moving, zooming in and out, or rotating the AR model. Furthermore, there is a learn anatomy module for the user to study and learn about the anatomy structures. In addition, the user can also play a simple anatomy puzzle game for entertainment, and at the same time learn the position of human digestive organs in the human body.

1.5 Impact, Significance and Contribution

By using this educational AR-based application, university students will have a better understanding of human digestive system because they can visualize the anatomy in 3D form, rather than just looking at the 2D images and descriptions in the textbooks or internet. The learning process of students can be improved with the implementation of AR in learning anatomy [1]. Besides that, the application provides a detailed and more realistic 3D model of the human digestive system because the 3D model is reconstructed based on the medical dataset of CT scans. Furthermore, the application helps the students to gain interest in learning human anatomy. It is fun for them to interact with the AR model and observe the organs at various angles. Moreover, the AR application is easy to access and cost-effective. According to a study carried out by Bergman, et al. [2], studying anatomy repeatedly enhances the retainment of the students' knowledge. Therefore, a learning material that is easily accessible is needed. The students only need a mobile phone to install and use the proposed application. Ubiquitous learning through mobile application will help to promote students' understanding and generate long-lasting understanding of the subject [3]. The application is also more cost-effective when compared to other learning materials such as plastic anatomical models and textbooks. In addition, the application also facilitates the incorporation of AR in the anatomy education in university, to create an interactive and better learning environment for undergraduate students.

1.6 Report Organization

The organization of this report are divided into seven chapters. In this chapter, Chapter 1, the background information, problem statement, project objectives, project scope, and contribution of the proposed project are defined.

In Chapter 2, review of the technologies that will be utilized in this project is made. Besides that, the review and critical remarks of the existing work done by other researchers are summarized. Then, a comparison between the reviewed papers and the proposed application in this project is carried out.

In Chapter 3, the methodology and general work procedures of the proposed project are described. Then, the system requirements such as the hardware, software, and the requirement definition such as functional requirements, and non-functional

requirements are specified. Furthermore, the system design is included in this chapter with UML diagrams such as use case diagrams and descriptions, activity diagrams, and sequence diagram. Besides that, the project timeline, implementation issues and challenges are also specified.

In Chapter 4, the preliminary work done is included. The process of image segmentation and 3D reconstruction, as well as the final results of the image segmentation are explained and proved with screenshots.

In Chapter 5, the system implementation is carried out and explained. The steps for setting up Unity and Vuforia Engine, installing modules for Android Build Support and iOS Build Support, importing 3D object to Unity and applying AR to the 3D object are explained thoroughly. Furthermore, the development of each scene in the Unity and the steps to build the application on Android and iOS devices are explained too.

In Chapter 6, the system evaluation and system testing are performed on the application developed. The test cases for each functionality module and their testing results are stated in this chapter. Besides that, the results of the survey carried out to get feedback from the target user are also explained. Then, objectives evaluation is done to evaluate whether the proposed application has achieved all the project objectives successfully.

Finally, in Chapter 7, a conclusion and summary of the entire project is included in the last chapter. The novelties and contributions, as well as the future work of the proposed project are also discussed in this chapter.

CHAPTER 2 LITERATURE REVIEW

2.1 Review of the Technologies

2.1.1 Augmented Reality (AR)

Augmented reality (AR) is a technology which superimposes digital information onto a live view using a device camera. The main difference between augmented reality (AR) and virtual reality (VR) is that AR overlays digital images onto a real picture or video, whereas VR creates a complete immersion 3D experience for the users. The types of augmented reality can be categorised into four main categories, namely marker-based AR, markerless AR, projection-based AR, and superimposition-based AR.

Marker-based AR

Figure 2.1.1.1 Marker-based AR.

Marker-based AR uses an image recognition technique where the user needs to use a camera to scan or point at a visual marker in order to produce the augmented image. The visual marker can be a QR code or any object that acts as the stimuli. In this proposed project, marker-based AR will be used, in which the user is required to scan the marker to display the augmented human digestive organs.

Markerless AR

Figure 2.1.1.2 Markerless-based AR.

Markerless AR, also known as location-based AR, does not require a visual marker. It uses technologies such as GPS, digital compass, accelerometer or other location-tracking technology to produce the augmented reality based on location or speed.

Projection-based AR

Figure 2.1.1.3 Projection-based AR.

Projection-based AR produces an augmented object by projecting artificial light onto surfaces. It can detect users' movement and touch so that users can interact with the projected light.

Superimposition-based AR

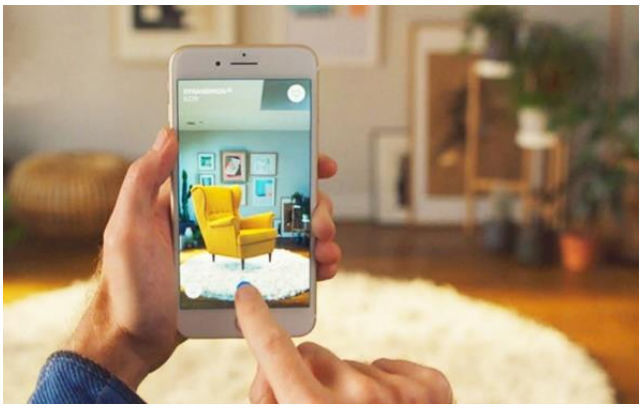


Figure 2.1.1.4 Superimposition-based AR.

Superimposition-based AR uses object recognition, whereby the augmented object replaces the original image completely or partially by overlaying objects. One good example is the Ikea AR app, where the users can place the virtual furniture into their rooms within their device screen. This allows the users to visualize the furniture in their rooms, assisting them to make a buying decision.

Adoption of AR in Education

Nowadays, many educators started to make use of technologies in delivering knowledge [4]. The adoption of AR in education is also becoming more popular as it can solve the limitations of traditional learning methods. According to Rosli, et al. [1], AR can help to develop students' understanding of the human anatomy more efficiently compared to using textbooks. AR provides a fun, interactive, and experiential approach to learning where the students can interact with the 3D objects and view them from different angles. This will increase the interest in learning a subject and motivate them to study it. According to Holzinger, et al. [4], the motivation to learn is an important factor for effective learning. Furthermore, AR application is easily accessible because only a mobile phone is needed. The students can access the AR application on their device wherever they are. AR also makes self-learning and online education more possible as students who have a mobile device can learn by themselves at any time [3]. Besides that, AR is more suitable to be implemented in education compared to VR because AR is much safer as it does not distract the students from the real world, and it also does not cause motion sickness [1]. AR does not require any special and costly equipment too.

2.1.2 Types of Medical Imaging

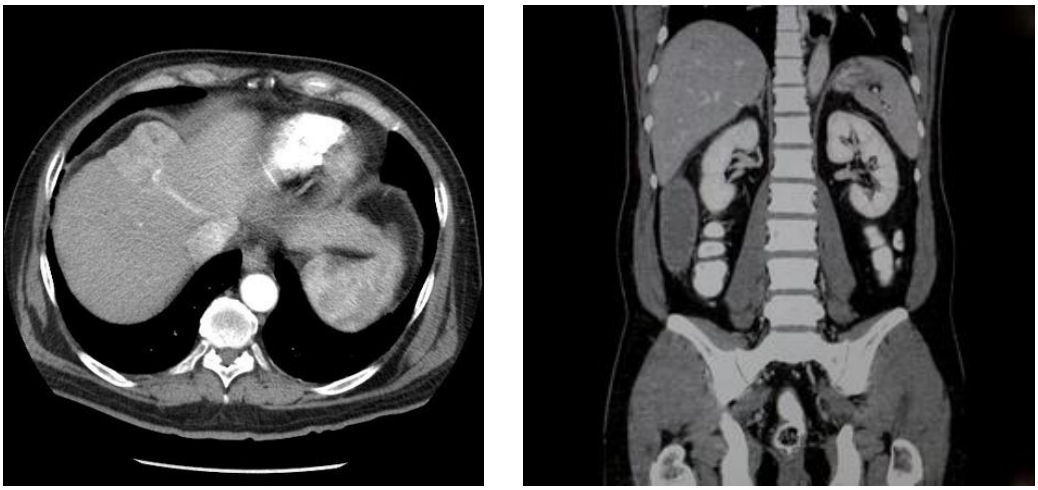


Figure 2.1.2.1 Examples of CT medical images.

Medical imaging is a technique that can show the internal body of a living human. Among all the medical scanning techniques, X-rays, computed tomography (CT), and magnetic resonance imaging (MRI) are the most common and widely available medical imaging techniques. Figure 2.1.2.1 shows some examples of CT medical images. X-rays are painless and rapid diagnostic that generates images of the structures inside the body, especially bones. Dense structures such as bones, calcifications and tumours look lighter on the x-ray film because they have absorbed the radiation, whereas less dense organs and soft tissues look darker because they allow radiation to pass through. CT imaging is a type of imaging that combines x-rays with computer technology to create a more detailed cross-sectional image of the human body. The doctor can use a CT scan to see the shape, size and location of the structures inside the body, such as the bones, organs, blood vessels, tissues and tumours. MRI imaging is another medical imaging technique which provides cross-sectional images of the human body. Unlike CT scans which uses radiation, MRI instrument takes high-resolution photographs of the bones and soft tissues using magnetic fields and a powerful computer [5]. In the proposed application, CT scans of the human digestive organs will be used to reconstruct the virtual 3D models because it provides a detailed cross-sectional image of the human body.

2.1.3 Medical Image Processing and Segmentation

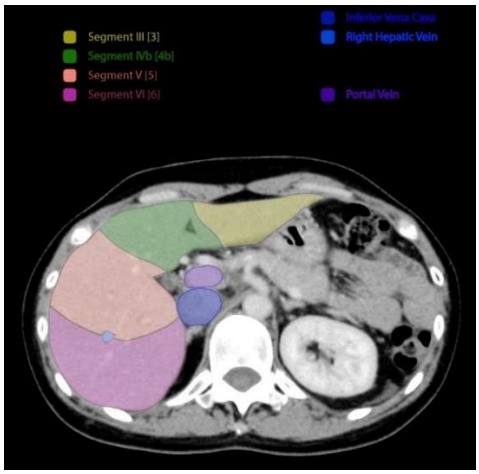


Figure 2.1.3.1 Example of segmentation on liver CT scan image.

Medical image processing is the technique of using the computer to handle digital image datasets of the human body. It is a widely used technique in the medical field for purposes such as diagnosis, surgical planning, researching and many more. Image segmentation is one of the techniques in image processing. It is a process to partition regions in an image, such as the labelling of structures. The segmentation technique is used to trace the borders of the object in the images and produce a 3D contour of the part of the body. Figure 2.1.3.1 shows an example of segmentation applied on liver CT scan image. The image segmentation can be carried out based on thresholding or edge detection, which are both used for identifying the border between the object and the background, or the structure within the same object [6]. Segmentation can be categorized into manual segmentation, semi-automatic segmentation, and automatic segmentation. Through image segmentation, the image is divided into regions. In the proposed project, a semi-automatic segmentation approach is used when reconstructing the 3D brain model based on the MRI scanning. The medical image is divided into several regions and the different region of the brain structure is identified.

2.1.4 3D Reconstruction of Medical Images

3D reconstruction is the process of reconstructing a 3D model based on images. It involves capturing the shape and appearance of real objects. The final output of this process is a 3D model [7]. Using the 3D reconstruction of medical images, the 3D model of the human anatomy can be created more accurately. This is because the 3D reconstruction technique uses the real medical imaging of the body part or internal

organ of the patient at many different angles to reconstruct the 3D model. The input medical dataset is the medical scanning of the body parts or internal organs, such as X-rays, CT scan and MRI scan [8].

2.2 Review of the Existing Systems/Applications

2.2.1 The Augmented Reality for Teaching Thai Students about the Human Heart

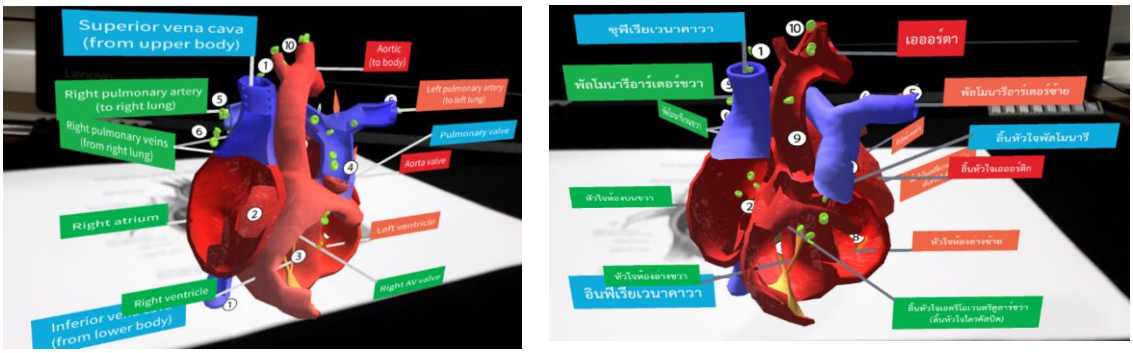


Figure 2.2.1.1 Interface of the mobile application.

Background

The research paper [9] discusses the development of a bilingual AR application for learning human heart anatomy. It uses a marker-based approach to display the augmented heart model by scanning the marker. The application supports handheld Android devices such as smartphones and tablets. The main objective of the paper is to help elementary school students in Thailand in learning human heart anatomy using the AR application. One of the main problems that the authors wanted to solve is the difficulty of Thai students to learn the internal organs through 2D figures in textbooks or on the internet. Besides that, the information on biology obtained from the internet is having a wide range of various contents. This will lead to difficulty to learn and thus, negatively affects the interest of students towards the biology subject. Hence, the application only focuses on the heart, and it uses the AR technique to stimulate students' interest in learning anatomy.

Strengths

One of the strengths of the application is the bilingual setting of teaching the human heart anatomy, which is also the uniqueness of this application. The students can choose to learn the heart anatomy in Thai language or English language. Previously, there are no existing application or research study on the development of AR application about human heart anatomy using Thai language. This research is the first approach of application development that provides a bilingual method of learning the human heart. The bilingual setting helps Thai students who are having difficulties learning anatomy using English language, which is not their dominant language. Besides, each structure of the heart is labelled properly. It also makes use of different colours to differentiate left side and right side of the human heart. In addition, the virtual heart in the application shows the flow of blood circulation with each heartbeat. This will assist the students to understand better the functions of each structure of the heart chambers and structures. The students can learn the direction of blood flow going in and out of the heart.

Weaknesses

The main weakness of this application is the lack of details. The application does not provide detailed information and functions of each structure. It only provides labels for the main structure of the heart and a short description of the direction of blood flow. Another weakness of the application is the 3D virtual heart model is not accurate and realistic. The construction of the heart model is not using medical imaging technologies such as MRI and CT scan. This will affect the accuracy of the heart model and may affect the learning outcome of the students.

Suggestions

The weaknesses of the application can be solved by adding more detailed information of each structure, and its corresponding functions. The descriptions of each structure should be provided clearly. This helps to enhance understanding of the anatomical structure. Besides, medical image technologies can be used for the 3D reconstruction of virtual heart model to obtain a more precise and realistic-looking virtual model. This will offer a realistic learning environment to the students.

In our proposed project, the details, and functions of each structure of the anatomy are provided precisely and clearly. Besides, medical image technology is also used for the 3D reconstruction of the virtual object. The input medical datasets are real CT scan of abdominal organs, which are the liver, pancreas, stomach, and gall bladder.

2.2.2 Utilising Mobile-Augmented Reality for Learning Human Anatomy

Background

The research paper [10] describes the development of a prototype of an AR mobile application, which is given the name Human Anatomy in Mobile Augmented Reality (HuMAR). The application adopted mobile-Augmented Reality (mAR) technology with a marker-based approach. The scope of application is restricted to the lower appendicular skeleton. The main goal is to improve the learning process of students through mobilizing the learning environment regardless of the learner's location and time. Furthermore, the paper also highlighted how mAR can help students to retain their memory in learning complex anatomy. The mobile application is targeted at higher education students because it is found that mAR technology has not been implemented in higher education sufficiently. The major problem to be solved is the difficulty of students in retaining long-lasting information when learning anatomy structure. This problem is due to hard to access learning material such as the anatomical structure from the laboratory and limited physical materials to be borrowed.

Strengths

The main strength of the application is the mobility and ease of access it provides to students for learning anatomy by utilizing the mAR technology. It solves the limitation of access to traditional learning materials. Students can access the learning material wherever and whenever they are using the mobile application. This can help to retain what they have learnt in their memory as they can make revision frequently. Another strength of the application is the user can change the angle view of the 3D bone in 360-degree angles and manipulate the object using finger interactions. Students will have a more exciting learning experience through this tactile learning style. Besides, the content of the application is correct and reliable, which is information obtained from professional anatomists. This includes the bone joint positions, skeletal system

descriptions, bone structure labels, and reference links. Each structure of the bones is labelled precisely. The images of the bone for 3D modelling development are obtained from capturing photos of articulated and non-articulated bones. Moreover, the concept of non-linear navigation enables the user to navigate the content of the application freely and easily without being restricted to a pre-determined path. The user can select every part of the bone and interact with the virtual object. Through the process of interacting with the virtual object, the students can learn the structure of the bone faster.

Weaknesses

The application has a limitation on several aspects. One of them is image smoothness. The image smoothness of the current prototype only reaches a satisfactory level and can be further enhanced. It is very important to have smooth changes of the virtual images so that user can have a better learning experience. Furthermore, the 3D object is not realistic enough. The realism of 3D objects is very critical to create a better and realistic learning environment for the users. This will help them to relate better to the real anatomy and motivate them to learn.

Suggestions

The image smoothness of the virtual objects and content can be improved to make the application better. The 3D object can be modelled by using medical image technology such as using MRI and CT scans to perform the reconstruction of the virtual model. This technique will offer a realistic 3D view of the virtual anatomical structure.

In our proposed project, a realistic 3D organ model is created from the medical datasets using reconstruction of 3D modelling and semi-automated segmentation techniques.

2.2.3 Augmented Reality for the Study of Human Heart Anatomy

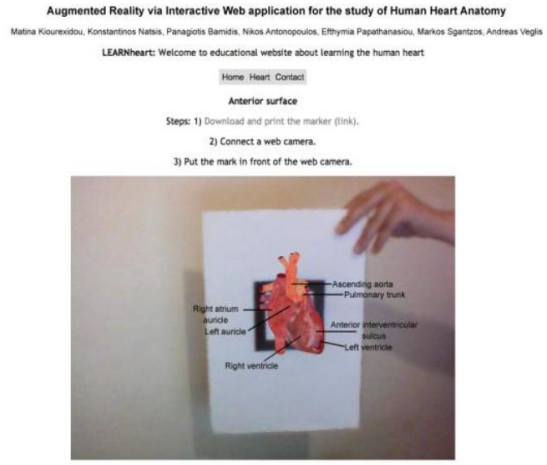


Figure 2.2.3.1 Interface of the web application.

Background

Kiourexidou, et al. [11] discusses the development process of a learning web application, by using the AR technique in displaying the 3D virtual model of a human heart. This web application is free for educational purpose and the target is undergraduate medical students in Greece. The equipment needed is a computer with a web camera to scan the marker, and an internet connection to access the web page. The universities in Greece are facing a problem, that is the dropping of teaching capacity of academic staff while the number of students in the universities keeps on increasing. This problem is causing insufficient teaching capacity, especially in anatomy education. To solve this problem, the authors proposed an alternative method for learning anatomy through the web application. Medical students can learn anatomy by themselves without guidance from university lecturers or tutors. The web application provides an efficient way of self-learning with a combination of medical lectures, virtual anatomical models of the human heart model and laboratory practices in the application.

Strengths

The web application solves the limitation of the traditional teaching method, whereby the students can access the application from home and do self-learning on the anatomy subject. Furthermore, another strength of the research is the gross appearance of the virtual heart can be adjusted to get a more colour realistic view of the heart anatomy. It uses imaging techniques to perform the 3D reconstruction on the CT data. Therefore, the medical students can have a more realistic view of heart anatomy as their learning

material because most of the time the doctors have to identify the structure of organ from medical imaging such as x-ray, MRI scan, and CT scan, which are all in a black and white scale.

Weaknesses

The limitation of the application is the resolution of the web camera, and the computer monitor will affect the full-colour appearance of the virtual heart, which might affect the user experience and the accuracy of a realistic virtual heart. However, they will not cause the virtual object to distort. Another weakness is the 3D model can only be rotated at 40 degrees to the right or left. Although it is more realistic because the heart that is still in cadavers or the human body also can only be viewed at approximately 40-degree in maximum, it is still better for the users to learn anatomy when they can view and rotate the model at 360-degree angles. Furthermore, the application has unclear user instruction. Through the cognitive walkthrough (CW) method of evaluation, the author found out that the guideline to use the web application is not given clear enough, which causes one of the users did not aware of the necessity to download and scan the marker in order for the virtual heart to appear. Other than that, another challenge that the authors are facing is the virtual 3D heart model still consist of some inaccuracy even though several refinements have been done to the model.

Suggestions

The virtual object should be made possible for the users to rotate it at fully 360-degree angles. This will assist the user to learn the 3D anatomy easier as they can rotate and change to various angle view to observe the 3D anatomy. The confusion of using the application can be solved by including a proper and clear user manual. The user manual will guide the user on using the application. Furthermore, adding an introductory video on the main page of the web application will provide further guidance to the user on how to use the application.

In our proposed project, the 3D model can be easily manipulated and rotated at 360-degree angles in different directions. The user can change the angle view freely to observe the anatomy structure. Besides, user guideline will be included in the proposed application so that the user is clear on how to use the application.

2.2.4 An Interactive Augmented Reality System for Learning Anatomy Structure

Background

The core objective of paper [12] is to develop an interactive AR learning system, which helps medical students to learn skull anatomy better and faster by using visual support and tangible augmented reality to enhance spatial memory. This AR system is only supported for computer use and the required equipment are a computer with a web camera and a marker. The main problem stated is the reduction of human anatomy teaching hours in medical education and limitation of traditional anatomy education. Although learning anatomy through dissection has a far better result of understanding compared to learning through the 2D figures in the textbook only, it has a lot of issues that come along with dissection. For example, the storing of cadavers, the lack of cadavers, emotional factors of medical students, and the amount of time required to perform the dissection.

Strengths

The major strength of the system is it provides an interactive learning environment. The system applies Tangible augmented reality (TAR) which enables users to manipulate the virtual 3D skull model using both of their hands intuitively. Tangible user interface (TUI) permits the user to interacts with the virtual objects through the physical environment, whereas TAR is a combination of the AR technique and TUI. The interactive two-hand manipulation significantly improves the interaction between the user and 3D model because the user can manipulate the virtual object freely and easily. The system also allows the user to rotate and view the virtual model at 360-degree angles. Furthermore, the user can assemble and disassemble the 3D skull model to learn the structure better. Accurate pop-up labels and details of each structure is also provided to support the students in identifying the position of each skull structure. Other than that, another strength of the system is the implementation of image technology in creating the 3D visualisation of the anatomical model of the skull. This provides a more realistic view of the skull anatomy. Therefore, the user can gain knowledge more accurately.

Weaknesses

The weakness of the system is it does not contain clear instructions to use the system. Beginner users might get confused and do not know how to manipulate the virtual object when they are unfamiliar with the AR technology used.

Suggestions

The system should include clear guidance to users on how to use the system, especially when many users are still unfamiliar with AR technology.

In our proposed project, brief and clear instruction will be provided in the proposed application. This will guide the user on how to use the application correctly and avoid confusion.

2.2.5 Human Anatomy Learning Systems Using Augmented Reality on Mobile Application

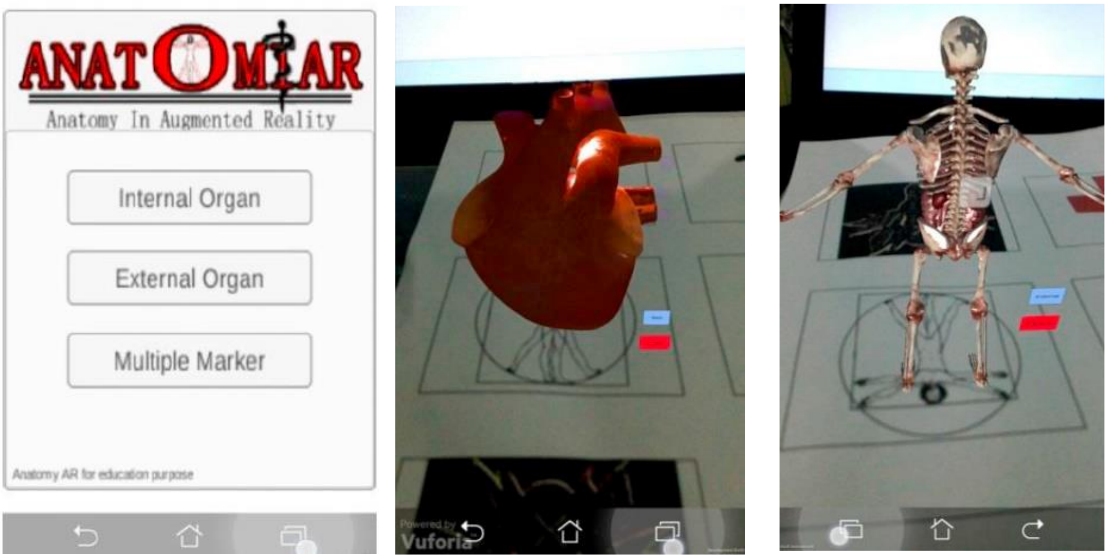


Figure 2.2.5.1 Interface of the mobile application AnatomyAR.

Background

In the paper, Kurniawan, et al. [13] discusses the development of a human anatomy learning system which is a marker-based AR mobile application. One critical problem that the authors wanted to solve is the difficulty of visualizing the body anatomy from 2D images on textbook into the form of 3D, which is the major problem of the

traditional learning method using textbooks. Another traditional method of learning anatomy, which is cadaver surgery, is more effective compared to textbooks because the students are able to see the actual internal organ and have a hands-on experience on a human body. However, it is very costly and complicated to be carried out.

Strengths

The main strength is the application provides many choices to the user for learning various organs of the human body. The user can view the human body in two layers, which is the external layer of the skin and also the internal organs. The details of each organ are shown when the user clicks on the virtual 3D model. The ability to view both the outer and inner layer of the human body leads to a better understanding of the human body anatomy. Another strength of the application is the touch features, whereby the user can manipulate the virtual object to view it from various angles. Furthermore, the user can zoom in and out of the virtual model to observe the details of the organ.

Weaknesses

The application contains several weaknesses. One of the weaknesses is the application does not provide labels of each part of the organs or skeleton on the 3D model. The label is only shown on the 2D images that are appeared after the user clicks on the 3D model. Besides, the user interface design is also the weakness of the application, because the font size is too small and difficult to read. Furthermore, the application does not provide any user manual or guideline on how to use and navigate the application. The users will feel confusing when using the application.

Suggestions

The weaknesses of the application can be resolved by several methods. The application should provide labels of each part of the anatomy structure on the 3D model so that it is more convenient for users to learn the name of each part of the anatomy. Besides, the user interface should be improved by enlarging the font size to an appropriate size for reading. Furthermore, the application can be further improved by adding speech to explain the descriptions of the anatomy structure. In addition, the application should provide clearer guidance for teaching the user on using the application, such as adding a short tutorial to guide beginner users.

In our proposed application, the users can click on any part of the 3D model to view its name and description. Proper instructions are also provided for the users to learn how to use the application. Besides, the user interface will be carefully designed so that it is easy to use and easy to read.

2.3 Comparison between Existing Systems and Proposed Application

Title	The Augmented Reality for Teaching Thai Students about the Human Heart	Utilising Mobile-Augmented Reality for Learning Human Anatomy	Augmented Reality for the Study of Human Heart Anatomy	Proposed Application
Platform	Android mobile devices	Android mobile devices	Web app, only for computer use	Android and iOS mobile devices
Focused body part	Heart	Lower appendicular skeleton	Heart	Liver, stomach, pancreas, gall bladder
Equipment	Mobile devices, back camera, marker	Tablet, back camera, marker	Computer, web camera, Internet connection, marker	Mobile devices, back camera, marker
Target audience	Elementary school Thai students	Higher education students	University medical students	University students
Use of medical image technology	X	X	√	√
Features:				
Rotate model at 360 degrees	√	√	Only 40 degrees to the right or left	√
Zoom in / out model	√	√	X	√
Move model	X	√	X	√
Select structure part of model	X	√	X	√
Description of structure part	X	√	X	√
Anatomy puzzle game	X	X	X	√
Language used	Thai, English	English	Greek, English	English

Table 2.3.1 Comparison between existing systems and proposed application (Part I).

Title	An Interactive Augmented Reality System for Learning Anatomy Structure	Human Anatomy Learning Systems Using Augmented Reality on Mobile Application	Proposed Application
Platform	System in computer	Android mobile devices	Android and iOS mobile devices
Focused body part	Skull	Entire human body anatomy in two layers – the outer layer of the skin, and internal organs	Liver, stomach, pancreas, gall bladder
Equipment	Computer, web camera, marker	Mobile device, back camera, marker	Mobile devices, back camera, marker
Target audience	University medical students	High school students and medical students	University students
Use of medical image technology	√	X	√
Features:			
Rotate model at 360 degrees	√	√	√
Zoom in / out model	√	√	√
Move model	√	X	√
Select structure part of model	√	√	√
Description of structure part	√	√	√
Anatomy puzzle game	X	X	√
Language used	English	English	English

Table 2.3.2 Comparison between existing systems and proposed application (Part II).

2.4 Concluding Remark

In this chapter, the technologies needed for the proposed project is reviewed. The main technologies involved in this project is the AR technology, medical image segmentation, and 3D reconstruction of medical images. Besides that, a few existing systems that are similar to the proposed application are also reviewed. Finally, a comparison between the reviewed systems and the proposed application in this project is carried out to analyse the strengths and weaknesses, and to discover possible features that can be further applied in the proposed application.

CHAPTER 3 SYSTEM METHODOLOGY/APPROACH

3.1 Methodology and General Work Procedures

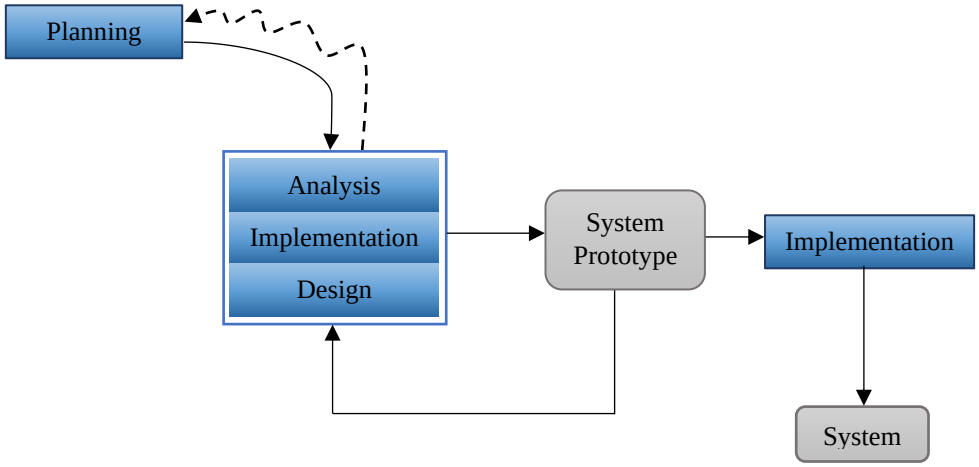


Figure 3.1.1 Methodology used in the proposed project.

The methodology used for the proposed project is the Rapid Application Development (RAD) based methodology, using the prototyping development. Figure 3.1.1 shows the overall sequence of development phases applied in the proposed project. RAD is a development methodology that emphasizes rapid prototype releases and iterations. The main reason for choosing this methodology is it will reduce the development time and speed up the product delivery. RAD is suitable for small-to-medium scale projects. The reduced amount of extensive pre-planning enables faster delivery of the product and also easier to make changes. Therefore, it is suitable for the proposed project since it is a small-scale project and requires fast delivery of the product in a short time. Besides that, the use of prototypes minimizes the project risk by breaking down the project into smaller segments. This makes the project easier to accommodate the changing requirements during the development process. It also provides high flexibility because adjustments can be done easily throughout the process [14].

The first phase to be carried out is the planning phase. In this phase, the project objective, scope and direction are determined. Relevant information is collected to have a basic understanding of the system and requirements. Other than that, the project timeline and work plan are also produced. After that, the basic analysis, design and implementation for the first prototype are started. The analysis, design and implementation phases are carried out concurrently. In analysis phase, the tools and technologies to be used in this

project are studied. The main tools used in this project are 3D Slicer, Unity with Vuforia engine and Visual Studio Code. The technologies involved in this project are the Augmented Reality (AR) technology and 3D reconstruction of medical images. Besides that, a few existing systems are being reviewed and analysed. The features, strengths and weaknesses of each system reviewed are studied and compared. The strengths and improvements that can be applied on this project are also gathered during this phase. In the design phase, the system designs, such as the use case diagrams, activity diagrams and sequence diagram are created. In implementation phase, the 3D model is being created using 3D reconstruction of medical images techniques in 3D Slicer and the system is also started being developed using Unity with Vuforia engine and C# scripts. Besides that, testing is also conducted throughout this phase to refine the prototype. These three phases, i.e., analysis, design and implementation phases, are carried out repeatedly in a cycle. Each cycle will produce a prototype. The prototype is then improved iteratively until the final product is completed.

3.2 System Requirements

3.2.1 Hardware

The hardware used in this project are a Windows laptop, a macOS virtual machine, an Android mobile device and an iOS mobile device. The Windows laptop is used for development of the proposed application such as performing segmentation and 3D reconstruction of the CT images, applying AR technology on the 3D model, developing the application using Unity, and building the application on Android mobile device. Then, the macOS virtual machine is needed for building the application on iOS mobile device. The mobile devices are used for testing the application during the development process.

Description	**Specifications**
Model	Acer Aspire E5-576G
Processor	Intel Core i5-8250U
Operating System	Windows 10
System Type	64-bit Operating System, x64-based processor
Graphic	NVIDIA GeForce MX150

Memory	8.00 GB
Storage	1TB SATA HDD

Table 3.2.1.1 Specifications of Windows laptop.

Description	**Specifications**
Model	Mac (virtual machine)
Processor	Virtualization engine - virtualize Intel VT-x/EPT or AMD-V/RVI, processor speed - 2.68 GHz
Operating System	macOS Monterey, version 12.3.1
System Type	64-bit Operating System, x64-based processor
Graphic	Display 3 MB
Memory	5.3 GB
Storage	110 GB SATA HDD

Table 3.2.1.2 Specifications of macOS virtual machine.

Description	**Specifications**
Name	OPPO R9s
Model	CPH1607
ColorOS version	V3.0.0i
Android version	6.0.1
Processor	Qualcomm MSM8953 Octa Core
RAM	4.0 GB
ROM	64 GB

Table 3.2.1.3 Specifications of Android mobile device.

Description	**Specifications**
Name	iPhone 6s
Model	A1688
iOS version	iOS 15.4.1
Processor	1.85GHz dual-core 64-bit ARMv8-A “Twister”
RAM	2 GB

ROM	32 GB

Table 3.2.1.4 Specifications of iOS mobile device.

3.2.2 Software

The main software used in this project are 3D Slicer to perform image segmentation and reconstruction of 3D model, and Unity with Vuforia Engine to apply AR onto the 3D object and to develop the application.

3D Slicer

Figure 3.2.2.1 3D Slicer logo.

3D Slicer is a free and open-source software that can runs on different operating systems. It is a popular software package that is commonly used for medical image processing, visualization, and imaging research. It supports multi-modality imaging. For example, CT imaging, MRI imaging, ultrasound imaging, X-ray microscopy and nuclear medicine. Many data sets are supported, such as images, segmentations, transformations, and surfaces, in either 2D, 3D or 4D form. The two main types of data that can be loaded to 3D Slicer is DICOM data and non-DICOM data [15]. DICOM is the international standard to communicate and handle medical images and related data. Non-DICOM data is any other types of data that are not DICOM files. It includes images, models, tables and point lists. In the proposed project, 3D Slicer will be used for the image segmentation process. The liver, stomach, pancreas and gall bladder are segmented using manual and semi-automatic approach.

Vuforia Engine in Unity

Figure 3.2.2.2 Unity and Vuforia engine.

Unity Editor is a widely used authoring platform to build AR experiences for mobile devices and digital eyewear [16]. Vuforia Engine is a software development kit (SDK) for developing AR applications for Android, iOS, Lumin and UWP. It can be added to the Unity project. Besides, the features from the Vuforia Engine can also be added to the project [17]. In the proposed project, Unity with Vuforia Engine package will be used for creating AR in the mobile application.

Xcode

Figure 3.2.2.3 Xcode logo.

Xcode is an IDE from Apple which is used to build software for Apple products [18]. Xcode is a prerequisite for building Unity game on iOS devices. When the Unity iOS game is built, an Xcode project is opened and generated automatically. In the proposed project, Xcode 13 is used for supporting the build of Unity game on iOS devices.

Microsoft Visual Studio 2019

Figure 3.2.2.4 Microsoft Visual Studio logo.

Microsoft Visual Studio is a comprehensive integrated development environment (IDE) from Microsoft for developing applications and programs [19]. It supports many programming languages such as C, C++, C#, JavaScript, etc. In the proposed project, Visual Studio 2019 is used to create C# script for the development of the application.

3.3 Requirement Definition

3.3.1 Functional Requirements

Display AR

a. The system shall allow users to download the target marker.
b. The system shall allow users to scan the target marker.
c. The system shall allow user to turn on or turn off the flashlight.
d. The system shall display the AR model after the target marker is detected.

Interact with AR

a. The system shall allow users to move the AR model using drag gesture.
b. The system shall allow users to zoom in and zoom out the AR model using pinch gesture.
c. The system shall allow users to rotate the AR model using rotate gesture.
d. The system shall allow users to start or stop the horizontal auto-rotate function on the AR model.
e. The system shall allow users to start or stop the vertical auto-rotate function on the AR model.

f. The system shall allow users to enable or disable organ segmentation function.
g. The system shall allow users to select on the structure part of the AR model by tap gesture.
h. The system shall highlight the selected part and display the selected part name.
i. The system shall allow users to view the information of the selected part.
j. The system shall allow users to show or hide different structure parts of the AR model.

Learn Anatomy

a. The system shall allow users to select on desired topic to be viewed.
b. The system shall display detailed information of the selected topic.
c. The system shall allow users to zoom in and out the anatomy structure image.
d. The system shall allow users to open the video player to play a video of the selected topic.
e. The system shall allow users to play, pause, restart the video, as well as to drag the time slider to change the current video frame playing.
f. The system shall allow users to enter or exit full screen mode.

Play Anatomy Puzzle Game

a. The system shall start and display a stopwatch that calculates the time used to complete the anatomy puzzle game once the user enters the game.
b. The system shall allow users to drag and drop the anatomy puzzle to desired position.
c. The system shall let the anatomy puzzle to remain at the position in the case of users dragging the puzzle to the correct position.
d. The system shall return the anatomy puzzle to the initial position in the case of users dragging the puzzle to the wrong position.
e. The system shall display a success panel with the time used to complete the game, when the users successfully completed the puzzle game.

f. The system shall allow users to play again the anatomy puzzle game after completing the game.
g. The system shall allow users to exit the anatomy puzzle game after completing the game.

3.3.2 Non-functional Requirements

Operational

a. The system should operate on Android and iOS mobile devices.
b. The system should be able to access the mobile device camera.
c. The system should be able to access the sensor features of the mobile devices, such as the accelerometer.

Performance

a. The system should be able to detect and display the AR model in different environmental condition such as low brightness.
b. The system should be able to detect and display the AR model in less than 1 second.
c. The system should provide response to user actions in less than 5 seconds.
d. The system should navigate the users smoothly within the application.

Security

a. Security should be provided within the existing architecture.
b. The system should direct users to the correct google drive link to download the target marker.

3.4 System Design / Overviews

3.4.1 Use Case Diagram

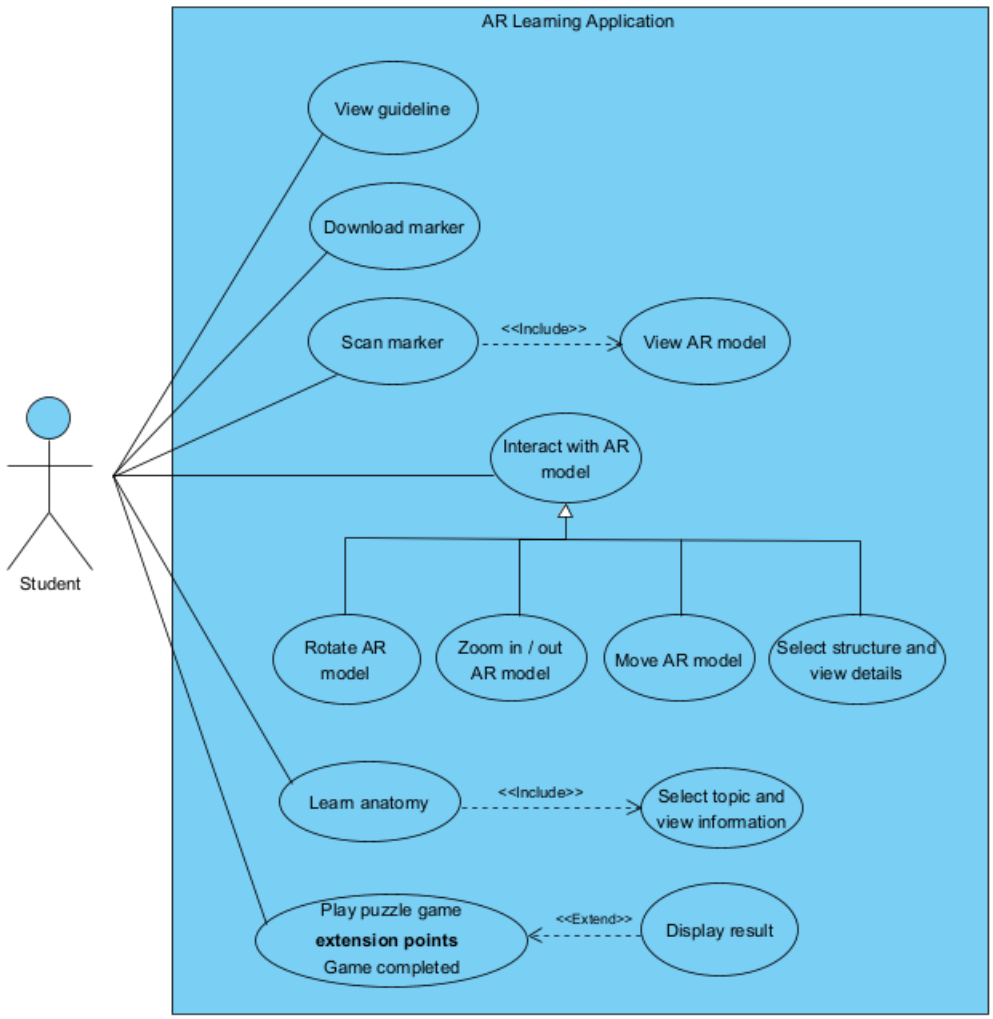


Figure 3.4.1.1 Use case diagram of the proposed application.

Figure 3.4.1.1 above shows the use case diagram of the proposed application. The student is the actor that interacts with the AR application. Firstly, the user can view guideline on how to use the AR application. The student can download the marker image from the application and scan the marker using the camera of his or her mobile phone. After successfully detected the marker, the 3D AR model will pop out on the screen. The student is allowed to interact with the AR model, such as rotating the model at 360 degrees in different directions, zoom in and zoom out the model, and moving the AR model, so that they can observe the anatomy from various angles. When the student selects one structure part of the model, the name and description of the structure part can be viewed. Other than that, the student can learn the anatomy of the human digestive system by selecting the topic and viewing the information of the selected topic. In

addition, the student can also play a simple anatomy puzzle game to learn about the position of human digestive organs in human body. After the game is completed, the result obtained will be generated and displayed.

3.4.2 Use Case Descriptions

<table>
<tr><td>Use Case Name: Interact with AR model</td><td>ID: 1</td><td>Importance Level: High</td></tr>
<tr><td>Primary Actor: Student</td><td colspan="2">Use Case Type: Detail, Essential</td></tr>
<tr><td colspan="3">Stakeholders and Interests:
Student – wants to rotate, zoom in/out, move, select structure of the 3D model and view details.</td></tr>
<tr><td colspan="3">Brief Description: This use case depicts how the student rotates, zooms in/out, moves, selects structure of the 3D model and view details.</td></tr>
<tr><td colspan="3">Trigger: Student wants to rotate, zoom in/out, move, select structure of the 3D model and view details.
Type: External</td></tr>
<tr><td colspan="3">Relationships:
Association: Student
Include: -
Extend: -
Generalization: Rotate AR model, Zoom in/out AR model, Move AR model, Select structure and view details.</td></tr>
<tr><td colspan="3">Normal Flow of Events:
1. The student clicks on the play AR button.
2. The application prompts the student to allow camera access.
3. The student make selection on camera access permission.
4. Once camera access is allowed, the application displays guideline on how to display the AR and interact with the AR model.
5. The student downloads the marker.
6. The student uses the phone camera to scan the marker.
7. Once the marker is detected, the application displays the AR model of the human digestive anatomy.
8. The student interacts with the AR model.
If the student rotates the AR model,
the AR model rotates.
If the student pinches in/out the AR model,</td></tr>
</table>

the AR model zooms in/out. If the student drags and drops the AR model, the AR model moves to the new position. If the student taps on one of the organ structures, the structure is selected, and the student is able to view the details of the selected structure.
SubFlows: N/A
Alternate/Exceptional Flows: 4a. The camera access is denied, the application redirects the student to home page. 5a. The marker is not detected, the student scans the marker again.

Table 3.4.2.1 Use case description of "Interact with AR Model" use case.

Use Case Name: Learn anatomy	ID: 2	Importance Level: Medium
Primary Actor: Student	Use Case Type: Detail, Essential	
Stakeholders and Interests: Student – wants to learn anatomy.		
Brief Description: This use case depicts how the student can learn anatomy using the application.		
Trigger: The student wants to learn anatomy. Type: External		
Relationships: Association: Student Include: Select topic and view information Extend: - Generalization: -		
Normal Flow of Events: 1. The student clicks on the learn anatomy button. 2. The application displays a list of all topics about the human digestive system anatomy. 3. The student selects a topic. 4. The application retrieves and displays the information of the selected anatomy topic.		
SubFlows: N/A		
Alternate/Exceptional Flows: N/A		

Table 3.4.2.2 Use case description of "Learn Anatomy" use case.

Use Case Name: Play Anatomy Puzzle Game	ID: 3	Importance Level: Medium
Primary Actor: Student	Use Case Type: Detail, Essential	
Stakeholders and Interests: Student – wants to play anatomy puzzle game for entertainment, and at the same time learning the position of human digestive organs in the human body.		
Brief Description: This use case depicts how the student plays an anatomy puzzle game using the application.		
Trigger: The student wants to play an anatomy puzzle game. Type: External		
Relationships: Association: Student Include: - Extend: Display Result Generalization: -		
Normal Flow of Events: 1. The student clicks on the puzzle game button. 2. The application displays the anatomy puzzle game. 3. The student drags and drops the anatomy puzzle onto the human body. 4. The application checks the puzzle's position. 5. Repeat steps 3 - 4 until all the anatomy puzzle is dragged to the correct position. 6. The application generates and displays the result obtained by students.		
SubFlows: N/A		
Alternate/Exceptional Flows: 5a. The anatomy puzzle's position is incorrect, the puzzle returns to its original position.		

Table 3.4.2.3 Use case description of "Play Anatomy Puzzle Game" use case.

3.4.3 Activity Diagrams

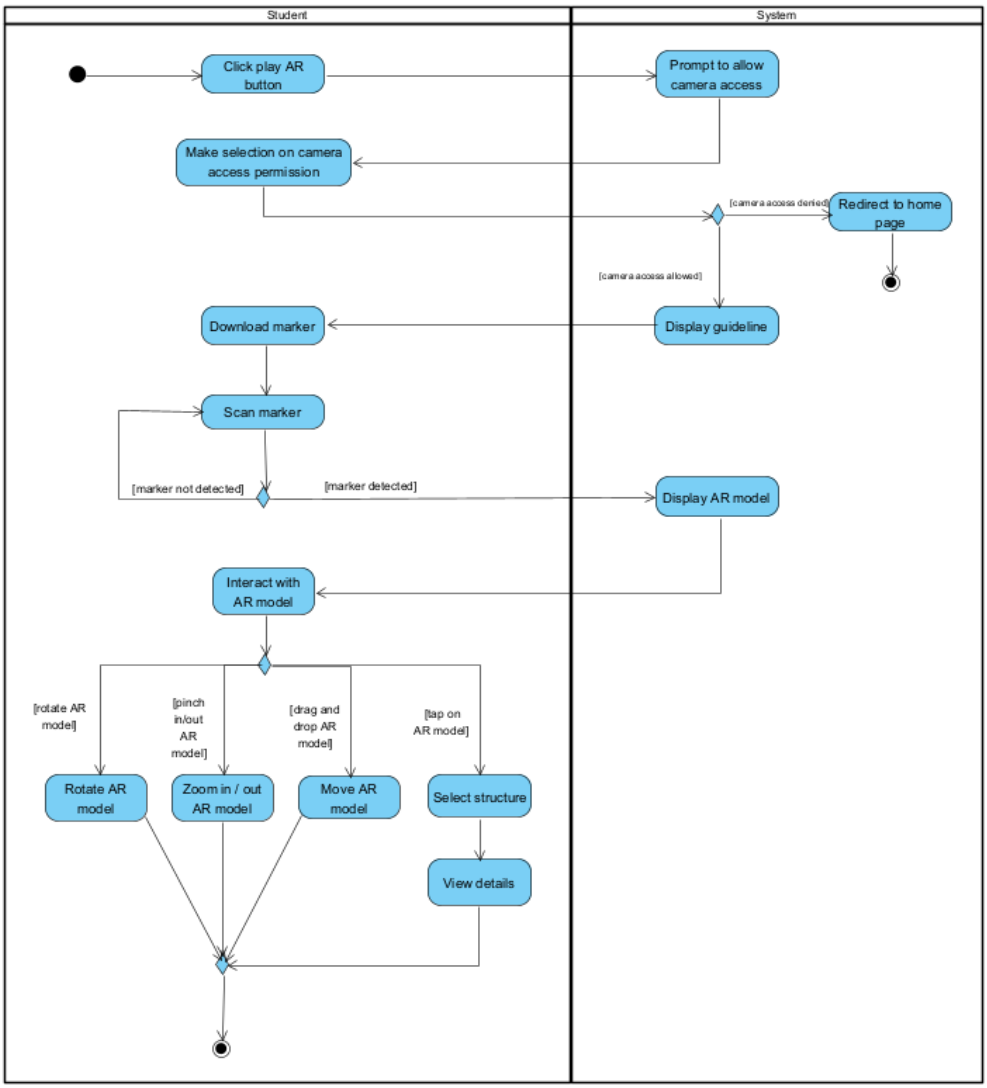


Figure 3.4.3.1 Activity diagram of “Interact with AR Model” use case.

The student initiates the activity by clicking on the play AR button at the home page. The system will immediately prompt the student to allow camera access. The student makes a selection on the camera access permission. If the student denies the camera access, the system will redirect the student back to the home page. If the student allows the camera access, then the guideline on how to display the AR and interact with the AR model will be displayed. Then, the student downloads the marker and scans the marker. The student must scan the marker until it is detected. Once the marker is detected, the system will display the AR model of the human digestive anatomy. Then, the student can start to interact with the AR model such as rotating the AR model, zooming in/out AR model, moving the AR model, and selecting the organ structure to view its details.

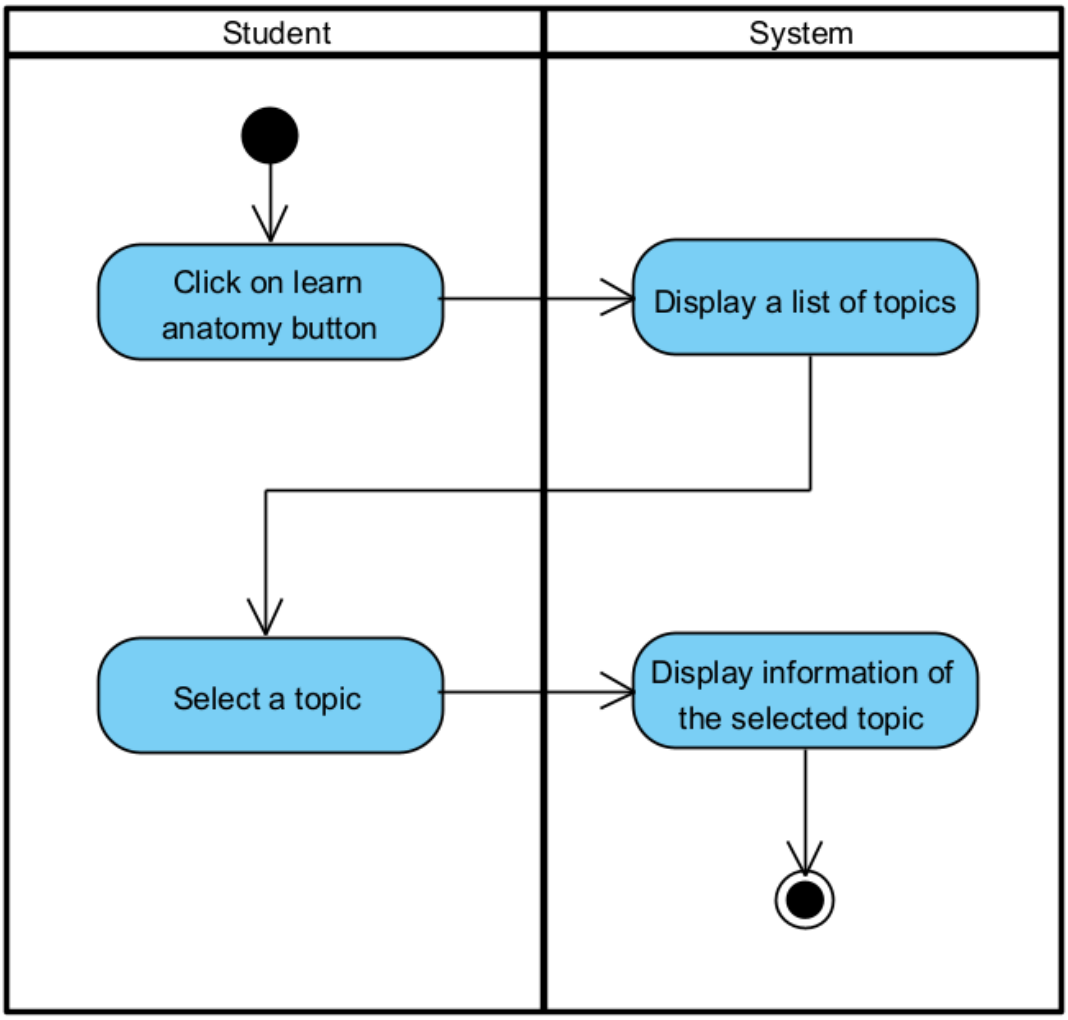


Figure 3.4.3.2 Activity diagram of “Learn Anatomy” use case.

The student initiates the activity by clicking on the learn anatomy button at the home page. Then, a list of topics about the human digestive system anatomy will be displayed. The student is required to select a topic. After that, the information of the selected anatomy topic is displayed.

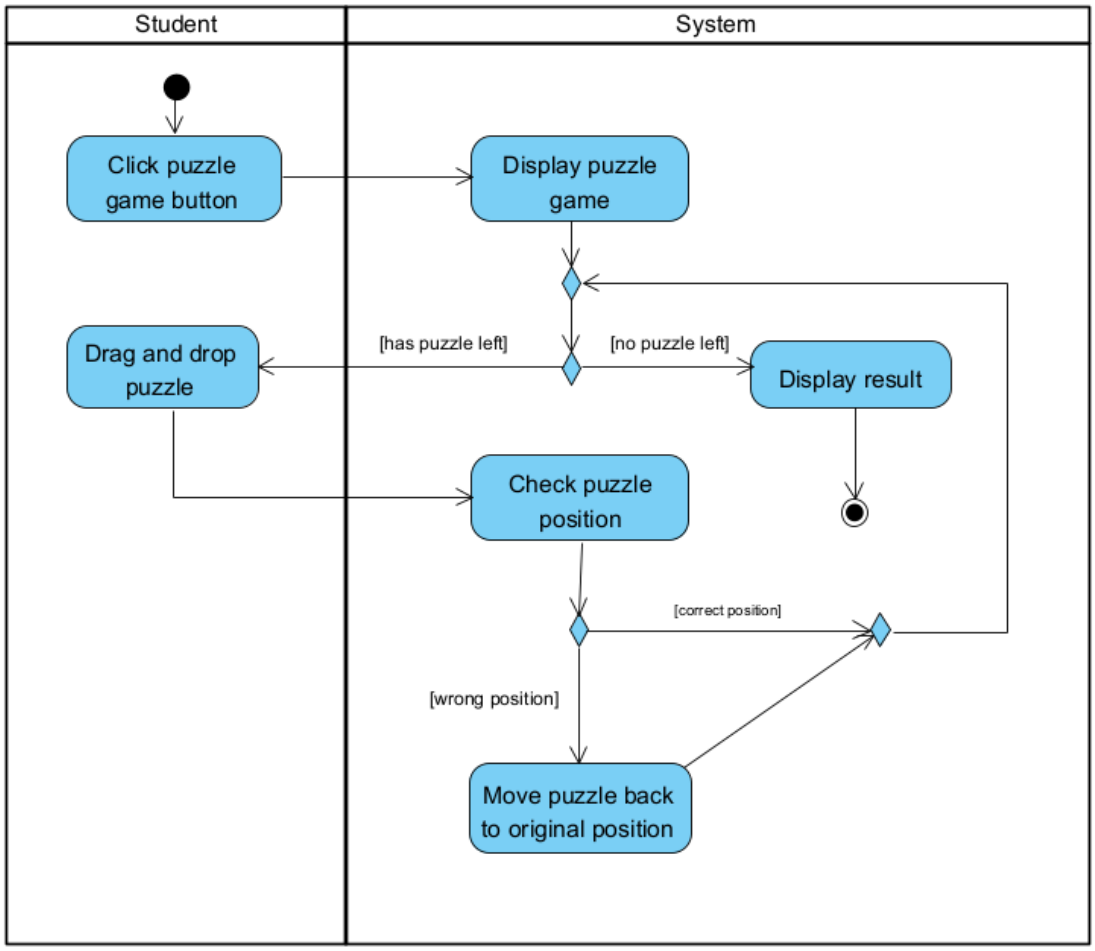


Figure 3.4.3.3 Activity diagram of "Play Anatomy Puzzle Game" use case.

The student initiates the activity by clicking on the puzzle game button at the home page. After that, the anatomy puzzle game is displayed. The student drags and drop the anatomy puzzle to the human body. Then, the system checks the puzzle's position. If the anatomy puzzle is placed at the wrong position, then the anatomy puzzle returns to its original position. This process is repeated until all the anatomy puzzle is dragged to the correct position. Finally, the results obtained by the students will be displayed.

3.4.4 Sequence Diagram

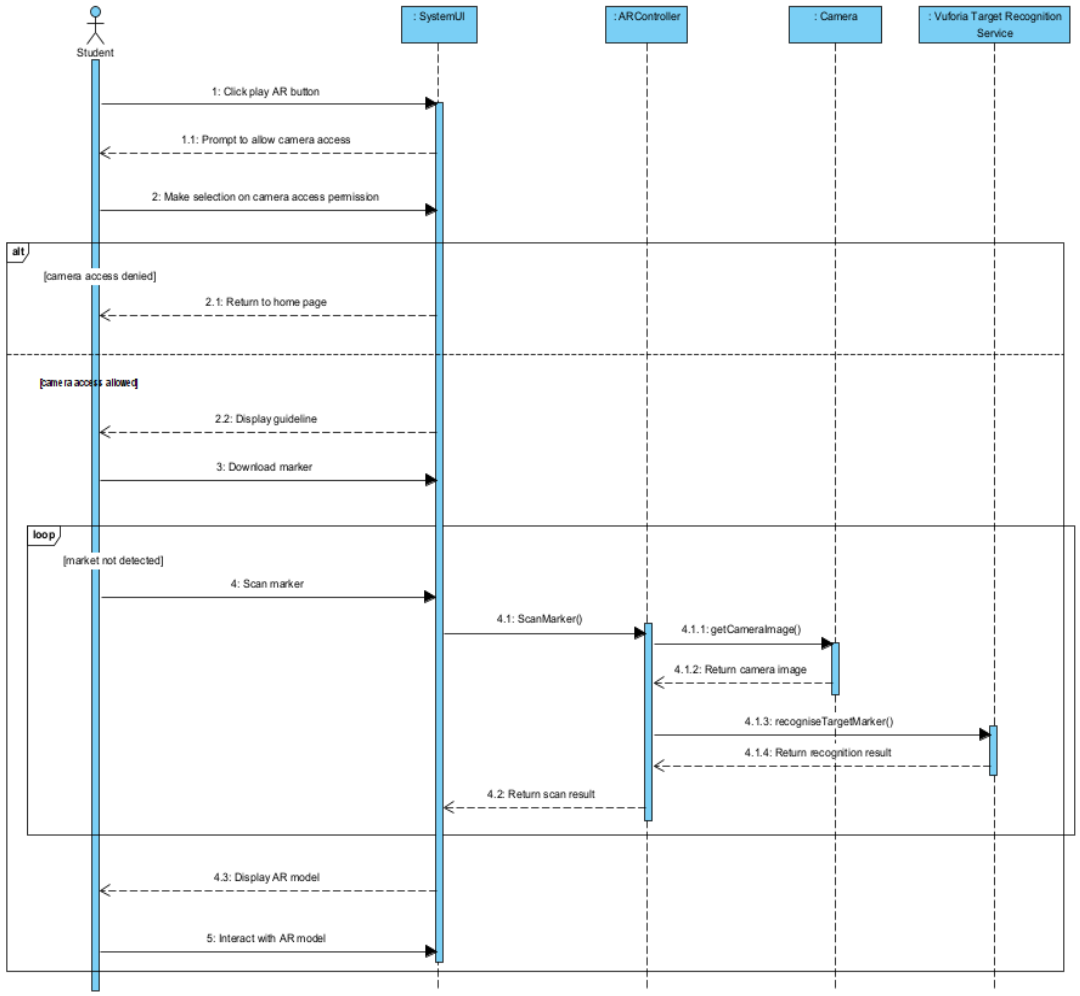


Figure 3.4.4.1 Sequence diagram of "Interact with AR Model" use case.

First, the student clicks on the play AR button at the home page. The system will prompt the user to allow the application to access to the student's device camera. The student makes selection on the camera access permission. If the student denies the camera access, the system will redirect the student back to the home page. If the student allows the camera access, the system will display the guideline on how to display the AR model and interact with the AR model. The student downloads the marker and scans the marker. The AR controller will get the camera image from the camera and recognise the target marker through Vuforia Target Recognition Service. Then, the AR controller returns the scan result to the system. If the marker is not detected, the student must scan the marker until the marker is detected. Once the marker is detected, the system will display the AR model of the human digestive anatomy on the student's device screen. Then, the student can start to interact with the AR model, such as rotating AR model,

zooming in/out AR model, moving the AR model, and selecting the organ structure to view its details.

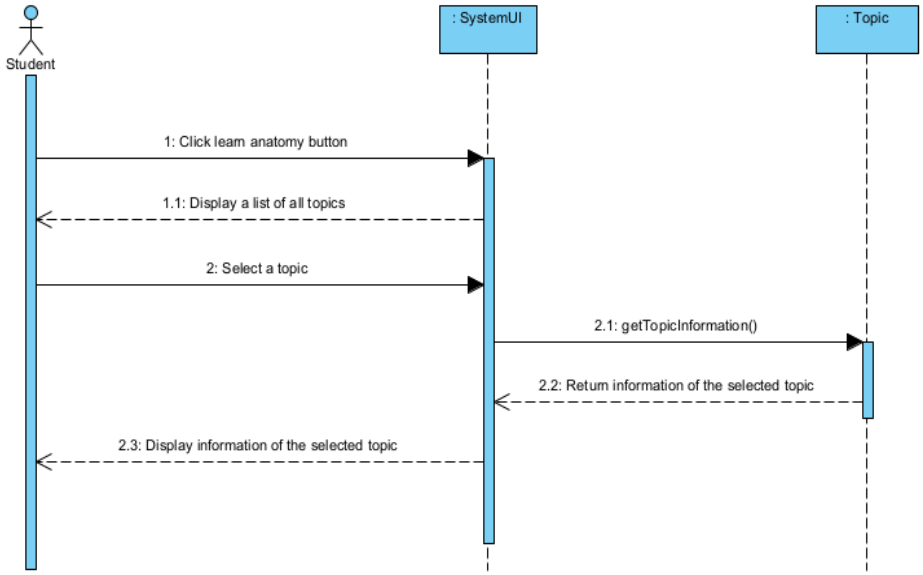


Figure 3.4.4.2 Sequence diagram of “Learn Anatomy” use case.

First, the student clicks on the learn anatomy button at the home page. Then, the system displays a list of all topics about the human digestive system anatomy. Next, the student selects a topic. The system gets the information of the selected topic and displays the information to the student.

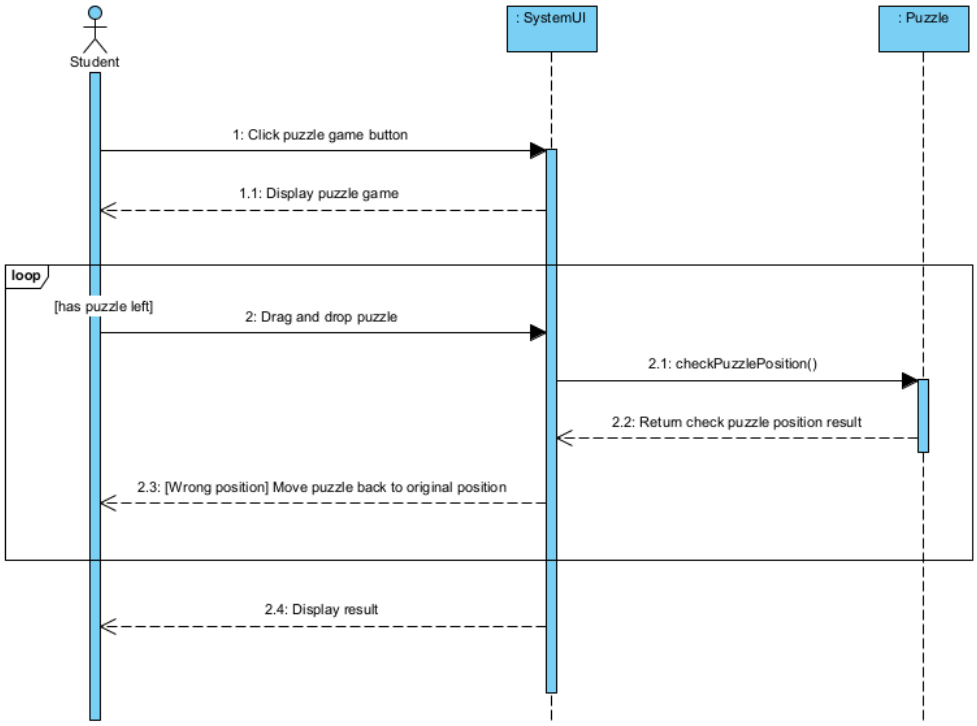


Figure 3.4.4.3 Sequence diagram of "Play Anatomy Puzzle Game" use case.

First, the student clicks on the puzzle game button at the home page. After that, the system displays the anatomy puzzle game of the human digestive system. The student drags and drops the anatomy puzzle to the human body. The system checks the puzzle's position and return the result. If the anatomy puzzle is placed at the wrong position, the system will move the puzzle back to its original position. This process is repeated until all the anatomy puzzle is dragged to the correct position and there is no puzzle left. Finally, the results obtained by the student will be displayed.

3.5 Implementation Issues and Challenges

One of the challenges is the difficulty in finding a high-quality medical image of the human digestive system as many medical datasets has restricted access or need to be paid for license. CT images with good quality is important so that a more precise and accurate 3D model can be produced and the process of reconstructing the 3D model from the medical images will also be easier. Another challenge is the lack of knowledge and experience in identifying the structure in the medical images precisely so that an accurate 3D model can be produced. Furthermore, another issue is some of the online academic journal articles cannot be accessed due to paid and restricted access.

Therefore, it is a challenge to do research on the project's study area. Last but not least, another challenge faced in this project is the lack of knowledge and experience in using Unity to develop the proposed application.

3.6 Project Timeline

3.6.1 Timeline for FYP1

Project Task	Project Weeks													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Planning														
Determine project title														
Define problem statement and motivation														
Define project scope and objective														
Define project impact, significance and contribution														
Define project background information														
Analysis														
Literature review on similar previous works														
Literature review on technologies used														
Critical remarks of previous works														
Benchmark existing application and project														
Design														
Gather user requirement														
Determine design specification														
Determine system design														
Implementation														
Preliminary work														
Deliver initial system														
FYP1 documentation														
FYP1 presentation														

Table 3.6.1.1 Schedule plan for FYP1.

The schedule plan for FYP1 is as shown in Table 3.6.1.1. The total number of weeks to carry out FYP1 is 14 weeks. The project task is divided into 4 main phases, which are the planning, analysis, design and implementation phase. The first two weeks are planned for project planning, where the project title, problem statement, scope, objective, significance, and background information will be determined. Week 3 to week 6 are planned for the analysis phase, where the literature review and benchmarking with existing work are carried out. Then, the following two weeks are planned for the design phase to gather user requirement, determine design specification and system design. During week 8 to week 12, the implementation phase is carried out to do preliminary work and deliver the initial system. Lastly, the presentation of the project is planned for week 13 and 14.

3.6.2 Timeline for FYP2

Project Task	Project Weeks													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Implementation and Testing														
Refine previous work in FYP1														
Develop the prototype														
Improve prototype incrementally														
Test and evaluate the system														
Compile and document project result														
Deliver final system														
FYP2 documentation														
FYP2 presentation														

Table 3.6.2.1 Schedule plan for FYP2.

The schedule plan for FYP2 is as shown in Table 3.6.2.1. the total number of weeks to carry out FYP2 is 14 weeks. The focus of FYP2 is on the development and implementation of the application, as well as the testing of the application. Before starting to develop the application, a refinement of the previous work in FYP1 is carried out first. Then, in the following week, the development of prototypes is started. The prototype is developed incrementally. The testing and evaluation of the prototype are also planned in the schedule. Finally, the final system is completed and submitted by week 13. Then, the presentation and product demonstration are planned for the last two weeks, week 13 and week 14.

3.7 Concluding Remark

To conclude, RAD based methodology is used for this project. The general work procedures in developing the proposed application are defined in this chapter. The hardware used to develop the application and perform testing on the application are stated in this chapter. Furthermore, the specification of the hardware is also stated. The four main software used in this project are 3D Slicer to perform image segmentation and reconstruction of 3D model, Unity with Vuforia Engine to apply AR onto the 3D object and to develop the application, Visual Studio to create C# script, and Xcode to build the application on iOS mobile devices. Next, a list of functional and non-functional requirements of the proposed application is also defined. Besides that, this chapter also shows the system design of the proposed application through use case

diagrams, use case descriptions, activity diagrams and sequence diagrams. In addition, the implementation issues and challenges are also described in this chapter. Lastly, the project timeline is created to ensure the project is able to be delivered on time.

CHAPTER 4 PRELIMINARY WORK

4.1 Overview of Preliminary Work Done

The preliminary work done in this project is creating image segmentation of liver, stomach, pancreas and gall bladder to produce a 3D model, using the Segment Editor module of 3D Slicer. The medical dataset used for the image segmentation is obtained from The Cancer Imaging Archive (TCIA) website [20] and 3D Slicer is used for the entire image segmentation process.

4.2 Process of Image Segmentation using 3D Slicer

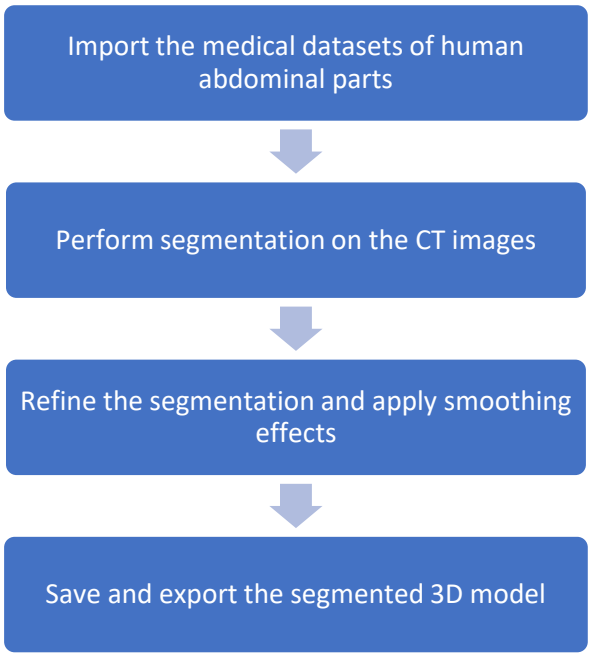


Figure 4.2.1 Process of image segmentation.

The process of image segmentation is divided into four main steps as shown in Figure 4.2.1. First, the medical datasets file of the human abdominal parts is imported. Second, segmentation is performed on the CT images. Third, the segmentation created is refined and smoothing effects is applied to smooth out the surface. Finally, the segmented 3D model is saved and exported in OBJ file type.

4.2.1 Importing medical datasets to 3D Slicer

The medical datasets used in this project is obtained through The Cancer Imaging Archive (TCIA) website [20].

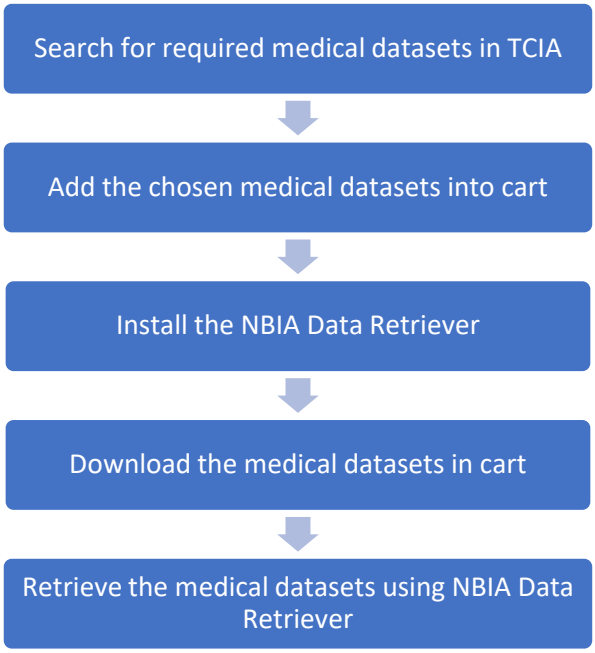


Figure 4.2.1.1 Steps to Obtain Medical Datasets from TCIA

The steps of acquiring the medical datasets from the TCIA website is as shown in Figure 4.2.1.1. First, the medical datasets are searched in the TCIA website. The user can preview the medical datasets in TCIA while searching for a suitable dataset. After finding for suitable datasets, the chosen datasets are added into the cart. Before downloading the datasets, the NBIA Data Retriever must be installed first. This is because, when a user download the datasets from TCIA, the downloaded file will be in a manifest file, which is in the format of "manifest-xxx.tcia". In order to open this manifest file, the NBIA is needed to be already installed in the user's computer. After installing the NBIA Data Retriever, the medical dataset in the cart is downloaded. Lastly, the medical datasets are retrieved using the NBIA Data Retriever.

The medical datasets which are downloaded from TCIA and used in this project is a CT scan of the human abdominal part, including the liver, stomach, pancreas, and gall bladder. The details of the CT datasets are shown as below:

Patient's Sex	Male
Patient's Age	63 years old
Modality	CT
Scan Option	Helical mode
Number of Images	134 images
Slice Thickness	5.00 mm

Study Date	27 May 2003
Manufacturer	GE Medical Systems
Data Collection Name	The Cancer Genome Atlas Liver Hepatocellular Carcinoma (TCGA-LIHC) data collection
Link	https://wiki.cancerimagingarchive.net/display/Public/TCGA-LIHC

Table 4.2.1.1 Details of CT datasets used.

4.2.2 Perform Segmentation on the CT images

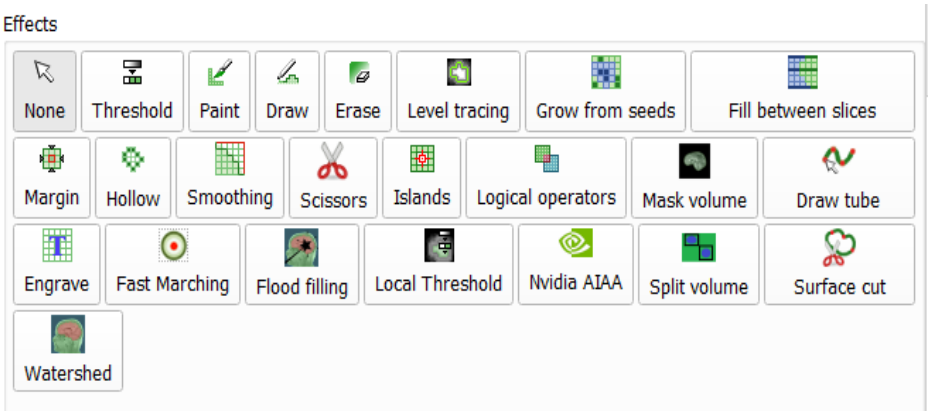


Figure 4.2.2.1 Segment Editor module in 3D Slicer.

To perform image segmentation, the Segment Editor module as shown in Figure 4.2.2.1 in the 3D Slicer is used. This module offers various useful segmentation methods using manual tools, semi-automatic tools, or automatic tools. The 'Paint' tool and 'Draw' tool are manual tools, where the user needs to draw, or paint based on the boundary manually. 'Threshold', 'Grow from Seeds', 'Fill between Slices', 'Interpolations' are examples of semi-automatic tools, while 'Nvidia AIAA' is an example of automatic tool [21].

In the segmentation process for this project, a few methods are used. Firstly, the 'Threshold' tool is used to determine a threshold range and applied for masking purpose. This tool will perform segmentation on all the slices automatically based on the threshold range set, hence, the user must select a suitable threshold range and make adjustments accordingly. After that, 'Paint' tool is used to paint a few selected slices to act as the "seeds" and then the 'Grow from Seeds' tool can be used to "grow" or generate the segment automatically by estimating the region of the target organ. However, when the 'Grow from Seeds' tool does not work nicely or detect the target region accurately for some of the segments, 'Fill between Slices' tool is used instead.

To use this tool, a few numbers of slices is manually drawn or painted on selected slices by tracing the contours on the target region of the organ structure, then the 'Fill between Slices' tool is initialized to fill the skipped slices by interpolating between the segmented slices. Furthermore, the 'Scissors' tool is used on the 3D view to further segment the organs into different regions. 'Logical Operator' tool is also used to add, subtract, or combine some of the segments.

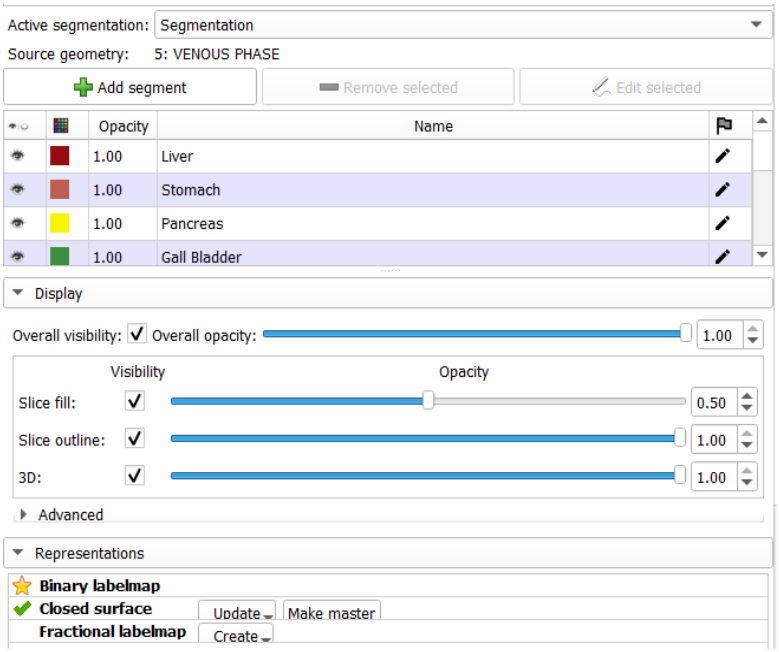


Figure 4.2.2.2 Segmentation module overview.

In the Segmentations module overview, the display properties of segmentations can be adjusted, and each segment created can be managed as shown in Figure 4.2.2.2. Each of the segments represents a specific region of an organ structure. Different display colours and labels can be set for each segment. A region can be represented in a binary label map or a closed surface. Binary label map representation is commonly used for 2D viewing and editing, while closed surface is used for 3D visualization [22].

4.2.3 Refining the Segmentation and Applying Smoothing Effects

After creating the segmentation, paint tool, draw tool and erase tool is used to further refine the details of the segmentation because the semi-automatic method might not be fully accurate. Lastly, smoothing tool is used to smooth out the segments. The smoothing methods include median, opening, closing, Gaussian and joint smoothing.

In this segmentation process, only median, closing and Gaussian smoothing is applied for smoothing the segments. Median method is used to get rid of all the small extrusions and fill up small holes and closing method is used to fill up sharp corners and gaps which are smaller than the specified kernel size. Besides that, Gaussian method is used to smooth out all the details on the segments.

4.2.4 Exporting the Segmented 3D model

After the image segmentation is done, the segmented 3D model is saved and exported in OBJ file type.

4.3 Results of Image Segmentation

In Figure 4.3.1, the list of segments done is shown. In Figure 4.3.2 to 4.3.10, the results of image segmentation of liver, stomach, pancreas and gall bladder are shown. The top left box is the axial view, the top right box is the 3D visualization, the bottom left box is the coronal view, and the bottom right box is the sagittal view of the CT images.

		Name	
		Liver	
		Stomach	
		Pancreas	
		Gall Bladder	
		Oesophagus	
		Duodenum	
		Inferior vena cava	
		Pancreas Tail	
		Pancreas Head	
		Pancreas Body	
		Pancreas Neck	
		Left Lobe	
		Right Lobe	
		Left Liver	
		Right Liver	
		Left Medial Section	
		Right Posterior Section	
		Right Anterior Section	
		Left Lateral Superior	
		Left Lateral Inferior	
		Right Posterior Superior	
		Right Posterior Inferior	
		Right Anterior Superior	
		Right Anterior Inferior	

Figure 4.3.1 List of segments with names and display colour.

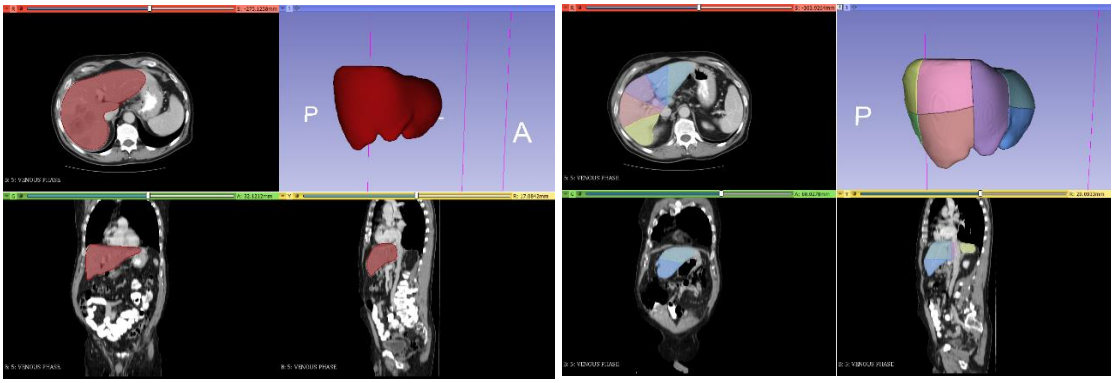


Figure 4.3.2 Segmentation of liver.

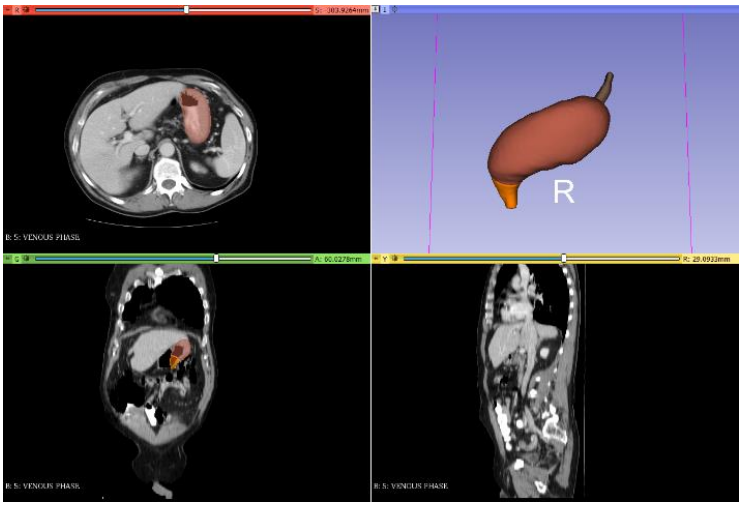


Figure 4.3.3 Segmentation of stomach.

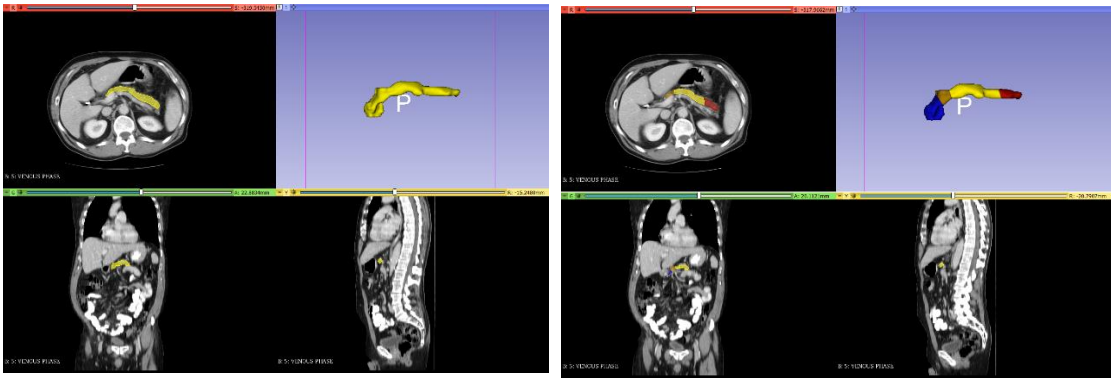


Figure 4.3.4 Segmentation of pancreas.

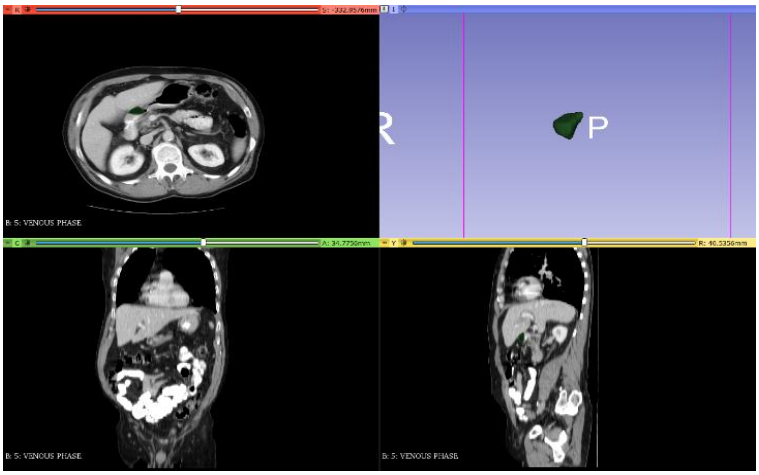


Figure 4.3.5 Segmentation of gall bladder.

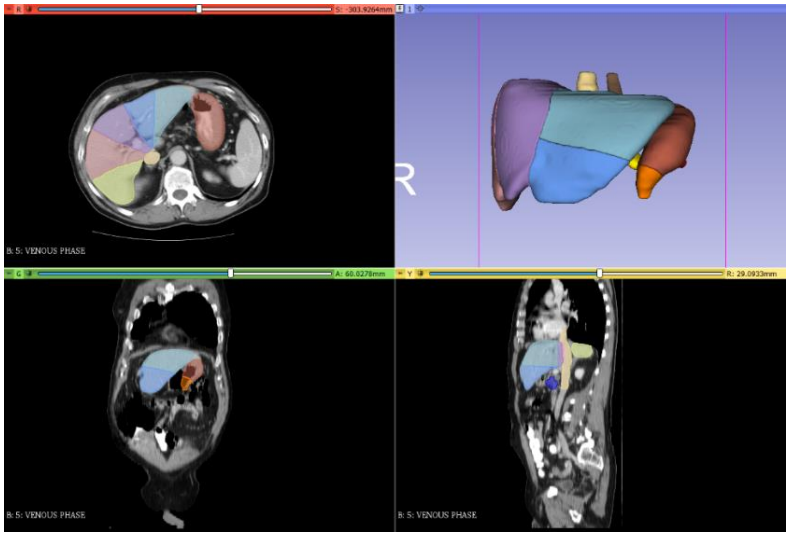


Figure 4.3.6 Full segmentation (anterior view).

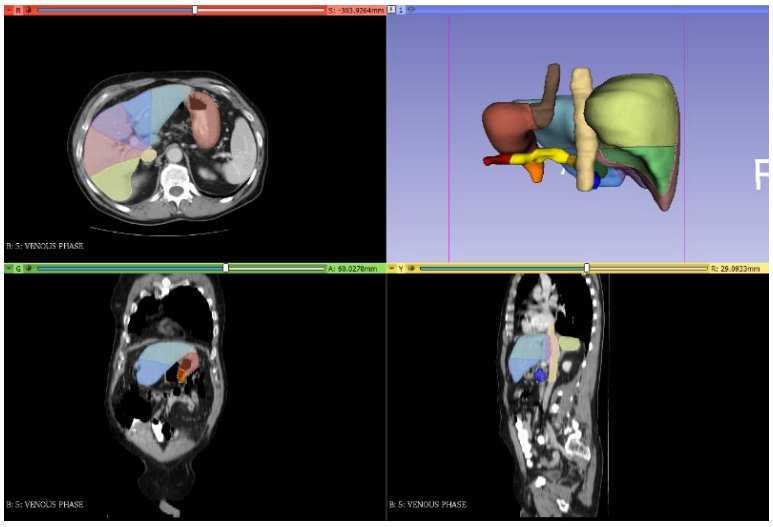


Figure 4.3.7 Full segmentation (posterior view).

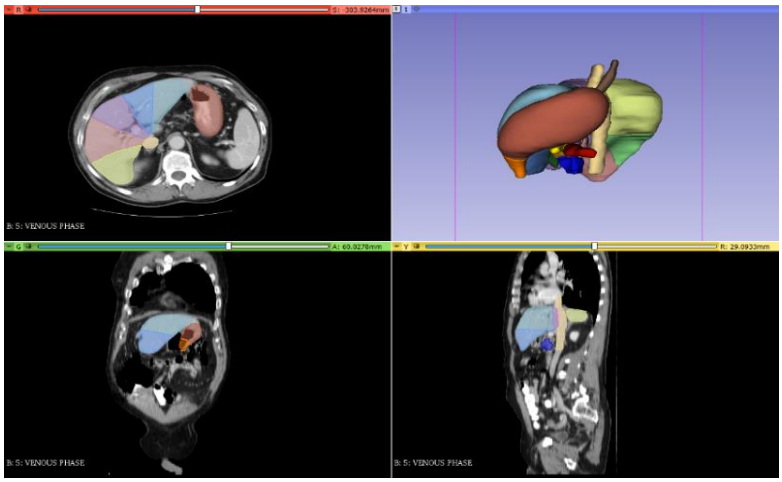


Figure 4.3.8 Full segmentation (left view).

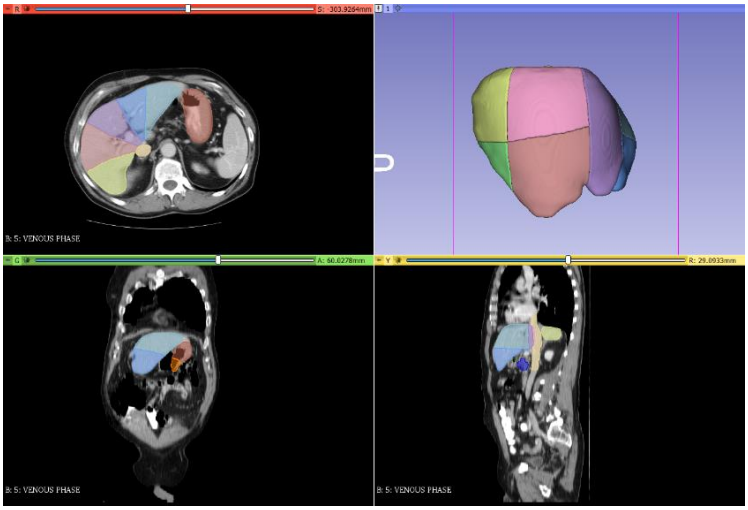


Figure 4.3.9 Full segmentation (right view).

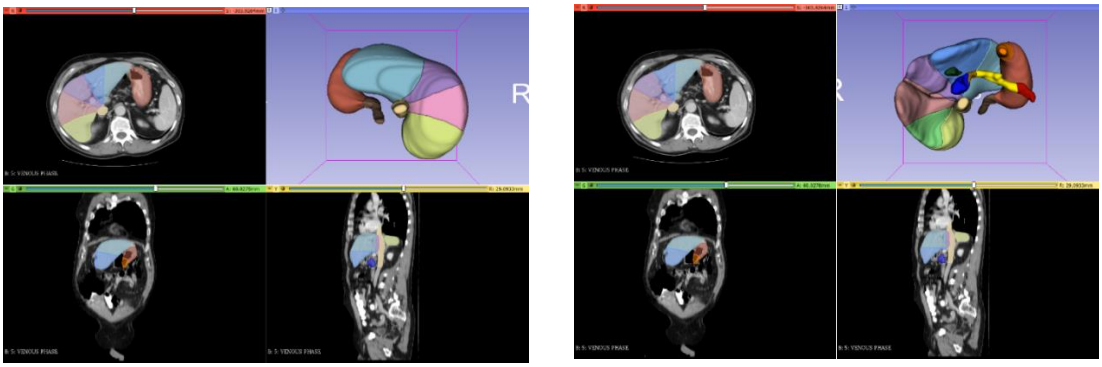


Figure 4.3.10 Full segmentation (superior view and inferior view).

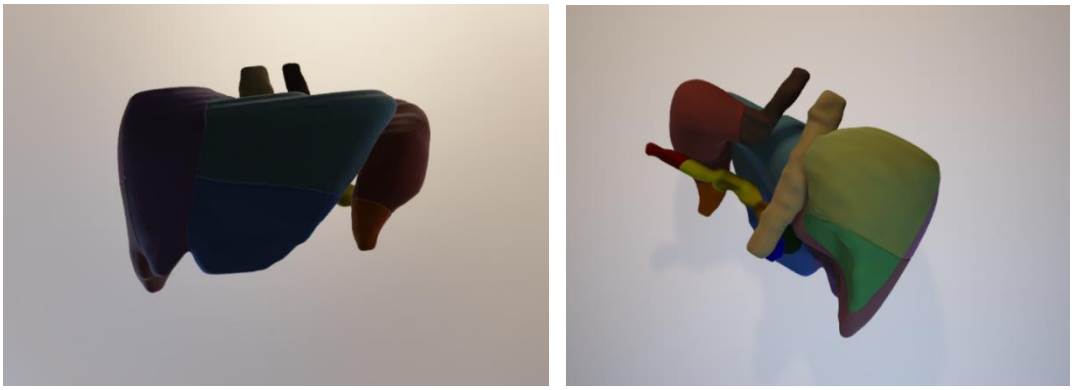


Figure 4.3.11 Final output of 3D model in OBJ file.

4.4 Concluding Remark

To conclude, the preliminary work done in FYP1 is discussed in this chapter. The preliminary work done is creating image segmentation of liver, stomach, pancreas and gall bladder to produce a 3D model, using the segment editor module of 3D Slicer. The medical dataset used for the image segmentation is a CT scan of the human abdominal part, including the liver, stomach, pancreas, and gall bladder, which is obtained from TCIA website. For the entire image segmentation and 3D reconstruction process, 3D Slicer is used. The process of image segmentation is divided into four main steps, which are importing the medical datasets file into 3D Slicer, performing segmentation semi-manually onto the slices of the CT images, refining and applying smoothing effects, and exporting the segmented 3D model in OBJ file type. Furthermore, the results of image segmentation are also shown through screenshots in this chapter.

CHAPTER 5 SYSTEM IMPLEMENTATION

5.1 Setting Up Unity

Unity Editor is one of the popular authoring platforms to create AR experiences for mobile devices. It is free, open-source, and can be installed on both Windows platform and macOS platform. To download and install Unity, the setup wizard, which is the Unity Hub, must first be installed. Unity Hub is the setup wizard that allows user to manage multiple versions of unity and packages easily. The Unity Hub version used in this project is Unity Hub 3.1.0-beta.2. Then, the Unity Hub is used to install the Unity Editor. The Unity Editor version used is 2020.3.26f1. In addition, the Android Build Support, Android SDK & NDK Tools, and OpenJDK modules are added to the Unity Editor. After installing the necessary modules, a new 3D project is created. Then, Unity will take some time to set up the project's core file.

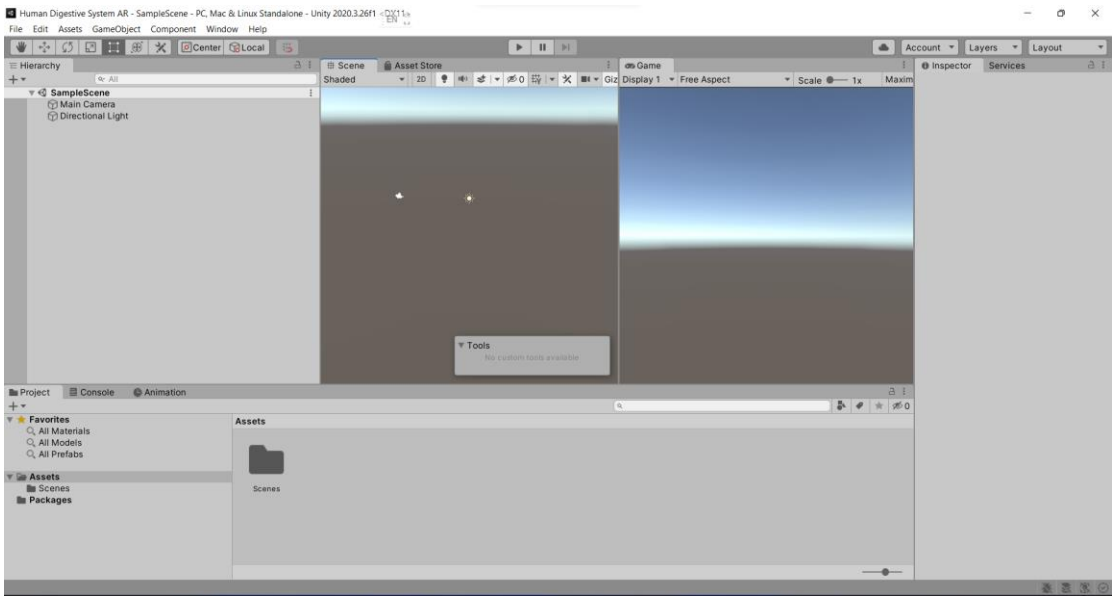


Figure 5.1.1 User interface of Unity Editor.

Once the project is created and opened, the user interface of Unity Editor is as shown in Figure 5.1.1 will appear. The figure shows the new empty project created. There are five main regions in this Unity Editor. Firstly, the region on the left side is the Scene Hierarchy. The Scene Hierarchy contains the list of all the objects of the currently open scene in a parent-child form. Next, the middle region is the Scene Window. The Scene is where the developer work with the content in the Unity. Then, if the user clicks on the Game tab, it will change to the game mode. Next, the region on the right side is the Inspector. The Inspector shows the properties and components of the selected game

object. Lastly, the bottom region is the Project Assets window, which stores all the assets of the project.

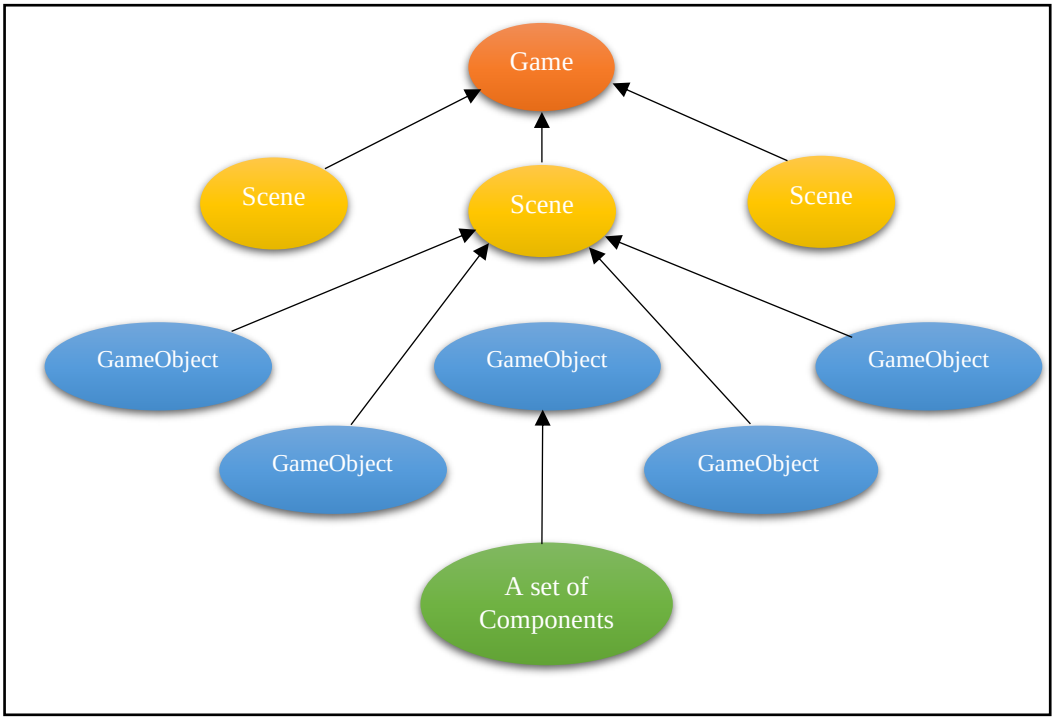


Figure 5.1.2 Overview of how Unity works.

Figure 5.1.2 shows an overview of how Unity works. A project built with Unity may have one or more scenes. The scenes in this project are the Main Menu Scene, Play AR Scene, Select Topic Scene, Topic Information Scene, Video Player Scene, and Anatomy Puzzle Game Scene. Each scene is made up of different game objects. Some examples of game object are 3D model, camera, buttons, text, and empty objects. Then, each game object has a set of components attached to them, which determines how the game object will behave in the scene and react to other game object in the scene. Some examples of component that can be attached to a game object are Transform, Physics, Audio, Image, Vertical Layout Group, Scripting etc.

Build Settings Configuration

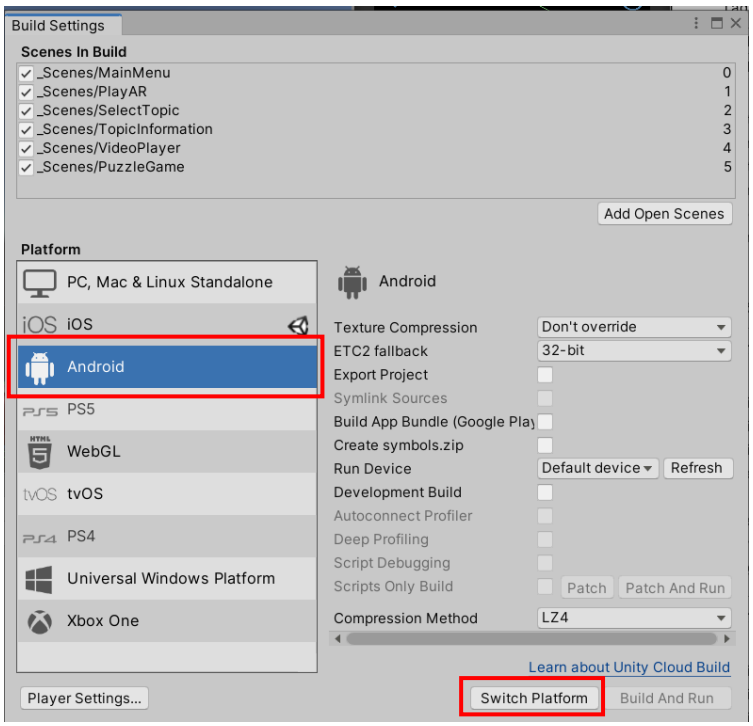


Figure 5.1.3 Build settings configuration.

Then, some configurations on the build settings are done. Go to File > Build Settings, at the Platform section, click on Android and switch platform to Android as shown in Figure 5.1.3.

Player Settings Configuration

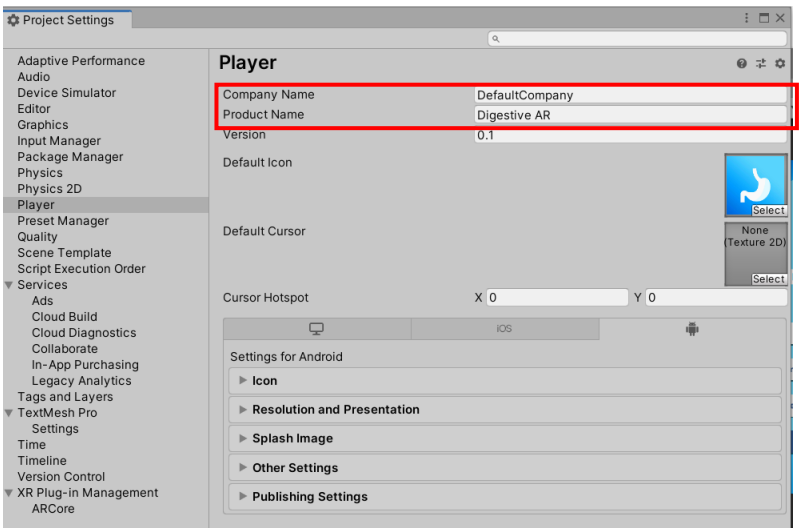


Figure 5.1.4 Player settings configuration.

After that, some configurations on the player settings are done. The company name and product name are set, and a default icon is assigned as shown in Figure 5.1.4.

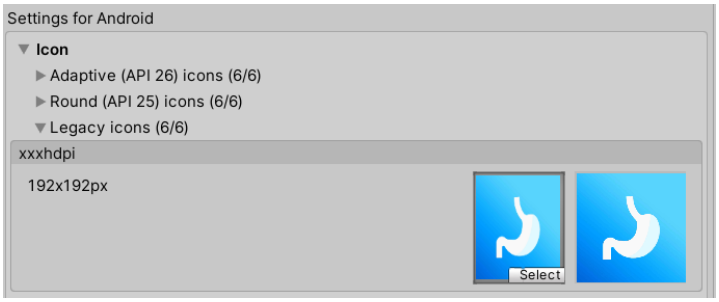


Figure 5.1.5 Player settings configuration – Icon.

The application logo is first created using the Photoshop software. Then, the logo, logo foreground and logo background are exported in PNG format. After that, the logo is imported into the Unity Assets folder, and changed to sprite format. Next, go to player settings and set the icon by dragging in the logo, logo foreground or logo background into the respective sections of the adaptive icons, round icons, and legacy icons as shown in Figure 5.1.5.

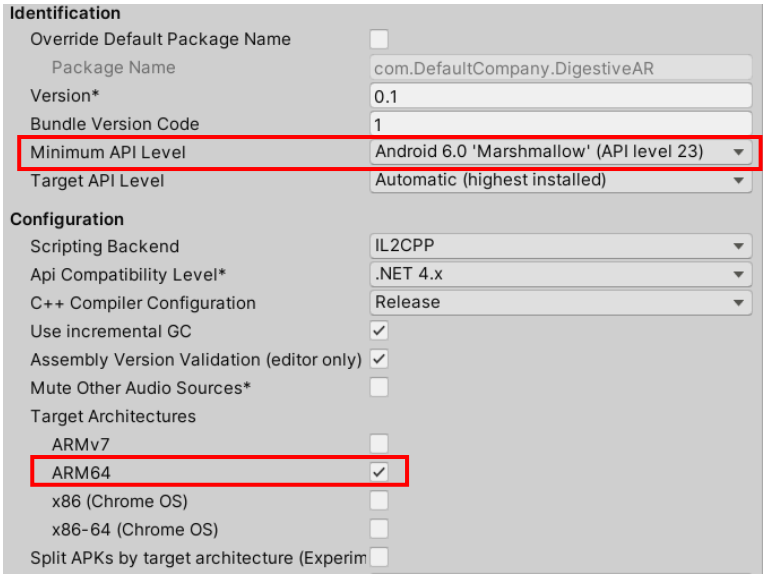


Figure 5.1.6 Player settings configuration – Identification and Configuration.

Figure 5.1.6 shows that the minimum API level for this application is set to Android 6.0, with API level 23 and the target architecture is set to ARM64.

5.2 Setting Up Unity and Xcode on macOS Virtual Machine

MacOS is required to build the Unity project on an iOS device. Due to the limitation of the project of using only a Windows personal computer (PC), a virtual machine with macOS is installed. Firstly, VMware Workstation Player, which is a free software tool to create and manage virtual machines, is downloaded onto the Windows PC. Then, a macOS virtual machine is created and installed in the VMware Workstation Player.

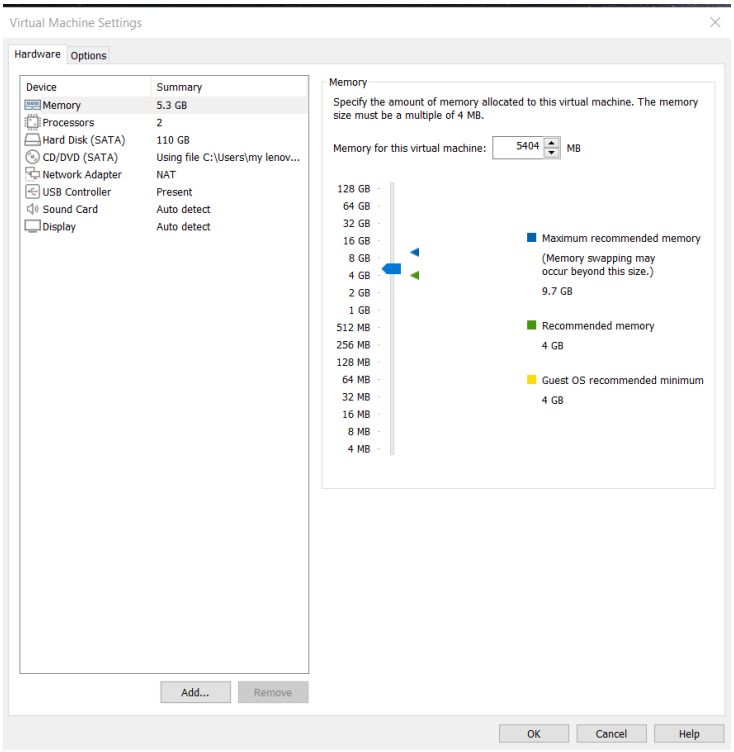


Figure 5.2.1 Configuration of virtual machine settings.

The configuration of the virtual machine settings is as shown in Figure 5.2.1. After creating and setting up the macOS virtual machine, Unity Hub and Unity Editor of version 2020.3.26f1 are installed onto the macOS virtual machine, and iOS build support module is installed too, similar to the steps of installing Unity on Windows PC. Besides that, Xcode is also installed onto the macOS virtual machine.

5.3 Setting Up Vuforia Engine

In this project, Vuforia 8 is installed and imported into the Unity Editor. First, the Vuforia SDK is downloaded from the Vuforia Engine developer portal. Then, go to

File > Build Settings > Player Settings > XR settings and enable the Vuforia Augmented Reality Support to activate the Vuforia Engine.

5.3.1 Adding Vuforia App License Key to Unity

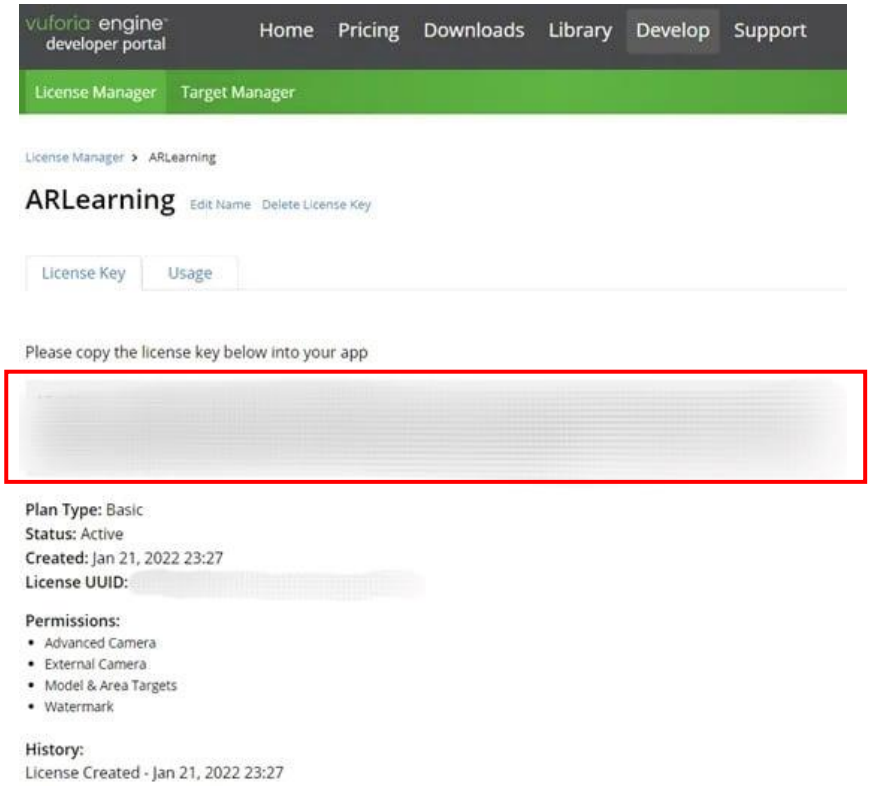


Figure 5.3.1.1 Vuforia engine developer portal.

To obtain the license key, at the Vuforia Engine developer portal, go to Develop > License Manager, then click on Get Development Key. Then, a development key will be generated automatically. Copy the license key in Figure 5.3.1.1 and go back to the Unity project.

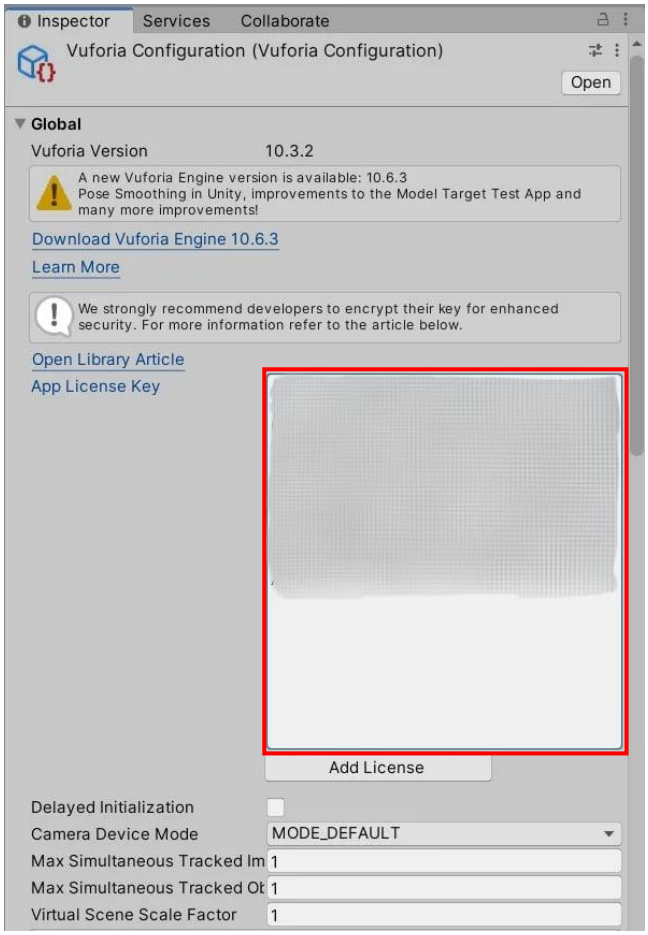


Figure 5.3.1.2 Adding license key at Vuforia Configuration.

In Unity, go to Windows > Vuforia Configuration, and paste the license key into the App License Key as shown in Figure 5.3.1.2.

5.3.2 Creating and Adding Target Marker Database to Unity

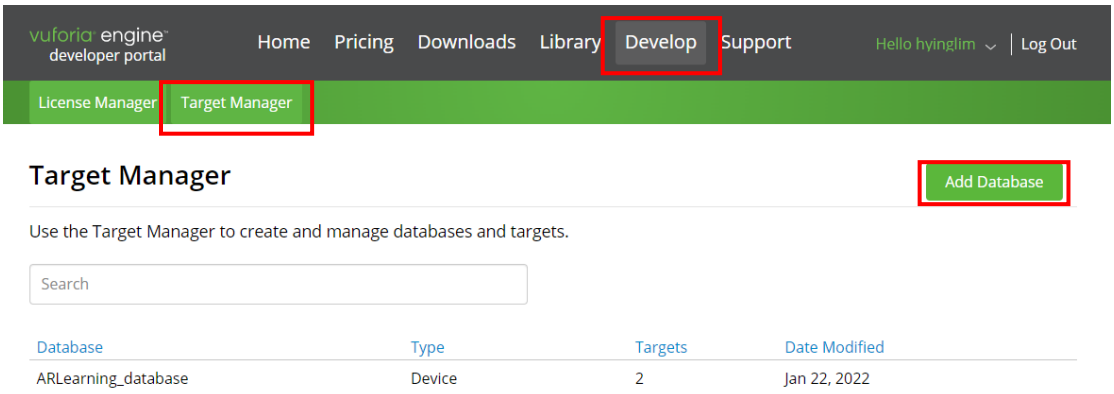


Figure 5.3.2.1 Target Manager at Vuforia Engine developer portal.

As shown in Figure 5.3.2.1, at developer portal > Develop tab > Target Manager tab > Add Database, then enter a name for the database. Select 'device' for the type and click Create.

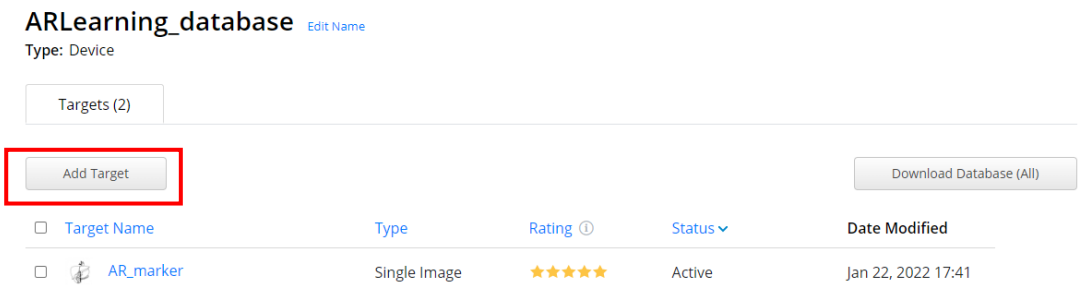


Figure 5.3.2.2 Adding target marker into database at Vuforia Engine developer portal.

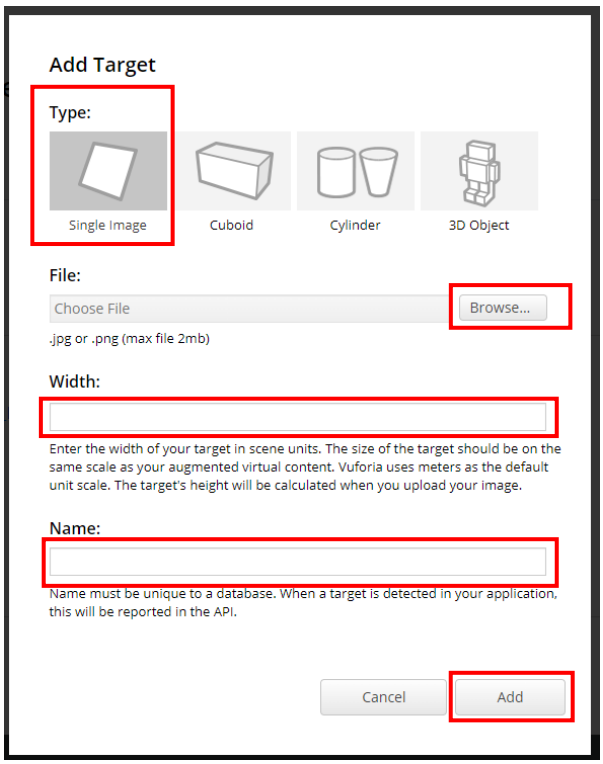


Figure 5.3.2.3 Vuforia developer portal adding target marker.

Then, as shown in Figure 5.3.2.2 and Figure 5.3.2.3, click add target, then select 'Single Image' type and browse the file to be uploaded. The width and name of the target are also specified.

Figure 5.3.2.4 Target marker uploaded.

As shown in Figure 5.3.2.4, the target marker uploaded for this project has the highest five-star rating for augmentable, meaning that the marker is suitable to be used for target image recognition of AR.

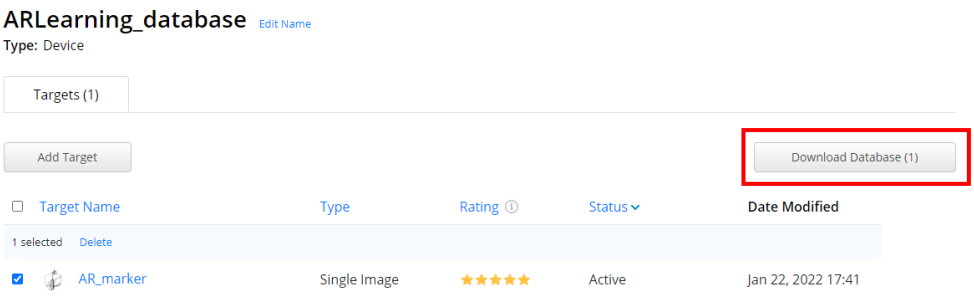


Figure 5.3.2.5 Downloading target marker database from Vuforia Engine developer portal.

As shown in Figure 5.3.2.5, download the database from the Vuforia Engine developer portal and import the database into Unity.

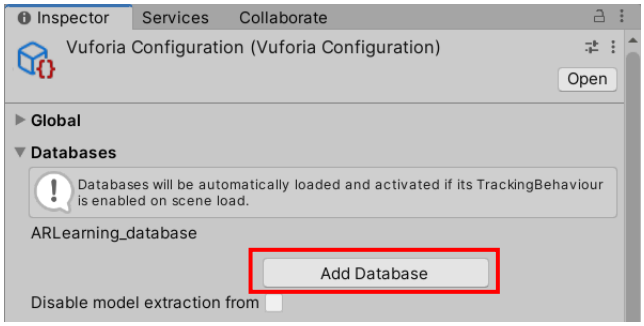


Figure 5.3.2.6 Adding database at Vuforia Configuration.

In Unity, go to Windows > Vuforia Configuration. As shown in Figure 5.3.2.6, under the database section, click add database to add the database.

5.4 Development of Main Menu Scene

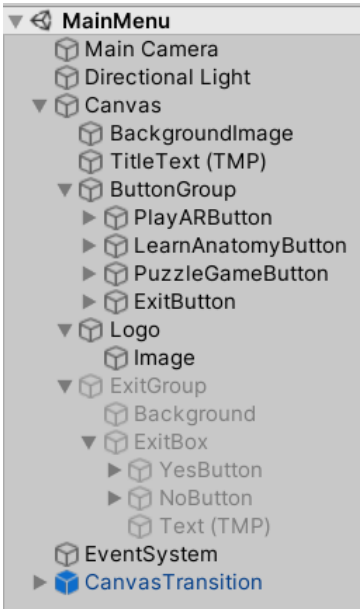


Figure 5.4.1 Hierarchy of Main Menu Scene.

To create the Main Menu Scene, the game objects as shown in Figure 5.4.1 are added to the scene hierarchy.

Game Object	Function / Description
BackgroundImage	The background of the Main Menu Scene
TitleText (TMP)	Text that displays the title of the application
ButtonGroup	The parent of the buttons
PlayARButton	Button to change current scene to Play AR Scene
LearnAnatomyButton	Button to change current scene to Select Topic Scene
PuzzleGameButton	Button to change current scene to Anatomy Puzzle Game Scene
ExitButton	Button to open and display an exit confirmation dialog box
Logo	Image of the application logo

ExitGroup	The parent of the exit confirmation dialog box and its background
ExitBox	Exit confirmation dialog box
YesButton	Button to exit the application
NoButton	Button to close exit confirmation dialog box

Table 5.4.1 Function / description of some main game objects in Main Menu Scene.

To create the user interface, a Canvas need to be added the Hierarchy Window as it is required for all UI elements in Unity. The Canvas is a place that holds all the UI elements, which means every UI element created will be the children of the Canvas. In addition, an EventSystem will be added into the Hierarchy window automatically when Canvas is being created. This EventSystem is used to capture mouse inputs.

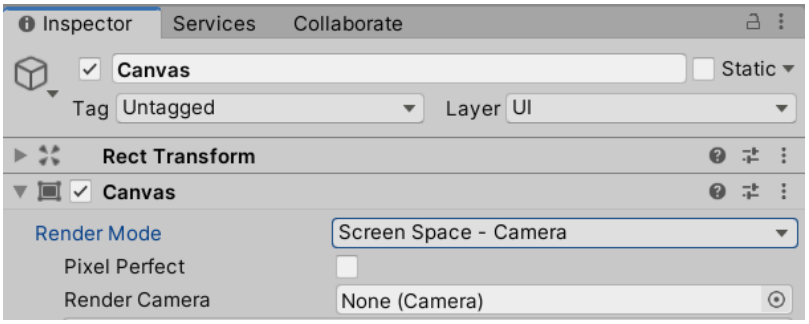


Figure 5.4.2 Inspector window of Canvas game object (Part I).

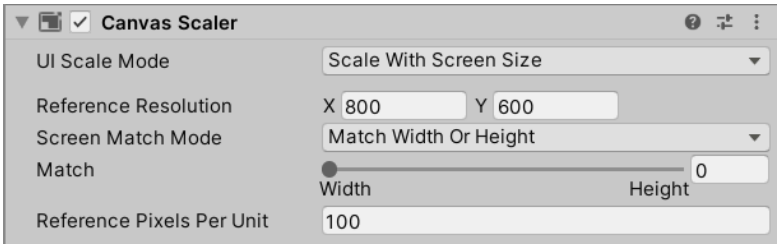


Figure 5.4.3 Inspector window of Canvas game object (Part II).

As shown in Figure 5.4.2, the render mode is set to “Screen Space – Camera” to make sure the UI will always be shown within the device’s camera view. Besides that, as shown in Figure 5.4.3, the UI scale mode is set to “Scale with ScreenSize” so that the user interface will change proportionately according to the screen size. The reference resolution is set to X = 800, and Y = 600, which is the common resolution of a mobile device.

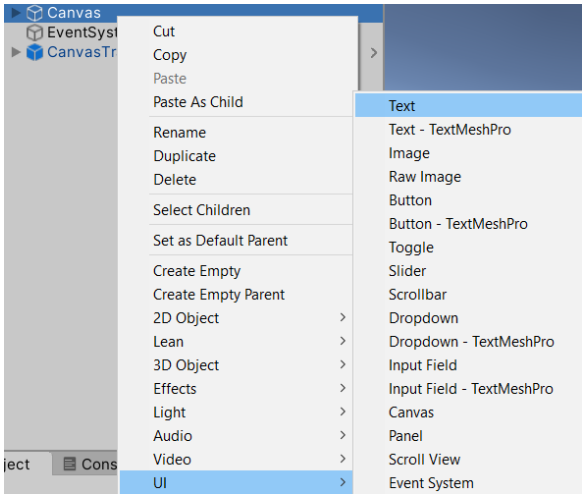


Figure 5.4.4 Creating UI elements.

The UI elements can be added by right clicking the hierarchy window and selecting the needed elements as shown in Figure 5.4.4. In this project, UI elements such as text, image, button, panel, time slider and toggle are used.

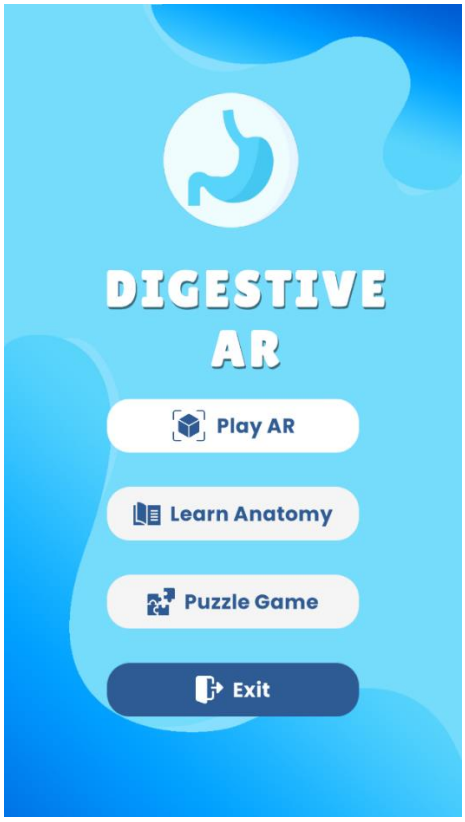


Figure 5.4.5 User interface of Main Menu Scene.

Figure 5.4.5 shows the main menu of the application developed. When the application is launched, this Main Menu Scene will be shown. There are four buttons on the main menu scene. When the user clicks the “Play AR” button, the application navigates to

the Play AR Scene. Next, when the user clicks the “Learn Anatomy” button, the application navigates to the Learn Anatomy Scene. When the user clicks the “Puzzle Game” button, the user will enter the Anatomy Puzzle Game Scene. Furthermore, if the user clicks the “Exit” button, an exit confirmation dialog box will pop out.

```
using UnityEngine;
using UnityEngine.SceneManagement;

Unity Script (1 asset reference) | 0 references
public class CanvasTransition : MonoBehaviour
{
    public static string SceneName;

    0 references
    public void Object_InActive()
    {
        this.gameObject.SetActive(false);
    }

    0 references
    public void Change_Scene()
    {
        SceneManager.LoadScene(SceneName);
    }

    0 references
    public void ChangeSceneButton(string sceneName)
    {
        this.gameObject.SetActive(true);
        SceneName = sceneName;
        GetComponent<Animator>().Play("endAnim");
    }

    0 references
    public void ExitAppButton()
    {
        Application.Quit();
    }

    0 references
    public void ChangeScreenToPortrait()
    {
        Screen.orientation = ScreenOrientation.Portrait;
    }

    0 references
    public void ChangeScreenToLandscape()
    {
        Screen.orientation = ScreenOrientation.Landscape;
    }
}
```

Figure 5.4.6 Canvas Transition script.

Figure 5.4.6 shows the C# script named “Canvas Transition”. The ChangeSceneButton() is used to change current scene to another scene. Besides, the ExitAppButton() is the method to exit the application. Furthermore, the ChangeScreenToPortrait() and ChangeScreenToLandscape() are used to change the screen orientation.

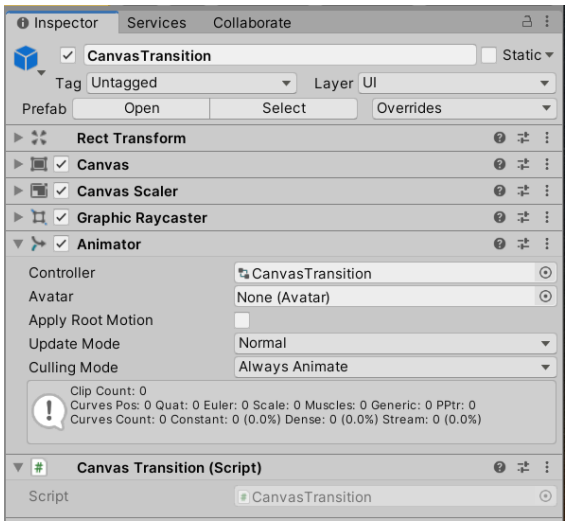


Figure 5.4.7 Inspector window of CanvasTransition game object.

The Canvas Transition script is added to the Canvas Transition game object as shown in Figure 5.4.7. Furthermore, this game object is dragged into the Assets folder to become a prefab, so that it can be used in other scenes too.

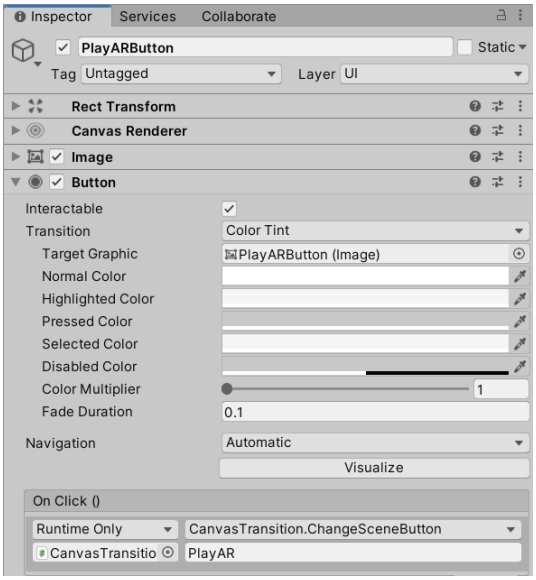


Figure 5.4.8 Inspector window of PlayARButton game object.

At the On Click() section of the PlayARButton, the ChangeSceneButton() is added as shown in Figure 5.4.8. When the user clicks on the PlayARButton, ChangeSceneButton() will be executed to change the scene to the Play AR Scene. Similar steps are done for other game objects such as the LearnAnatomyButton, PuzzleGameButton game objects.

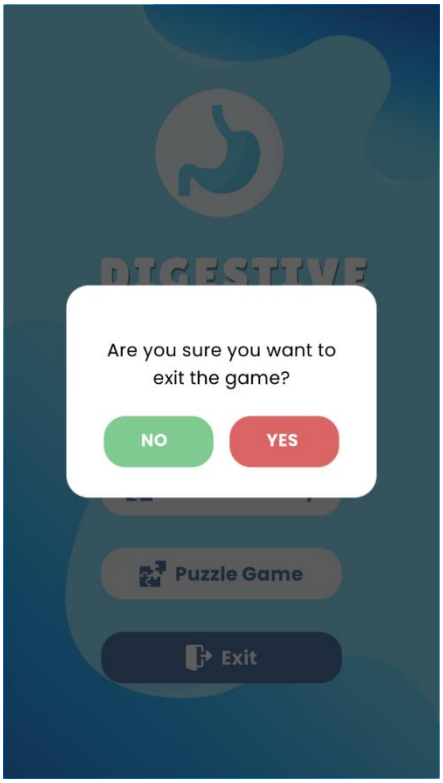


Figure 5.4.9 Exit confirmation dialog box.

When the user clicks on the “Exit” button, a confirmation dialog box will appear, as shown in Figure 5.4.9. The user can choose “YES” to exit the application, or “NO” to close the dialog box and go back to the main menu.

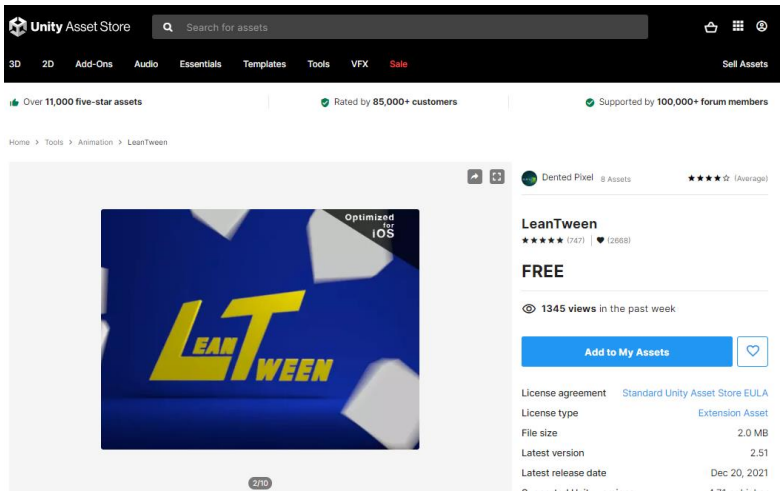


Figure 5.4.10 LeanTween at Unity Asset Store.

To apply animation when opening and closing the dialog box, LeanTween is used. Figure 5.4.10 shows LeanTween, which is a free asset provided by Unity at the Unity

asset store. In this application, some libraries of LeanTween are used to help in applying animations in the application.

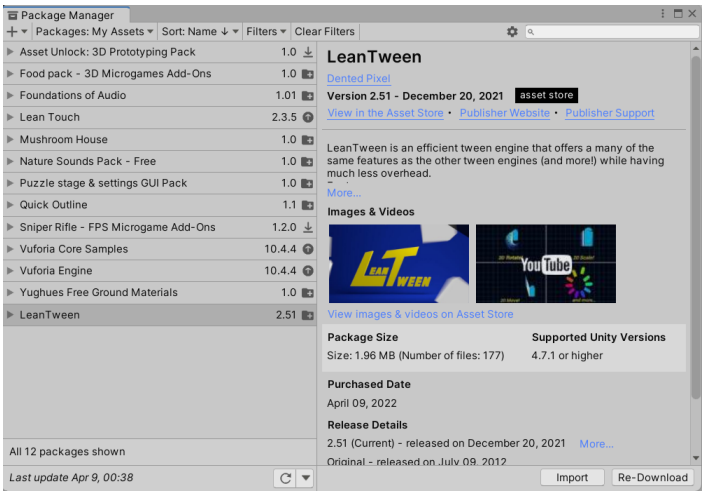


Figure 5.4.11 Package Manager window to download and import LeanTween.

Firstly, the LeanTween is added into Unity through Asset Store. Then, LeanTween is downloaded and imported into the project through Package Manager in the Unity, as shown in Figure 5.4.11.

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

public class ConfirmationBox : MonoBehaviour
{
    public Transform dialogBox;
    public CanvasGroup background;
    public GameObject  text;
    public Transform noButton, yesButton;

    private void OnEnable()
    {
        // fade in background
        background.alpha = 0;
        background.LeanAlpha(1, 0.5f);

        // scale dialog box from zero to one
        dialogBox.localScale = Vector2.zero;
        dialogBox.LeanScale(Vector2.one, 0.4f);

        noButton.localScale = Vector2.zero;
        yesButton.localScale = Vector2.zero;
        noButton.LeanScale(Vector2.one, 2f).setEase(LeanTweenType.easeOutElastic);
        yesButton.LeanScale(Vector2.one, 2f).setEase(LeanTweenType.easeOutElastic);
        LeanTween.alphaText(text.GetComponent<RectTransform>(), 1f, .5f).setDelay(1f);
    }

    public void CloseDialogBox()
    {
        // fade out background
        background.LeanAlpha(0, 0.5f);

        // scale dialog box from one to zero
        dialogBox.LeanScale(Vector2.zero, 0.7f).setEaseInBack().setOnComplete(OnComplete);
    }

    public void OnComplete()
    {
        gameObject.SetActive(false);
    }
}
```

Figure 5.4.12 Confirmation Box script.

Then, Figure 5.4.12 shows the C# script created for the animation of the dialog box. The OnEnable() method will be invoked once the dialog box is opened. This method defines the animation when opening the dialog box. Then, the CloseDialogBox() will be invoked for performing the animation when the close dialog box button is clicked. After that, the dialog box is set to be inactive.

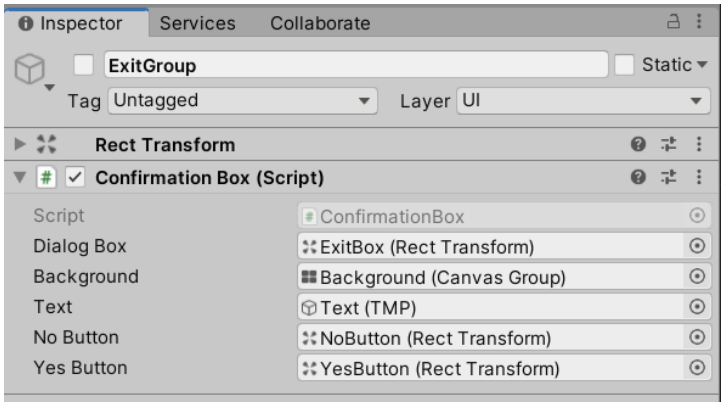


Figure 5.4.13 Inspector window of ExitGroup game object.

Figure 5.4.13 shows the inspector window of ExitGroup game object. The Confirmation Box script is added into ExitGroup game object and the necessary game objects are assigned to this script.

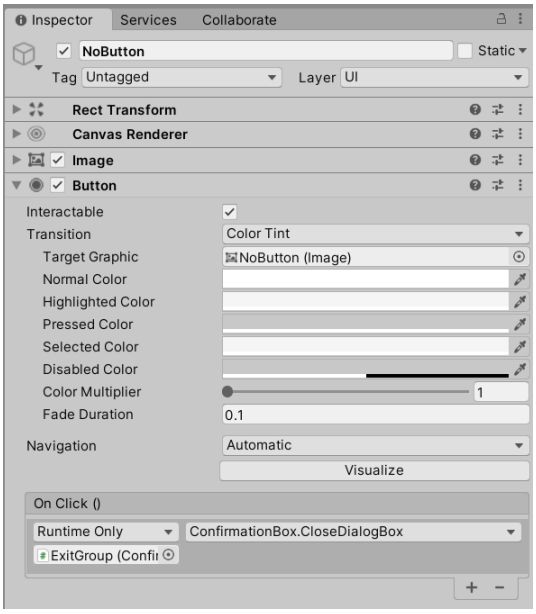


Figure 5.4.14 Inspector window of NoButton game object.

Figure 5.4.14 shows the inspector window of the NoButton game object of the exit confirmation dialog box. At the On Click() section, the CloseDialogBox method is

added, so that when the user clicks on the NoButton, this method will be executed to perform the animation that closes the dialog box.

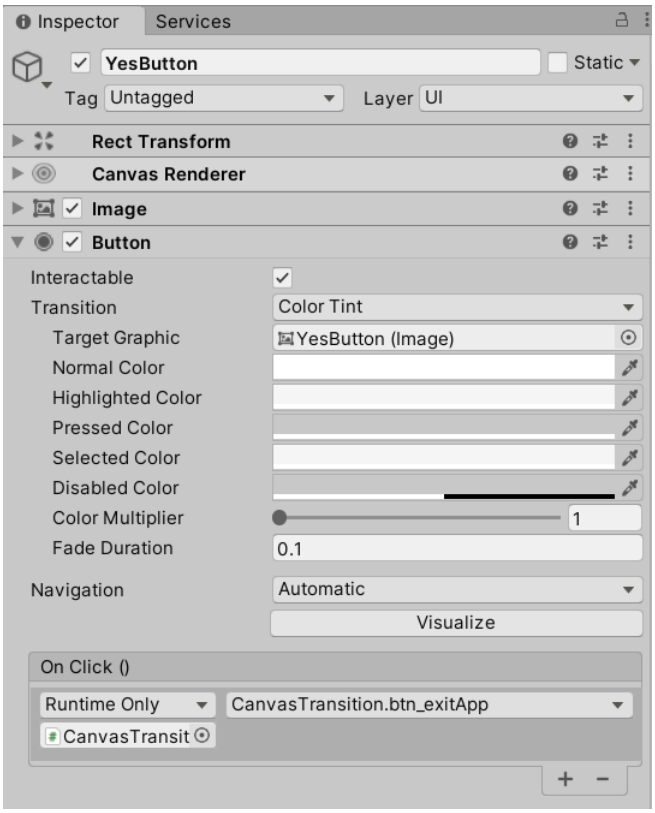


Figure 5.4.15 Inspector window of YesButton game object.

Figure 5.4.15 shows the inspector window of the YesButton game object of the exit confirmation dialog box. At the On Click() section, the btn_exitApp method of Canvas Transition script is added, to perform the function of exiting the application. The detail of this method is shown in Figure 5.4.6.

5.5 Development of Play AR Scene

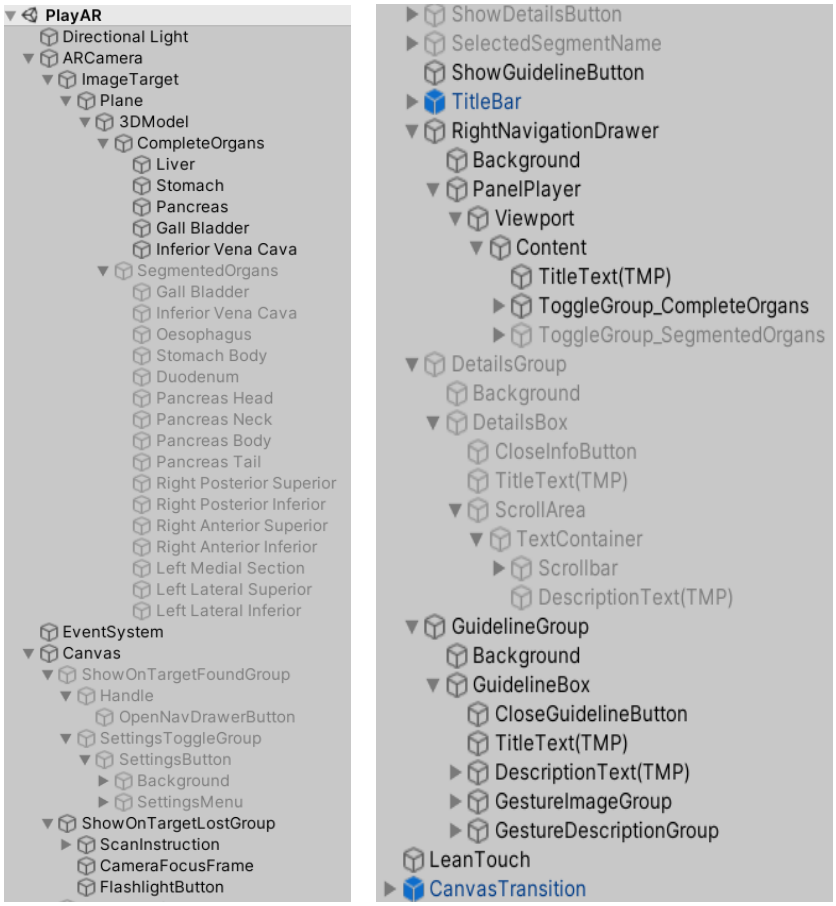


Figure 5.5.1 Hierarchy of Play AR Scene.

To create the Play AR Scene, the game objects as shown in Figure 5.5.1 are added to the scene hierarchy.

Game Object	Function / Description
ARCamera	The camera view for augmented reality
ImageTarget	The image target for augmented reality
CompleteOrgans	The 3D model of organs that are in complete form
SegmentedOrgans	The 3D model of organs that are in segmented form
ShowAfterScanGroup	The parent of the game objects that will be shown after the target marker is detected
ShowBeforeScanGroup	The parent of the game objects that will be shown before the target marker is detected
AutoRotateButton	Button to rotate the AR model automatically
ToggleSegmentationButton	Button to toggle segmentation of the AR model

ToggleFlashlightButton	Button to toggle flashlight of the device
SelectedSegmentNameText (TMP)	To display the selected segment name
ShowDetailsButton	The button to open and display the pop-up box of the details of the selected structure
ShowGuidelineButton	The button to open and display the dialog box of the guidelines on how to use the AR function
RightNavigationDrawer	The right navigation drawer which allows users to hide or show the ticked or unticked structure
DetailsGroup	The parent of the details pop-up box and its background
GuidelineGroup	The parent of the guideline dialog box and its background
LeanTouch	A free Unity asset for various gesture functions
OpenNavDrawerButton	The button to open the right navigation drawer

Table 5.5.1 Function / description of some main game objects in Play AR Scene.

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

public class ARGuideline : MonoBehaviour, IPointerClickHandler
{
    [SerializeField]
    TextMeshProUGUI mainText;

    // Start is called before the first frame update
    void Start()
    {
        CustomizeText();
    }

    void CustomizeText()
    {
        mainText.text = "1.  Click <color=blue><u><link=https://drive.google.com/file/d/1os7MNJNsPW7rR9iIM3H5X4OF-ia0OTBU/view?usp=sharing >here</link></u></c
                        "2.  Enable the permission to use your device's camera when asked, or go to your device's settings to enable it.\n" +
                        "3.  Scan the image target using your camera, and wait for it to be detected.\n" +
                        "4.  Once the image target is detected, the AR model will be displayed on your device screen.\n" +
                        "5.  You can interact with the AR model using the following features.";
    }

    public void OnPointerClick(PointerEventData eventData)
    {
        int index = TMP_TextUtilities.FindIntersectingLink(mainText, Input.mousePosition, null);

        if (index > -1)
        {
            Application.OpenURL(mainText.textInfo.linkInfo[index].GetLinkID()); // open the URL link
        }
    }
}
```

Figure 5.5.2 AR Guideline script.

Figure 5.5.2 shows the script for setting the text of the guidelines on how to use the AR function, with specific styles such as blue font colour for the target marker link. The OnPointerClick() is used to open the URL link. The application will redirect the user to a google drive link to download the target marker.

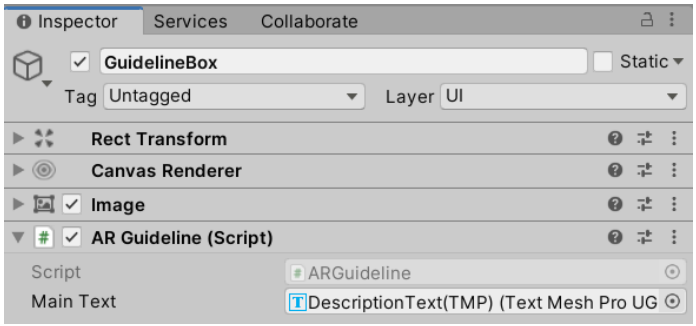


Figure 5.5.3 Inspector window of GuidelineBox game object.

Figure 5.5.3 shows that the AR Guideline script is added to the GuidelineBox game object with the text game object assigned to it.

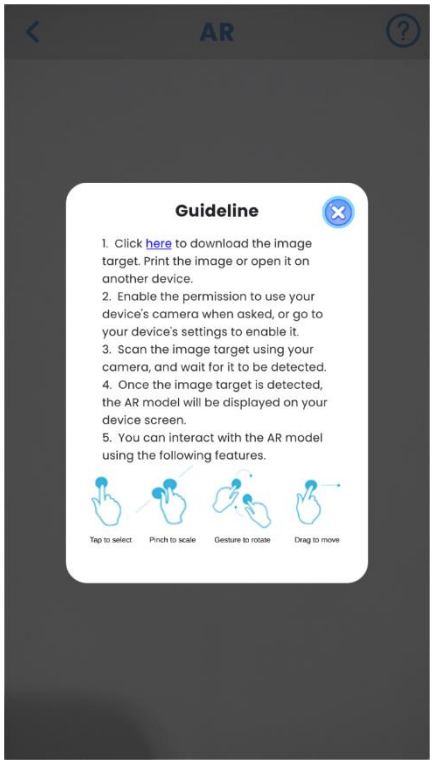


Figure 5.5.4 Guideline panel in Play AR Scene.

Figure 5.5.4 shows the user interface of the Play AR scene once the user enters the scene. The guideline panel displayed guides the users on how to download the target marker and use AR function. When the user clicks on the link provided in the guideline, the user will be navigated to download the target image. Then, the user can close the guideline panel. The user can open back the guideline panel by clicking on the help button at the top-right corner of the screen.

Creating AR Camera and Image Target Game Object

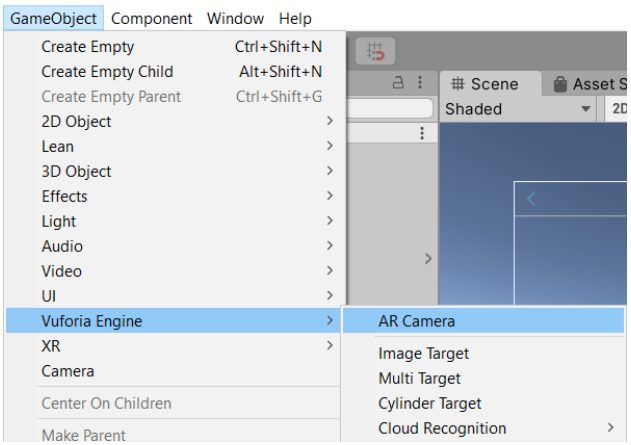


Figure 5.5.5 Creating AR Camera game object.

First, go to GameObject > Vuforia Engine > AR Camera to create the AR Camera game object as shown in Figure 5.5.5. In the Hierarchy window, right click on the AR Camera game object > Vuforia Engine > Image Target to create the Image Target game object as a child of the AR Camera game object.

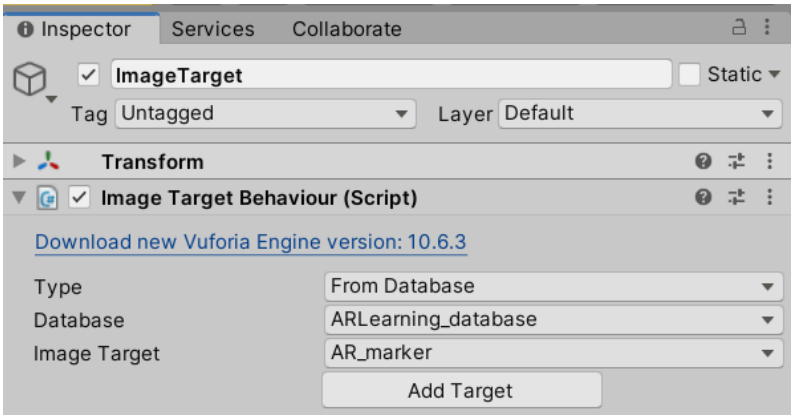


Figure 5.5.6 Inspector window of Image Target game object.

Select the Image Target game object, then select the type, database and image target as shown in Figure 5.5.6, to use the image target from the database that was imported from the Vuforia Engine developer portal. This image target will be the target marker for the user to point their camera at, to show up the augmented object.

Importing 3D Object of Human Digestive System Anatomy

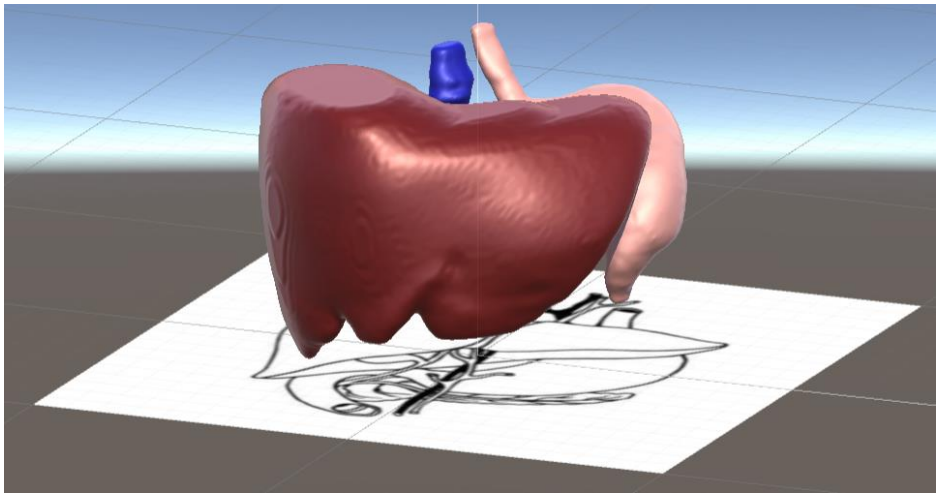


Figure 5.5.7 3D Model positioned above image target.

The 3D model of the human digestive system anatomy from the preliminary work done is imported into Unity Assets folder. Then, the 3D model is dragged to be the child of the Image Target game object. After that, the scale and position of the object is adjusted so that it is positioned above the image target as shown in Figure 5.5.7. The 3D model is unpacked by right clicking on the 3D Model game object > Prefabs > Unpack Completely, so that the different parts of the model can be moved, edited and grouped together.

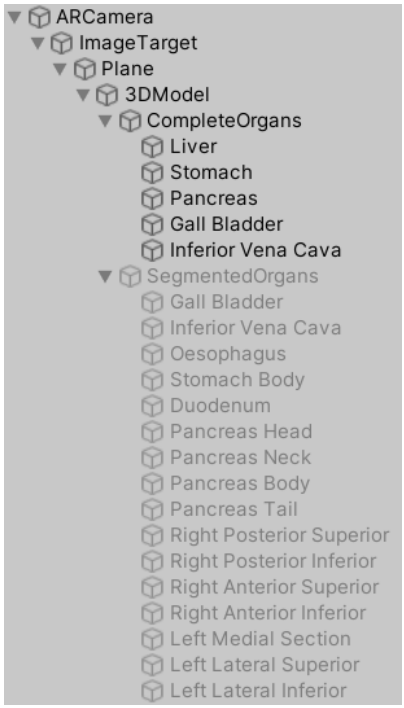


Figure 5.5.8 Arrangement of 3D model parts in Hierarchy.

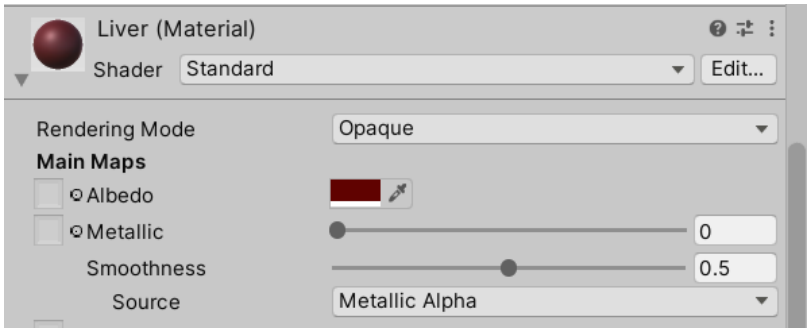


Figure 5.5.9 Material component of Liver game object.

Furthermore, the 3D Model is arranged into two groups of game objects, which are the Complete Organs Model and Segmented Organs Model as shown in Figure 5.5.8. This is to prepare the 3D model for the use of toggle organ segmentation function later. Besides, a material component is added onto each structure of the model to add the respective colours for each organ as shown in Figure 5.5.9.

Setting Up AR Camera

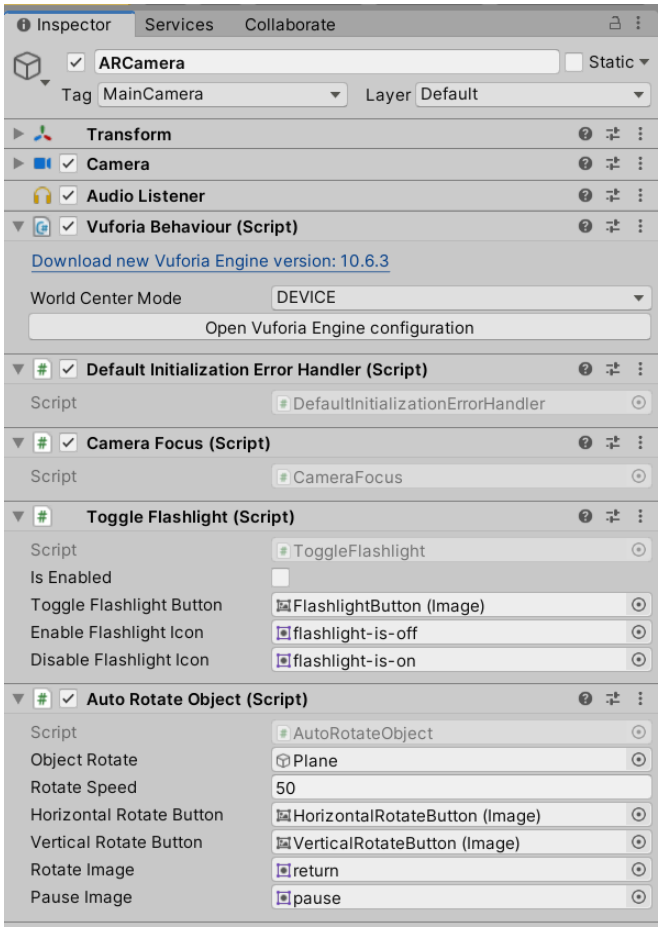


Figure 5.5.10 Inspector window of AR Camera game object.

Based on Figure 5.5.10, a few scripts are added to the AR Camera game object, such as the Camera Focus script, Toggle Flashlight script, and Auto Rotate Object script.

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

public class CameraFocus : MonoBehaviour
{
    // Start is called before the first frame update
    void Start()
    {
        VuforiaApplication.Instance.OnVuforiaStarted += StartVuforiaFocus;
    }

    public void StartVuforiaFocus()
    {
        VuforiaBehaviour.Instance.CameraDevice.SetFocusMode(FocusMode.FOCUS_MODE_CONTINUOUSAUTO); // focus the camera
    }
}
```

Figure 5.5.11 Camera Focus script.

Figure 5.5.11 shows the Camera Focus script, which is used to focus the device camera, so that it can detect the target image.

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

public class AutoRotateObject : MonoBehaviour
{
    public GameObject objectRotate;
    public float rotateSpeed = 50f;
    bool isEnabledHorizontal = false, isEnabledVertical = false;

    public void HorizontalRotateButtonClicked()
    {
        isEnabledHorizontal = !isEnabledHorizontal;
    }

    public void VerticalRotateButtonClicked()
    {
        isEnabledVertical = !isEnabledVertical;
    }

    // Update is called once per frame
    void Update()
    {
        if (isEnabledHorizontal == true)
        {
            objectRotate.transform.Rotate(Vector3.up, rotateSpeed * Time.deltaTime); // rotate the object horizontally
        }
        else if (isEnabledVertical == true)
        {
            objectRotate.transform.Rotate(Vector3.left, rotateSpeed * Time.deltaTime); // rotate the object vertically
        }
    }
}
```

Figure 5.5.12 Auto Rotate Object script.

Figure 5.5.12 shows the Auto Rotate Object script which is used for enabling auto rotation of the 3D object in horizontal or vertical direction.

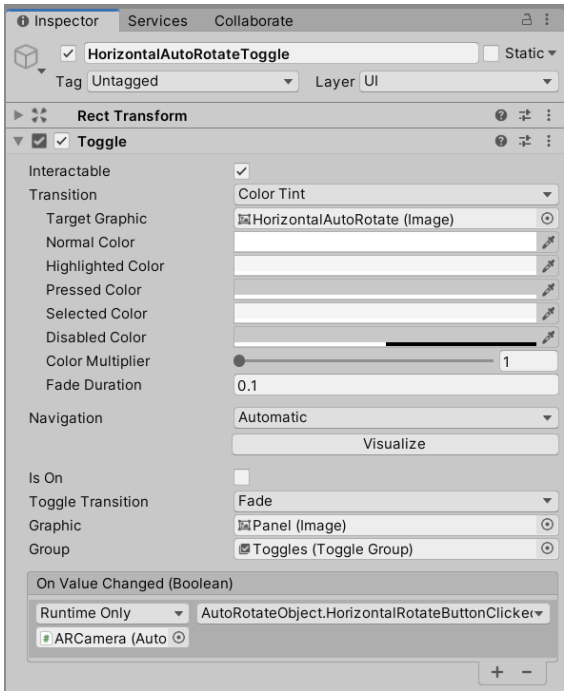


Figure 5.5.13 Inspector window of HorizontalAutoRotateToggle game object.

The HorizontalRotateButtonClicked method is added to the game object as shown in Figure 5.5.13 so that when the user clicks on this toggle button, the horizontal autorotation of the 3D model will be toggled. Similar steps are done for the vertical auto-rotation toggle function.

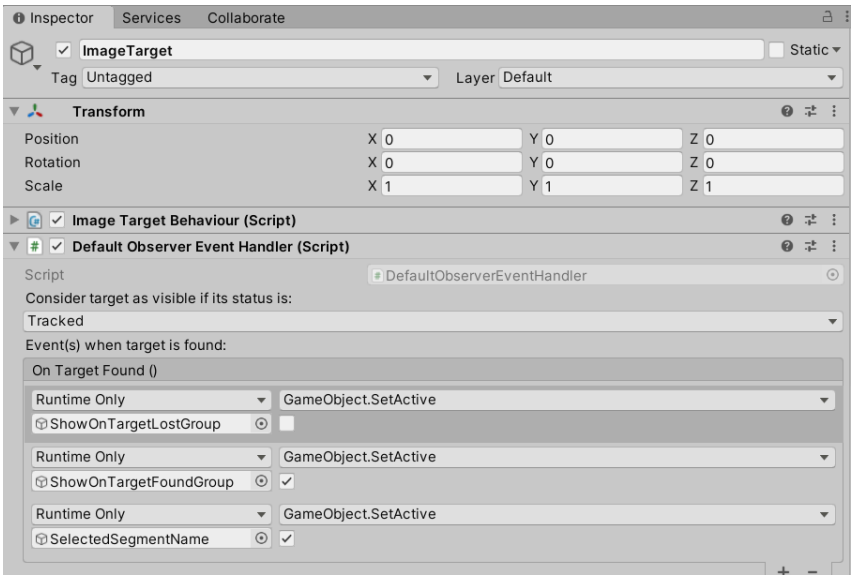


Figure 5.5.14 Inspector window of Image Target game object (Part I).

Figure 5.5.15 Inspector window of Image Target game object (Part II).

Figure 5.5.14 shows the inspector window of Image Target game object. The game objects to be shown or hidden when the target is found or lost are defined in the On Target Lost method and On Target Lost method.

Manipulate 3D Model Function

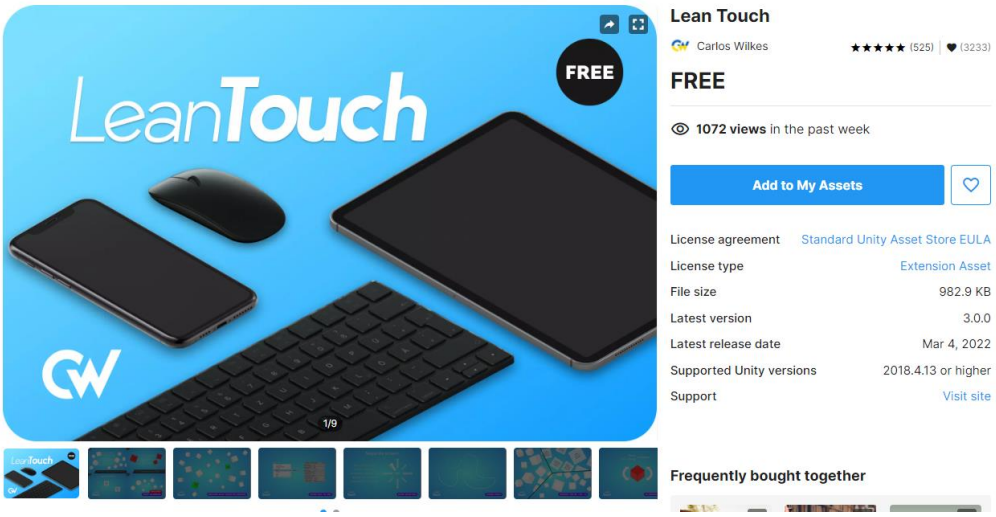


Figure 5.5.16 LeanTouch from Unity Asset store.

LeanTouch from the Unity Asset store is downloaded and imported into the Unity project to build the functions of interacting with the AR model using fingertips gesture. LeanTouch provides a lot of scripts that is useful for this application.

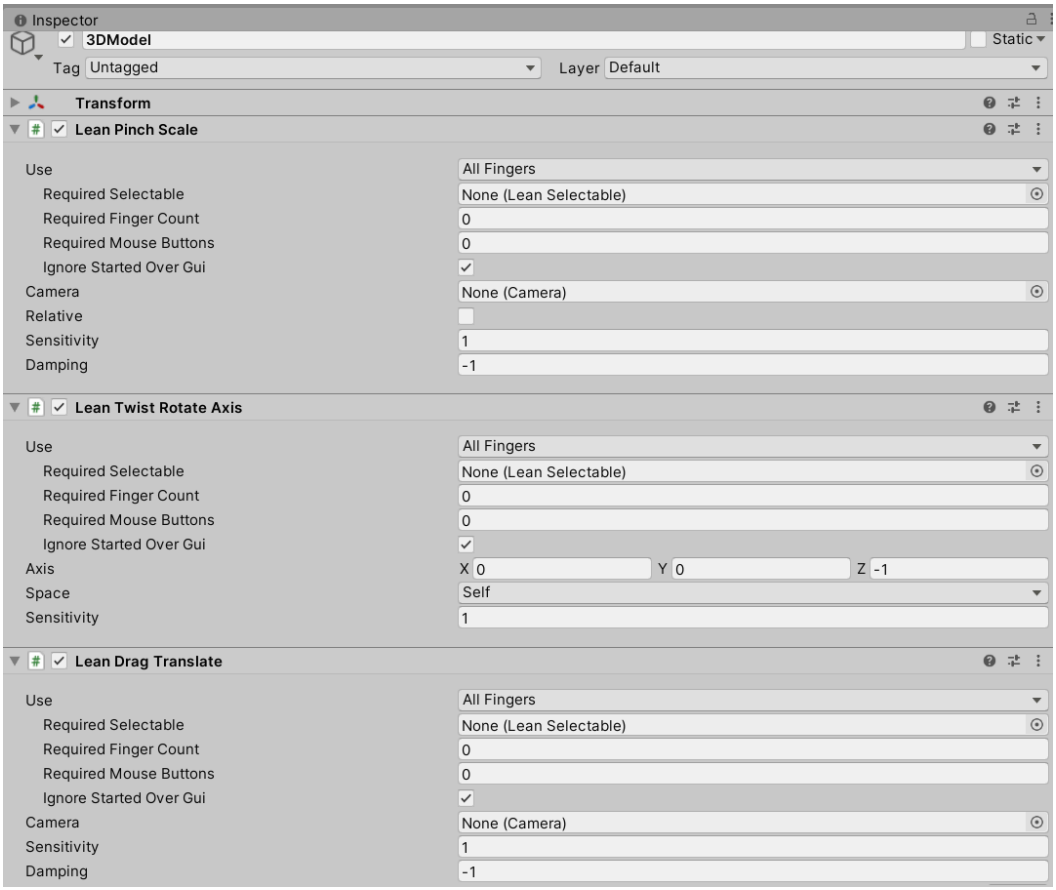


Figure 5.5.17 Inspector window of 3D Model game object.

A few scripts from LeanTouch are used in this application as shown in Figure 5.5.17. Lean Pinch Scale script is used for the scaling function so that the user can scale the model using pinch gesture. Next, Lean Twist Rotate Axis script is used for the rotate function so that the user can rotate the model using twist rotate gesture. Lastly, Lean Drag Translate script is used for the dragging function so that the user can move the model using drag gesture.

Select Structure Part and Show Details Function

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

public class SelectStructurePart : MonoBehaviour
{
    string objectName;
    public TextMeshProUGUI selectedSegmentNameText;
    public TextMeshProUGUI titleText;
    public TextMeshProUGUI descriptionText;
    public GameObject informationGroup;
    public Image showInfoButton;
    public GameObject CompleteModel;
    public GameObject SegmentedModel;
    Transform[] children;

    // Update is called once per frame
    void Update()
    {
        if (!informationGroup.transform.gameObject.activeSelf && Input.touchCount > 0 && Input.touches[0].phase == TouchPhase.Began)
        {
            Ray ray = Camera.main.ScreenPointToRay(Input.GetTouch(0).position);
            RaycastHit Hit;

            if (Physics.Raycast(ray, out Hit))
            {
                objectName = Hit.transform.name;
                Debug.Log("objectName" + objectName);

                //disable the outline of previously selected part
                if (CompleteModel.transform.gameObject.activeSelf)
                {
                    foreach (Transform child in CompleteModel.transform)
                    {
                        if (child.gameObject.activeSelf)
                        {
                            child.gameObject.GetComponent<Outline>().enabled = false;

                        }
                    }
                }
```

Figure 5.5.18 Select Structure Part script (Part I).

```
                if (SegmentedModel.transform.gameObject.activeSelf)
                {
                    foreach (Transform child in SegmentedModel.transform)
                    {
                        if (child.gameObject.activeSelf)
                        {
                            child.gameObject.GetComponent<Outline>().enabled = false;
                        }
                    }
                }

                //enable the outline of currently selected part
                Hit.transform.gameObject.GetComponent<Outline>().enabled = true;
                Debug.Log("before switch-case, objectName: " + objectName);

                //assign name and description of selected part
                switch (objectName)
                {
                    case "Liver":
                        selectedSegmentNameText.gameObject.SetActive(true);
                        selectedSegmentNameText.text = objectName;
                        titleText.text = objectName;
                        descriptionText.text = "The liver is a spongy, wedge-shaped, reddish-brown internal organ. It is largest solid organ
                            "filters the blood to remove toxins, controls blood sugar levels, regulates blood clotting and performs many oth
                            "the liver is on the right upper abdomen under the rib cage." +
                            "\n\n<b>Functions:</b>\n" +
                            "(i)    Removes toxins from the blood.\n" +
                            "(ii)   Removes old red blood cells.\n" +
                            "(iii)  Produces bile which is a fluid that aids in the digestion of food.\n" +
                            "(iv)   Metabolizes proteins, carbohydrates, and lipids so that the body can absorb it.\n" +
                            "(v)    Produces substances that aid in the clotting of blood.\n" +
                            "(vi)   Control the amount of blood in the body.\n" +
                            "(vii)  Store glycogen and vitamins.";
                        showInfoButton.gameObject.SetActive(true);
                        break;
                    case "Stomach":
                        selectedSegmentNameText.gameObject.SetActive(true);
                        selectedSegmentNameText.text = objectName;
                        titleText.text = objectName;
                        descriptionText.text = "The stomach is a hollow, muscular bean-shaped organ which digests food. The stomach  secrete
                            "which facilitates food digestion by breaking down the food into smaller pieces so that it can be passed to the
                            "It is located in the upper abdomen on the left side of your body. The top of the stomach is connected to the oe
```

Figure 5.5.19 Select Structure Part script (Part II).

```
                    break;
                case "Right Anterior Inferior":
                    selectedSegmentNameText.gameObject.SetActive(true);
                    selectedSegmentNameText.text = objectName;
                    titleText.text = objectName;
                    descriptionText.text = "The liver consists of two main parts: the larger right lobe and the smaller left lobe. T
                    showInfoButton.gameObject.SetActive(true);
                    break;
                case "Left Medial Section":
                    selectedSegmentNameText.gameObject.SetActive(true);
                    selectedSegmentNameText.text = objectName;
                    titleText.text = objectName;
                    descriptionText.text = "The liver consists of two main parts: the larger right lobe and the smaller left lobe. T
                    showInfoButton.gameObject.SetActive(true);
                    break;
                case "Left Lateral Superior":
                    selectedSegmentNameText.gameObject.SetActive(true);
                    selectedSegmentNameText.text = objectName;
                    titleText.text = objectName;
                    descriptionText.text = "The liver consists of two main parts: the larger right lobe and the smaller left lobe. T
                    showInfoButton.gameObject.SetActive(true);
                    break;
                case "Left Lateral Inferior":
                    selectedSegmentNameText.gameObject.SetActive(true);
                    selectedSegmentNameText.text = objectName;
                    titleText.text = objectName;
                    descriptionText.text = "The liver consists of two main parts: the larger right lobe and the smaller left lobe. T
                    showInfoButton.gameObject.SetActive(true);
                    break;
                default:
                    Hit.transform.gameObject.GetComponent<Outline>().enabled = false;
                    selectedSegmentNameText.gameObject.SetActive(false);
                    break;
            }
        }
    }
}
```

Figure 5.5.20 Select Structure Part script (Part III).

A script named as “Select Structure Part” is created for select and highlight function. When the user taps on one of the structure parts of the 3D model using his or her fingertip, the structure part will be selected and highlighted with outline. Then, the script also set the name and description of the selected structure part so that it can be displayed to the user later.

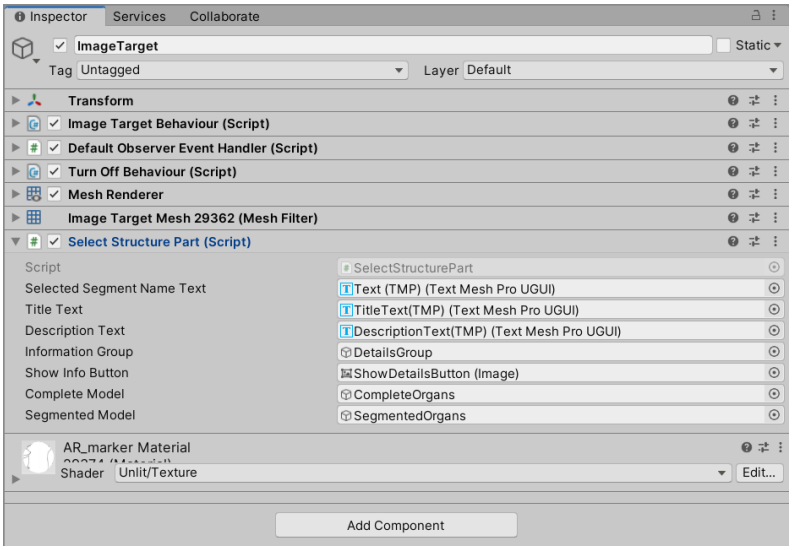


Figure 5.5.21 Inspector window of ImageTarget game object.

Figure 5.5.21 shows that the Select Structure Part script is added to the ImageTarget game object and the necessary game objects are assigned to this script.

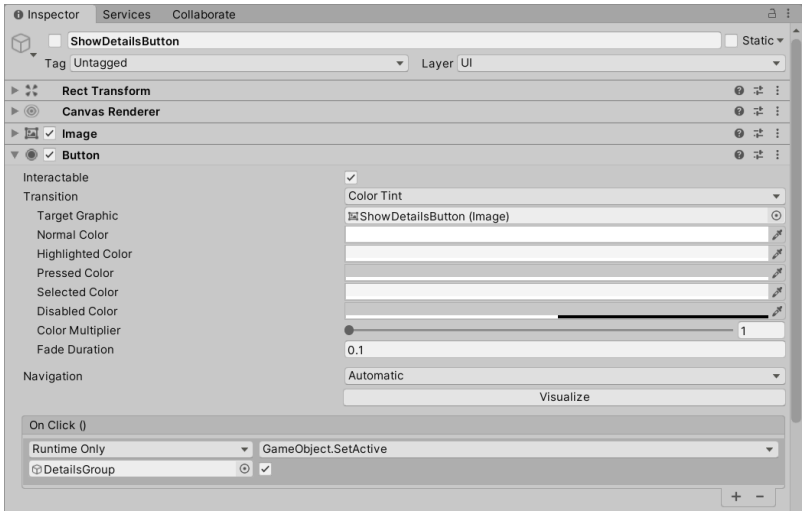


Figure 5.5.22 Inspector window of ShowDetailsButton game object.

Figure 5.5.22 shows the inspector window of the ShowDetailsButton. The DetailsGroup game object, which is the panel to display the description of the selected part, is set to active once the On Click method is triggered. This will pop out the details panel to allow users to view the description of the selected structure.

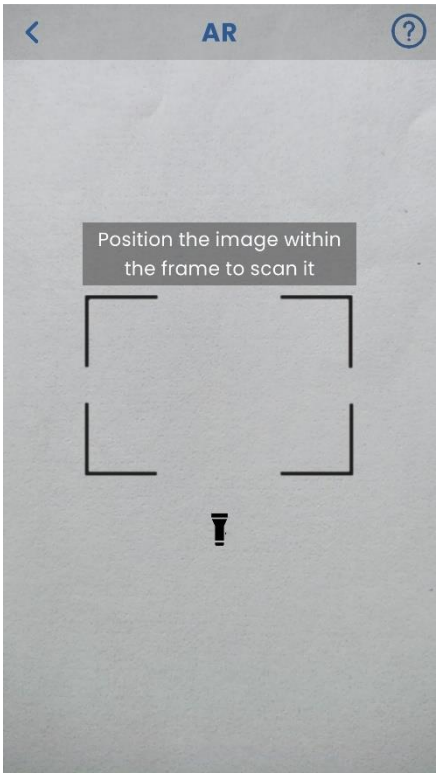


Figure 5.5.23 User interface of Play AR Scene before marker detected.

After closing the guideline panel, the user interface as shown in Figure 5.5.23 will be displayed to the user before the user start to scan the target image. The user is required

to scan the target image that is downloaded from the guideline link, using his device's camera. In addition, there is a flashlight button at the middle of the screen. This flashlight function is useful if the user's environment is too dark until the marker cannot be detected.

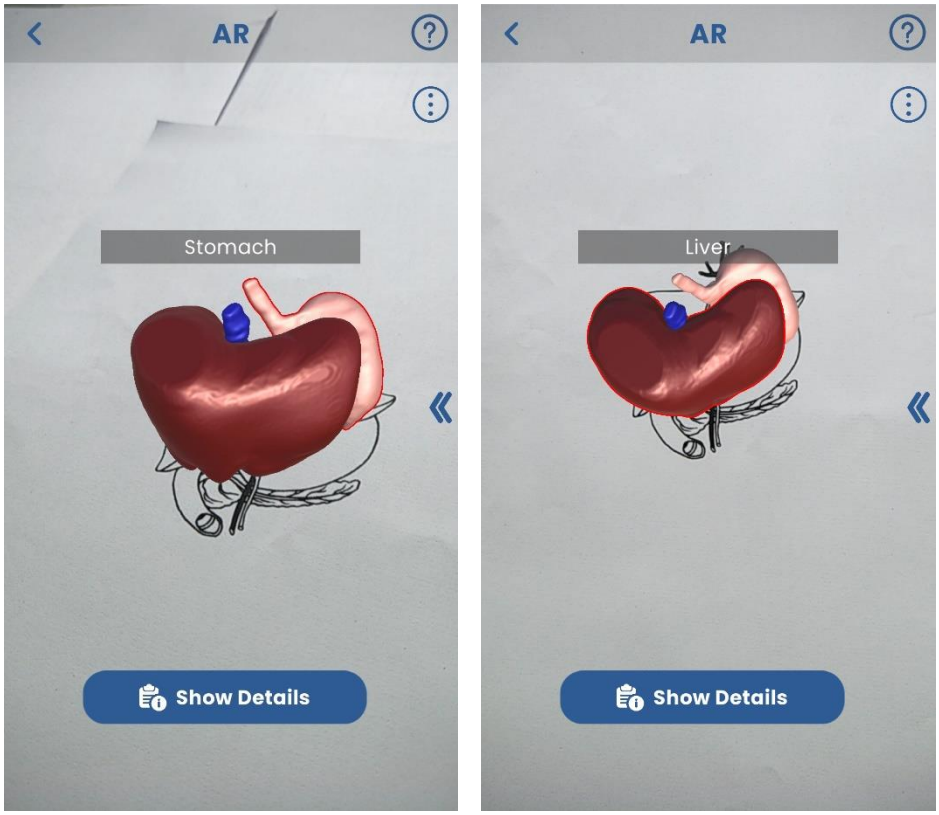


Figure 5.5.24 User interface of Play AR Scene when a structure part is selected.

After scanning and detecting the target image successfully, the AR model of the liver, stomach, pancreas and gall bladder will pop out on the user device screen. The user can now interact with the AR model using different gesture. For example, pinch in/out using two fingertips to zoom in/out the AR model, rotate using two fingertips to rotate the AR model, drag and drop the AR model to move it to another position. The user can also tap on the organ to select the structure part as shown in Figure 5.5.24.

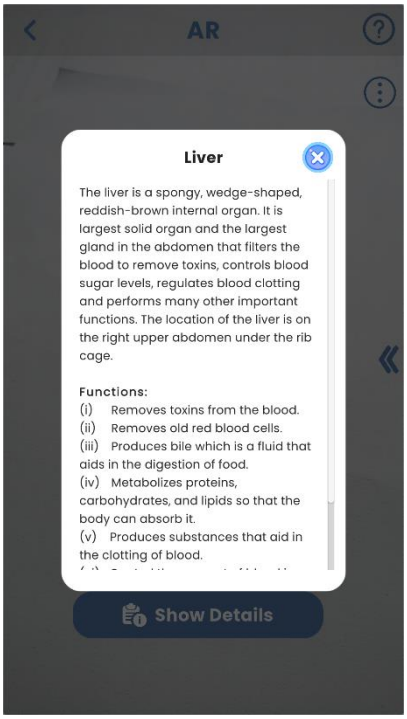


Figure 5.5.25 Information panel of selected structure.

When a structure part is selected, the user can click “Show Details” button to view the details of the selected structure. Figure 5.5.25 shows the details of the selected part.

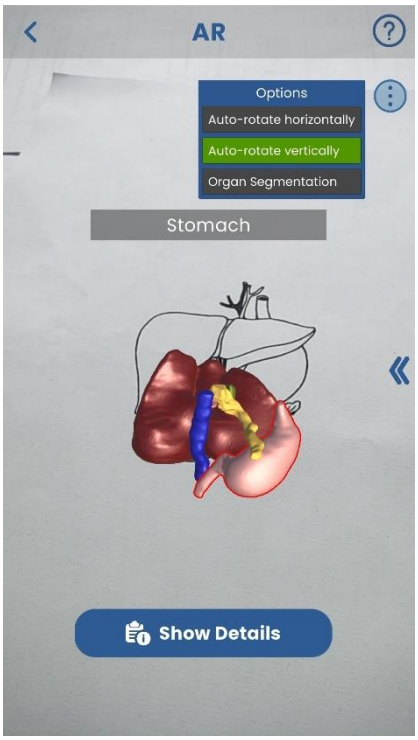


Figure 5.5.26 AR model is auto-rotating.

Figure 5.5.26 shows the AR model is auto-rotating vertically when the user enables it.

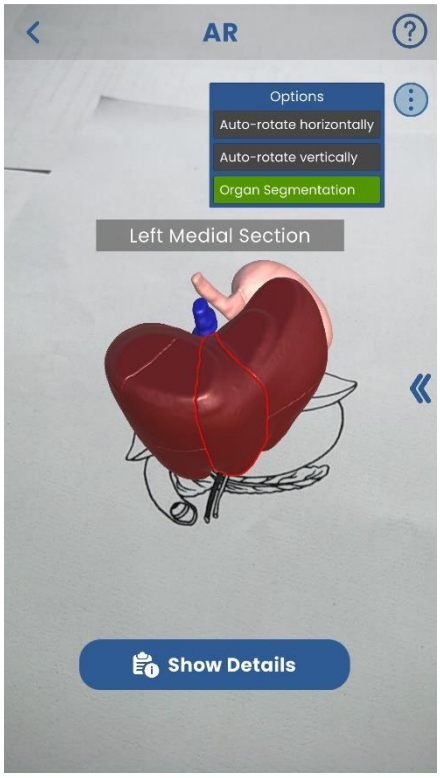


Figure 5.5.27 AR model in segmented form.

Figure 5.5.27 shows the organs are segmented when the user enables the organ segmentation function.

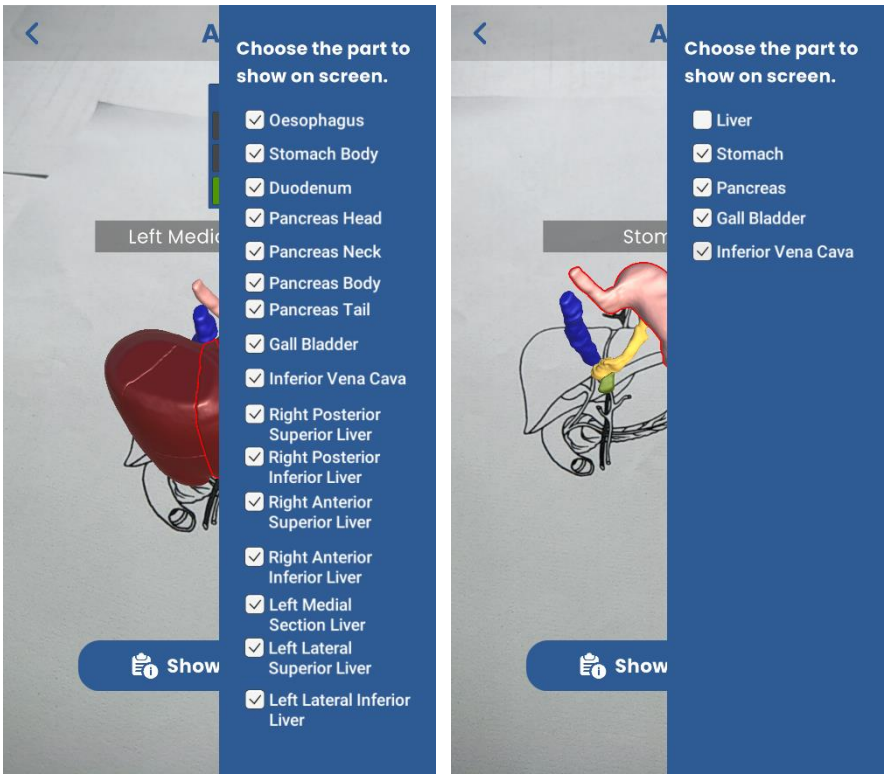


Figure 5.5.28 Right navigation panel to show/hide parts of AR model.

In addition, when the user clicks on the arrow button at the right side of the screen, the right navigation panel will slide into the screen, as shown in Figure 5.5.28. The user can tick or untick the organs listed in the right navigation panel to show or hide the organ on the screen. The list of organs changes based on whether the organ segmentation mode is enabled.

5.6 Development of Select Topic Scene

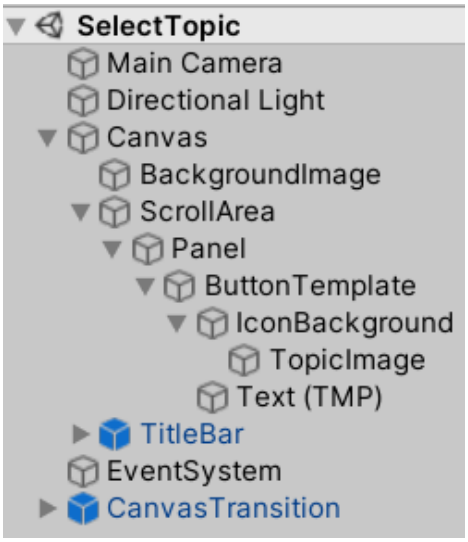


Figure 5.6.1 Hierarchy of Select Topic Scene.

To create the Select Topic Scene, the game objects as shown in Figure 5.6.1 are added to the scene hierarchy.

Game Object	Function / Description
ScrollArea	The area that allows scrolling, which has the Scroll Rect component
Panel	The parent of the buttons which has the Vertical Layout Group component
ButtonTemplate	Button to change current scene to the Topic Information Scene
TopicImage	Image of the anatomy topic
Text (TMP)	Text Mesh Pro of the name of the topic

Table 5.6.1 Function / description of some main game objects in Select Topic Scene.

```
using System;
using UnityEngine;
using UnityEngine.UI;
using TMPro;

0 references
public static class ButtonExtension
{
    1 reference
    public static void AddEventListener<T>(this Button button, T param, Action<T> OnClick)
    {
        button.onClick.AddListener(delegate ()
        {
            OnClick(param);
        });
    }
}

Unity Script (1 asset reference) | 5 references
public class SelectTopic : MonoBehaviour
{
    public static int topicSelectedIndex;
    public static string topicSelected;
    [SerializeField] private Topic[] allTopics;

    [Serializable]
    1 reference
    public struct Topic
    {
        public string TopicName;
        public Sprite TopicImage;
    }

    // Start is called before the first frame update
    Unity Message | 0 references
    void Start()
    {
        GameObject buttonTemplate = transform.GetChild(0).gameObject;
        GameObject g;
        int N = allTopics.Length;

        for(int i = 0; i < N; i++)
        {
            g = Instantiate(buttonTemplate, transform);
            g.transform.GetChild(0).GetChild(0).GetComponent<Image>().sprite = allTopics[i].TopicImage; //set the topic image
            g.transform.GetChild(1).GetComponent<TextMeshProUGUI>().text = allTopics[i].TopicName; //set the topic name

            g.GetComponent<Button>().AddEventListener(i, TopicClicked);
        }

        Destroy(buttonTemplate); //destroy the initial button template
    }

    1 reference
    private void TopicClicked(int topicIndex)
    {
        topicSelectedIndex = topicIndex;
        topicSelected = allTopics[topicIndex].TopicName;
    }
}
```

Figure 5.6.2 Select Topic script.

A C# script named “Select Topic” is created as shown in Figure 5.6.2. This script is to create the buttons of each anatomy topic with topic image and topic name, and to store the topic clicked by the user into a static variable to be passed to the next scene.

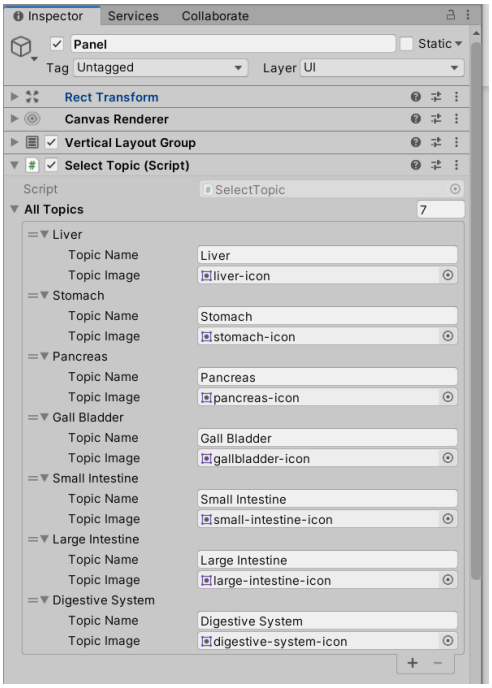


Figure 5.6.3 Inspector window of Panel game object.

After created the Select Topic script, add this script to the Panel game object. Then, assign the name and image for each of the anatomy topics.

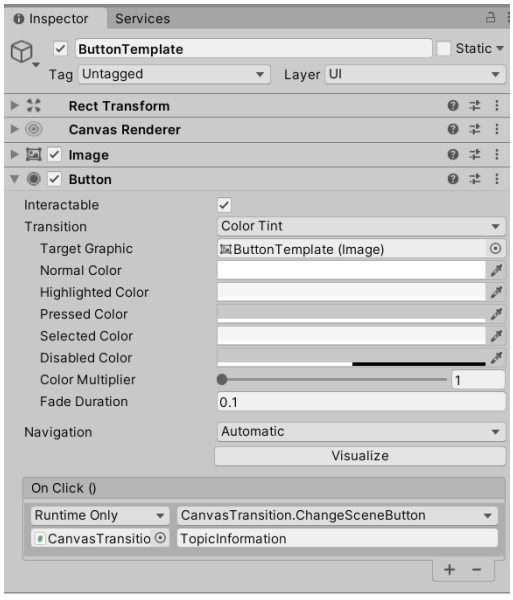


Figure 5.6.4 Inspector window of ButtonTemplate game object.

At the On Click() section of the ButtonTemplate game object, ChangeSceneButton method of CanvasTransition script is added, so that the scene will be changed to the Topic Information Scene when the user clicks on the ButtonTemplate.

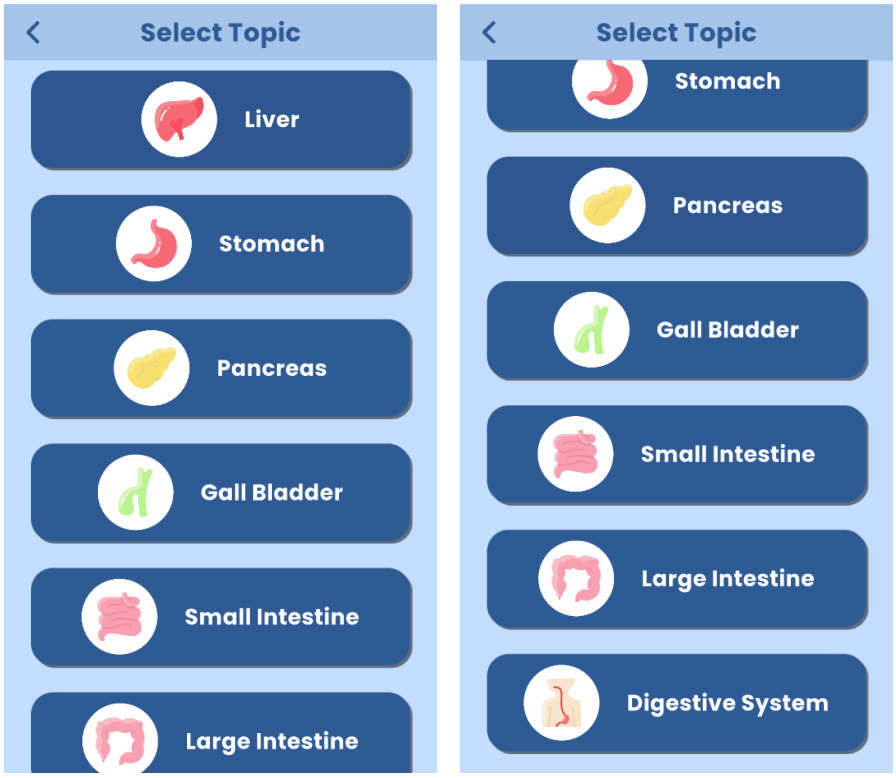


Figure 5.6.5 User interface of Learn Anatomy Scene.

Figure 5.6.5 shows the user interface of the Learn Anatomy Scene developed. There is a list of all anatomy topics. The user can select the topic to view by clicking on the topic.

5.7 Development of Topic Information Scene

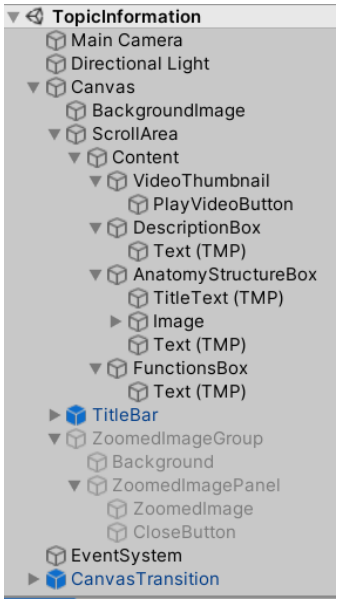


Figure 5.7.1 Hierarchy of Topic Information Scene.

To create the Topic Information Scene, the game objects as shown in Figure 5.7.1 are added to the scene hierarchy.

Game Object	Function / Description
ScrollArea	The area that allows scrolling, which has the Scroll Rect component
Content	The parent of the content of the video and topic informations
VideoThumbnail	The video thumbnail image
PlayVideoButton	Button to change the current scene to Video Player Scene, then open and play the video
DescriptionBox	The box that contains the description of the organ topic
AnatomyStructureBox	The box that contains the anatomy structure of the organ topic
FunctionsBox	The box that contains the functions of the organ topic
ZoomedImageGroup	The parent of the panel that contains a zoomed in version of the anatomy structure image
ZoomedImagePanel	A panel that contains a zoomed in version of the anatomy structure image
CloseButton	Button to close the panel that contains a zoomed in version of the anatomy structure image

Table 5.7.1 Function / description of some main game objects in Topic Information Scene.

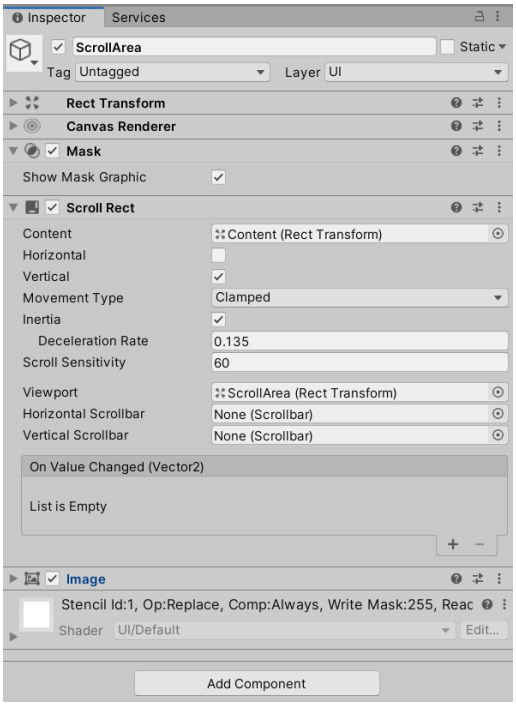
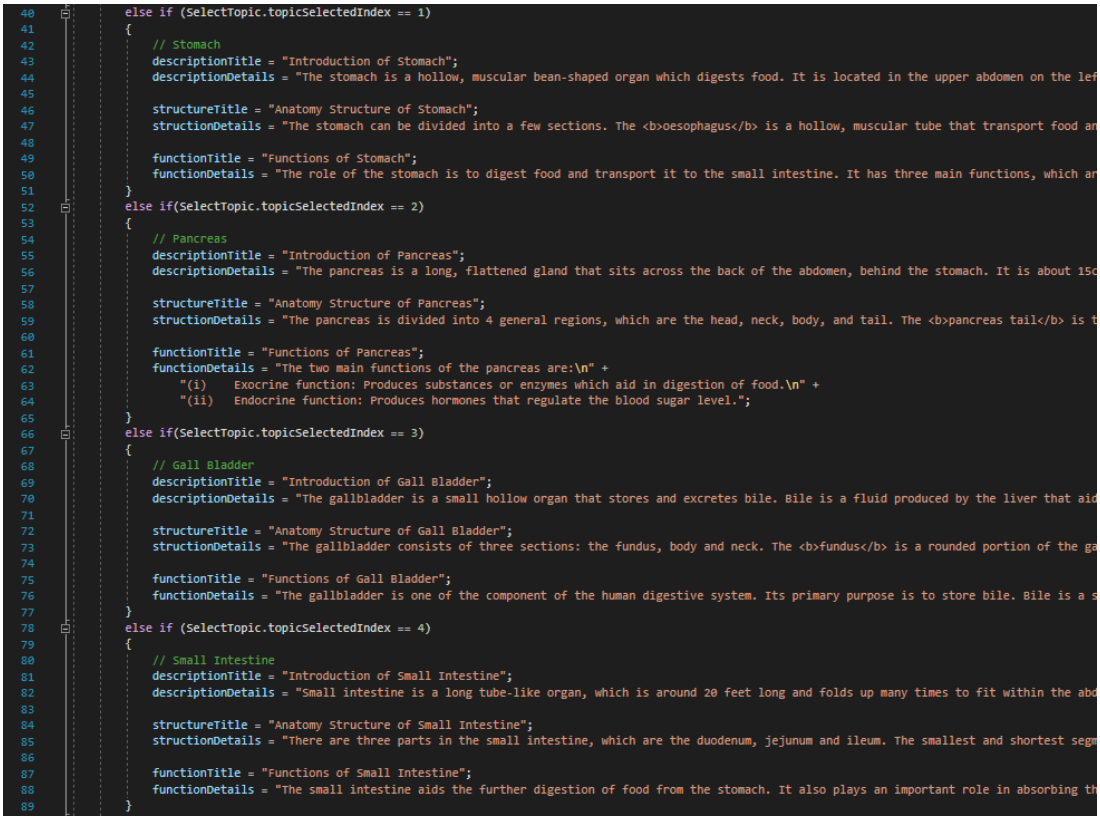


Figure 5.7.2 Inspector window of ScrollArea game object.

A ScrollArea game object is added to the canvas so that the user can scroll up and down the content of the topic information. Then, ScrollRect component is added to this game object. Under the ScrollRect component, the content to be scrolled is assigned, and only vertical movement is enabled. In addition, the Scroll Sensitivity is set to 60 so that the user can scroll at an appropriate speed.

```
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class TopicInformation : MonoBehaviour
{
    public TextMeshProUGUI TitleBarText;
    public Sprite[] videoThumbnails;
    public Sprite[] structureImages;
    public GameObject zoomedStructureImage;

    // Start is called before the first frame update
    void Start()
    {
        GameObject videoThumbnail = transform.GetChild(0).gameObject;
        GameObject description = transform.GetChild(1).gameObject;
        GameObject structure = transform.GetChild(2).gameObject;
        GameObject structureImage = structure.transform.GetChild(1).gameObject;
        GameObject function = transform.GetChild(3).gameObject;

        string descriptionTitle, descriptionDetails, structureTitle, structionDetails, functionTitle, functionDetails;

        // Set the video thumbnail, image and texts based on the selected topic from previous Select Topic scene
        if (SelectTopic.topicSelectedIndex == 0)
        {
            // Liver
            descriptionTitle = "Introduction of Liver";
            descriptionDetails = "The liver is a spongy, wedge-shaped, reddish-brown internal organ. It is largest solid organ and th

            structureTitle = "Anatomy Structure of Liver";
            structionDetails = "The liver consists of two main parts: the <b>larger right lobe</b> and the <b>smaller left lobe</b>.

            functionTitle = "Functions of Liver";
            functionDetails = "The liver is responsible for hundreds of functions. The following are a few of the most crucial:\n" +
                "(i)    Removes toxins from the blood.\n" +
                "(ii)   Removes old red blood cells.\n" +
                "(iii)  Produces bile which is a fluid that aids in the digestion of food.\n" +
                "(iv)   Metabolizes proteins, carbohydrates, and lipids so that the body can absorb it.";
        }
```

Figure 5.7.3 Topic Information script (Part I).



```
        else if (SelectTopic.topicSelectedIndex == 1)
        {
            // Stomach
            descriptionTitle = "Introduction of Stomach";
            descriptionDetails = "The stomach is a hollow, muscular bean-shaped organ which digests food. It is located in the upper abdomen on the lef

            structureTitle = "Anatomy Structure of Stomach";
            structionDetails = "The stomach can be divided into a few sections. The <b>oesophagus</b> is a hollow, muscular tube that transport food ar

            functionTitle = "Functions of Stomach";
            functionDetails = "The role of the stomach is to digest food and transport it to the small intestine. It has three main functions, which ar
        }
        else if(SelectTopic.topicSelectedIndex == 2)
        {
            // Pancreas
            descriptionTitle = "Introduction of Pancreas";
            descriptionDetails = "The pancreas is a long, flattened gland that sits across the back of the abdomen, behind the stomach. It is about 15c

            structureTitle = "Anatomy Structure of Pancreas";
            structionDetails = "The pancreas is divided into 4 general regions, which are the head, neck, body, and tail. The <b>pancreas tail</b> is t

            functionTitle = "Functions of Pancreas";
            functionDetails = "The two main functions of the pancreas are:\n" +
                "(i)    Exocrine function: Produces substances or enzymes which aid in digestion of food.\n" +
                "(ii)   Endocrine function: Produces hormones that regulate the blood sugar level.";
        }
        else if(SelectTopic.topicSelectedIndex == 3)
        {
            // Gall Bladder
            descriptionTitle = "Introduction of Gall Bladder";
            descriptionDetails = "The gallbladder is a small hollow organ that stores and excretes bile. Bile is a fluid produced by the liver that aid

            structureTitle = "Anatomy Structure of Gall Bladder";
            structionDetails = "The gallbladder consists of three sections: the fundus, body and neck. The <b>fundus</b> is a rounded portion of the ga

            functionTitle = "Functions of Gall Bladder";
            functionDetails = "The gallbladder is one of the component of the human digestive system. Its primary purpose is to store bile. Bile is a s
        }
        else if (SelectTopic.topicSelectedIndex == 4)
        {
            // Small Intestine
            descriptionTitle = "Introduction of Small Intestine";
            descriptionDetails = "Small intestine is a long tube-like organ, which is around 20 feet long and folds up many times to fit within the abd

            structureTitle = "Anatomy Structure of Small Intestine";
            structionDetails = "There are three parts in the small intestine, which are the duodenum, jejunum and ileum. The smallest and shortest segm

            functionTitle = "Functions of Small Intestine";
            functionDetails = "The small intestine aids the further digestion of food from the stomach. It also plays an important role in absorbing th
        }
```

Figure 5.7.4 Topic Information script (Part II).

```
        else if (SelectTopic.topicSelectedIndex == 5)
        {
            // Large Intestine
            descriptionTitle = "Introduction of Large Intestine";
            descriptionDetails = "Large intestine is a long tube-like organ, which is also the connector between the small intestine at one end and anus at another en

            structureTitle = "Anatomy Structure of Large Intestine";
            structionDetails = "Large intestine is made up by cecum, colon, rectum and anus. The beginning of the large intestine, <b>cecum</b> has a closed end like

            functionTitle = "Functions of Large Intestine";
            functionDetails = "There are a few major roles of large intestine. Its first function is recovery of water and electrolytes. It has an imperative role in
        }
        else
        {
            // Human Digestive System
            descriptionTitle = "Introduction of Human Digestive System";
            descriptionDetails = "Human digestive system is a system that helps the body digest food. There are digestive tract, structures and organs that digest the

            structureTitle = "Anatomy Structure of Human Digestive System";
            structionDetails = "Different structures or organs play different roles in human digestive system. The beginning of digestive tract is the <b>mouth</b>. T

            functionTitle = "Functions of Human Digestive System";
            functionDetails = "There are a few of main functions of human digestive system. The first one is motility that is moving the food through the digestive tr
        }

        // Set video thumbnail, structure image, and zoomed structure image
        videoThumbnail.GetComponent<Image>().sprite = videoThumbnails[SelectTopic.topicSelectedIndex];
        structureImage.GetComponent<Image>().sprite = structureImages[SelectTopic.topicSelectedIndex];
        zoomedStructureImage.GetComponent<Image>().sprite = structureImages[SelectTopic.topicSelectedIndex];

        // Set the title bar to be the topic selected
        TitleBarText.text = SelectTopic.topicSelected;

        // Set the texts
        description.transform.GetChild(0).GetComponent<TextMeshProUGUI>().text = "<size=26><b>" + descriptionTitle + "</b></size>\n" + descriptionDetails;
        structure.transform.GetChild(0).GetComponent<TextMeshProUGUI>().text = structureTitle;
        structure.transform.GetChild(2).GetComponent<TextMeshProUGUI>().text = structionDetails;
        function.transform.GetChild(0).GetComponent<TextMeshProUGUI>().text = "<size=26><b>" + functionTitle + "</b></size>\n" +  functionDetails;
    }
}
```

Figure 5.7.5 Topic Information script (Part III).

A C# script named “TopicInformation” is created as shown in Figure 5.7.3 to Figure 5.7.5. The function of this script is to set the title bar and the content of the Topic Information Scene, such as the video thumbnail, anatomy structure image, and description texts, based on the anatomy topic selected by the user from the previous Select Topic Scene.

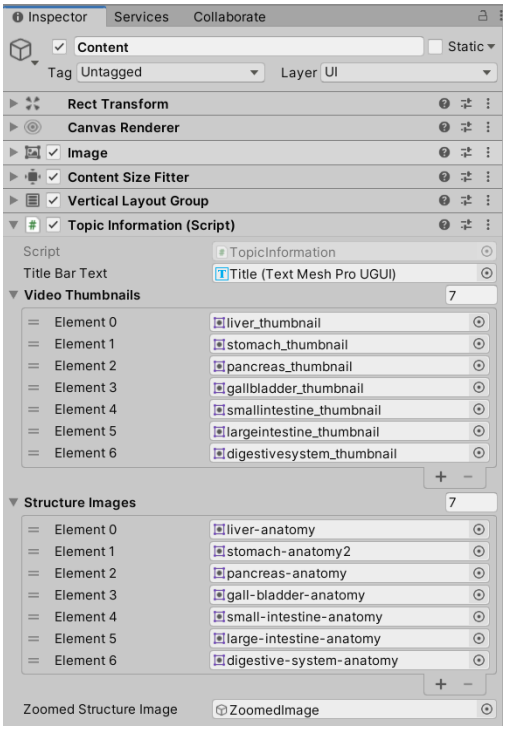


Figure 5.7.6 Inspector window of Content game object.

Then, the Topic Information script is added to the Content game object. The text of the title bar, and the respective video thumbnail sprites and structure sprites is assigned to the Topic Information script.

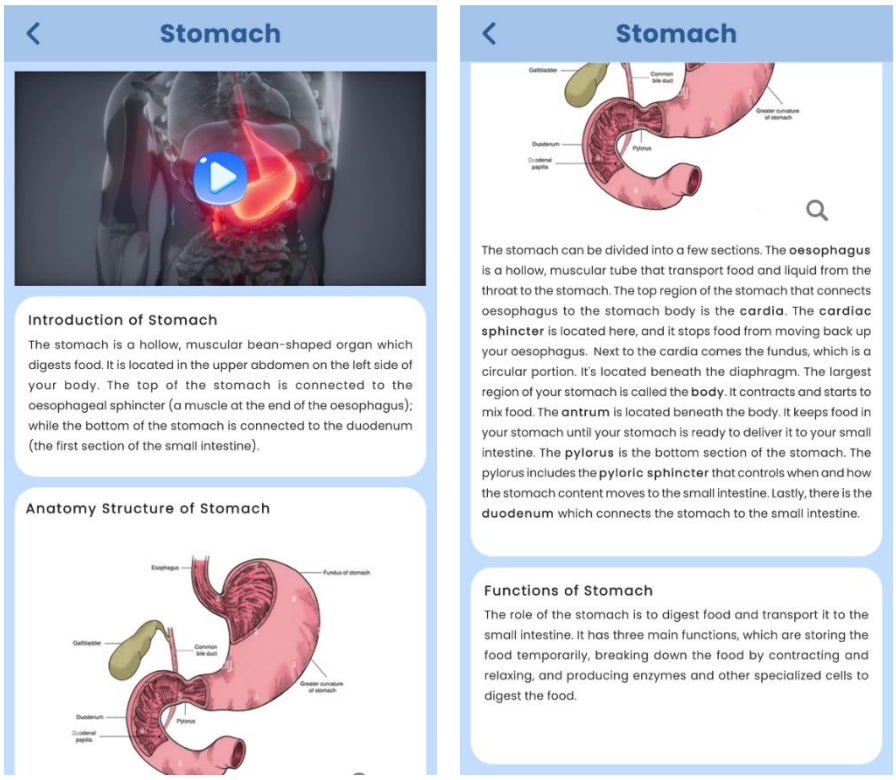


Figure 5.7.7 User interfaces of Topic Information Scene.

Figure 5.7.7 shows the user interface of the Topic Information Scene developed. After the user selects an anatomy topic from the Select Topic Scene, the user will be navigated into this Topic Information Scene. The detailed information of the topic selected by the user, including a short video about the anatomy organ, a brief introduction of the organ, anatomy pictures and description of the organ, and the function of the organ are displayed in this scene.

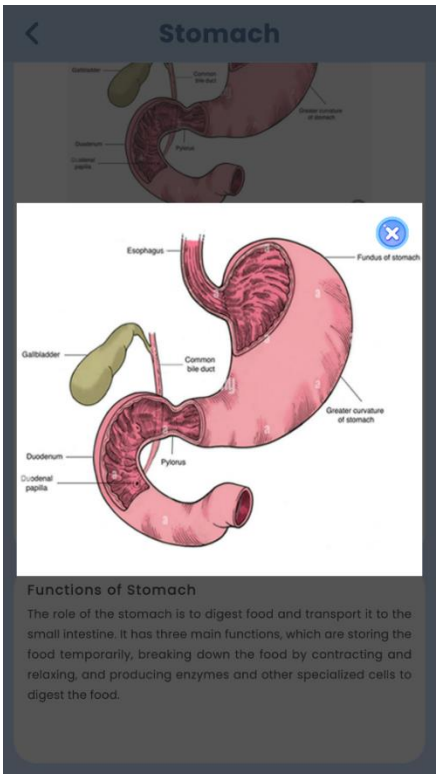


Figure 5.7.8 User interface of Topic Information Scene when structure image is opened.

Figure 5.7.8 shows that the user interface when the user clicks on the anatomy picture to open a zoomed in version of the anatomy picture so that they can view the picture more clearly.

5.8 Development of Video Player Scene

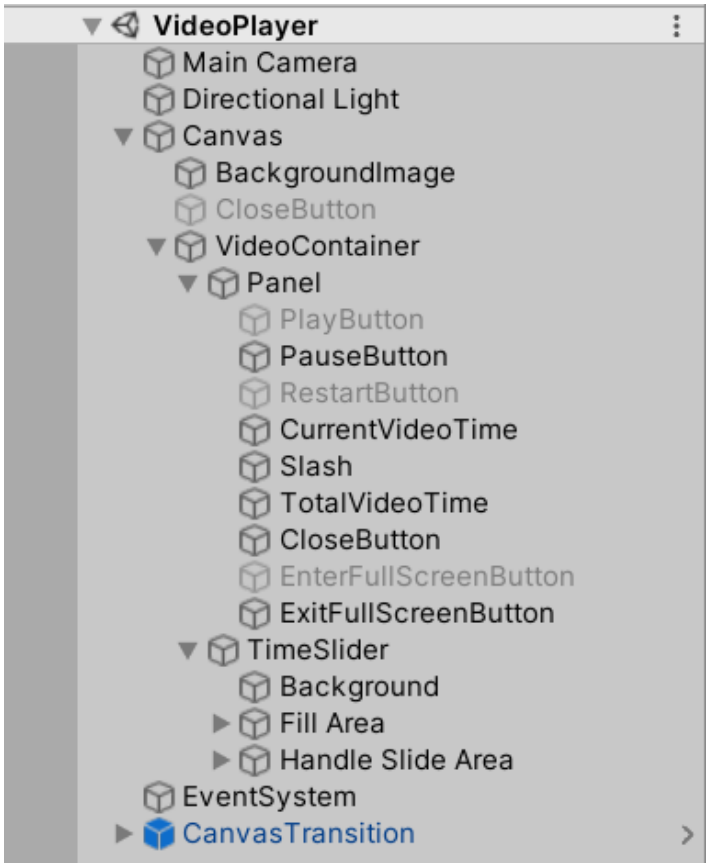


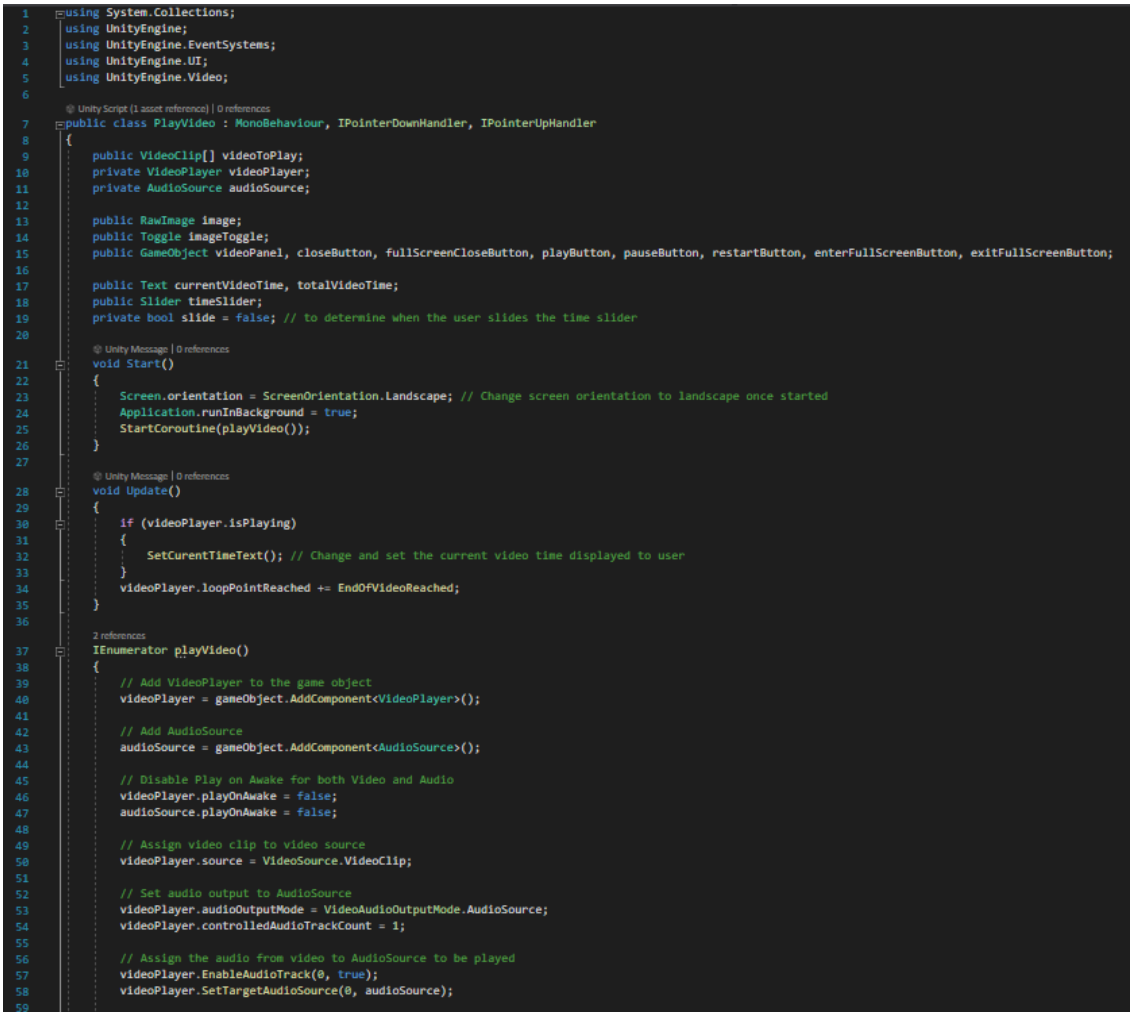
Figure 5.8.1 Hierarchy of Video Player Scene.

To create the Video Player Scene, the game objects as shown in Figure 5.11.2 are added to the scene hierarchy.

Game Object	**Function / Description**
VideoContainer	The parent of the video player and buttons
PlayButton	Button to play or resume the video
PauseButton	Button to pause the video
RestartButton	Button to restart the video
CurrentVideoTime	The text of the current video time
TotalVideoTime	The text of the total video time
CloseButton	Button to close the video and change scene back to Topic Information Scene
ExitFullScreenButton	Button to exit the full screen mode of the video by changing screen orientation to portrait

EnterFullScreenButton	Button to enter the full screen mode of the video by changing screen orientation to landscape
TimeSlider	Slider that shows the progress of the video playing and allows the user to slide it to change the current video frame playing.

Table 5.8.1 Function / description of some main game objects in Video Player Scene.



```
using System.Collections;
using UnityEngine;
using UnityEngine.EventSystems;
using UnityEngine.UI;
using UnityEngine.Video;

Unity Script (1 asset reference) | 0 references
public class PlayVideo : MonoBehaviour, IPointerDownHandler, IPointerUpHandler
{
    public VideoClip[] videoToPlay;
    private VideoPlayer videoPlayer;
    private AudioSource audioSource;

    public RawImage image;
    public Toggle imageToggle;
    public GameObject videoPanel, closeButton, fullScreenCloseButton, playButton, pauseButton, restartButton, enterFullScreenButton, exitFullScreenButton;

    public Text currentVideoTime, totalVideoTime;
    public Slider timeSlider;
    private bool slide = false; // to determine when the user slides the time slider

    Unity Message | 0 references
    void Start()
    {
        Screen.orientation = ScreenOrientation.Landscape; // Change screen orientation to landscape once started
        Application.runInBackground = true;
        StartCoroutine(playVideo());
    }

    Unity Message | 0 references
    void Update()
    {
        if (videoPlayer.isPlaying)
        {
            SetCurentTimeText(); // Change and set the current video time displayed to user
        }
        videoPlayer.loopPointReached += EndOfVideoReached;
    }

    2 references
    IEnumerator playVideo()
    {
        // Add VideoPlayer to the game object
        videoPlayer = gameObject.AddComponent<VideoPlayer>();

        // Add AudioSource
        audioSource = gameObject.AddComponent<AudioSource>();

        // Disable Play on Awake for both Video and Audio
        videoPlayer.playOnAwake = false;
        audioSource.playOnAwake = false;

        // Assign video clip to video source
        videoPlayer.source = VideoSource.VideoClip;

        // Set audio output to AudioSource
        videoPlayer.audioOutputMode = VideoAudioOutputMode.AudioSource;
        videoPlayer.controlledAudioTrackCount = 1;

        // Assign the audio from video to AudioSource to be played
        videoPlayer.EnableAudioTrack(0, true);
        videoPlayer.SetTargetAudioSource(0, audioSource);
```

Figure 5.8.2 Play Video script (Part I).

```
60          // Set video to play then prepare Audio to prevent Buffering
61          videoPlayer.clip = videoToPlay[SelectTopic.topicSelectedIndex];
62          videoPlayer.Prepare();
63
64          // Wait until video is prepared
65          while (!videoPlayer.isPrepared)
66          {
67              yield return new WaitForEndOfFrame();
68          }
69
70          // Assign the Texture from Video to RawImage to be displayed
71          image.texture = videoPlayer.texture;
72
73          // Play video and audio of the video
74          videoPlayer.Play();
75          audioSource.Play();
76
77          SetTotalTimeText(); // Set the total video time displayed to user
78      }
79
            1 reference
80      void EndOfVideoReached(VideoPlayer videoPlayer)
81      {
82          videoPlayer.playbackSpeed = videoPlayer.playbackSpeed / 10.0F;
83          videoPanel.SetActive(true);
84          playButton.SetActive(false);
85          pauseButton.SetActive(false);
86          restartButton.SetActive(true);
87      }
88
            1 reference
89      void SetCurentTimeText()
90      {
91          // Calculate and set the current video time displayed to user
92          if (!slide)
93          {
94              timeSlider.value = (float)videoPlayer.frame / (float)videoPlayer.frameCount;
95          }
96          string minutes = Mathf.Floor((int)videoPlayer.time / 60).ToString("00");
97          string seconds = ((int)videoPlayer.time % 60).ToString("00");
98          currentVideoTime.text = minutes + ":" + seconds;
99      }
100
            1 reference
101     void SetTotalTimeText()
102     {
103         // Calculate and set the total video time displayed to user
104         string minutes2 = Mathf.Floor((int)videoPlayer.clip.length / 60).ToString("00");
105         string seconds2 = ((int)videoPlayer.clip.length % 60).ToString("00");
106         totalVideoTime.text = minutes2 + ":" + seconds2;
107     }
108
            0 references
109     public void Play()
110     {
111         // Continue playing the video and video audio
112         videoPlayer.Play();
113         audioSource.Play();
114
115         // Enable pause button and disable play and restart button
116         playButton.SetActive(false);
117         pauseButton.SetActive(true);
118         restartButton.SetActive(false);
119     }
```

Figure 5.8.3 Play Video script (Part II).

```
121     public void Pause()
122     {
123         // Pause the video and video audio
124         videoPlayer.Pause();
125         audioSource.Pause();
126 
127         // Enable play button and disable pause and restart button
128         playButton.SetActive(true);
129         pauseButton.SetActive(false);
130         restartButton.SetActive(false);
131     }
            0 references
132     public void Restart()
133     {
134         // Restart and play the video
135         imageToggle.isOn = true;
136         StartCoroutine(playVideo());
137 
138         // Enable pause button and disable play and restart button
139         playButton.SetActive(false);
140         pauseButton.SetActive(true);
141         restartButton.SetActive(false);
142     }
143 
            0 references
144     public void EnterFullScreen()
145     {
146         // Enter full screen mode by changing screen orientation to landscape
147         Screen.orientation = ScreenOrientation.Landscape;
148         closeButton.SetActive(false);
149         fullScreenCloseButton.SetActive(true);
150         enterFullScreenButton.SetActive(false);
151         exitFullScreenButton.SetActive(true);
152     }
153 
            0 references
154     public void ExitFullScreen()
155     {
156         // Exit full screen mode by changing screen orientation to portrait
157         Screen.orientation = ScreenOrientation.Portrait;
158         closeButton.SetActive(true);
159         fullScreenCloseButton.SetActive(false);
160         enterFullScreenButton.SetActive(true);
161         exitFullScreenButton.SetActive(false);
162     }
163 
            0 references
164     public void OnPointerDown(PointerEventData a)
165     {
166         slide = true;
167     }
168 
            0 references
169     public void OnPointerUp(PointerEventData a)
170     {
171         // Change the video frame to the frame that user slides to.
172         float frame = (float) timeSlider.value * (float)videoPlayer.frameCount;
173         videoPlayer.frame = (long) frame;
174         slide = false;
175     }
176 }
```

Figure 5.8.4 Play Video script (Part III).

In this scene, a C# script called “Play Video” is created, as shown in Figure 5.8.2 to Figure 5.8.4. This script contains all the necessary methods for the video player, such as the methods for play, pause, restart, calculate and display video current time and total time, enter and exit full screen mode, and slide video time slider.

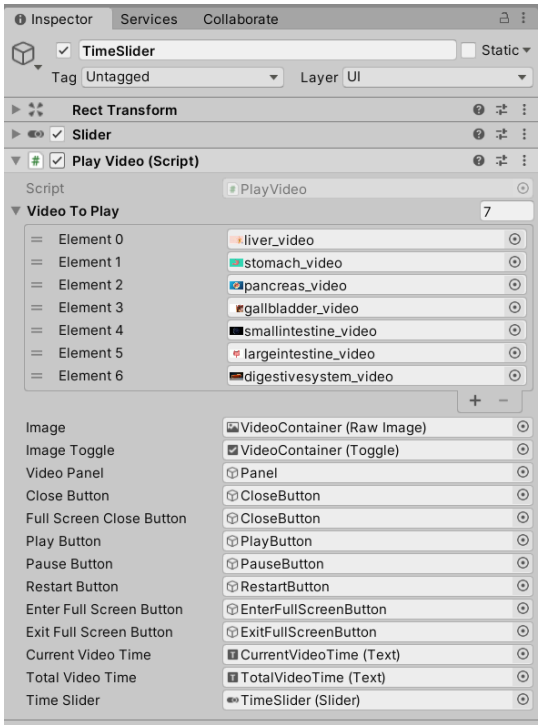


Figure 5.8.5 Inspector of TimeSlider game object.

The Play Video script is added to the TimeSlider game object. Then, the video clips and all the required game object are assigned to the script by drag and drop.

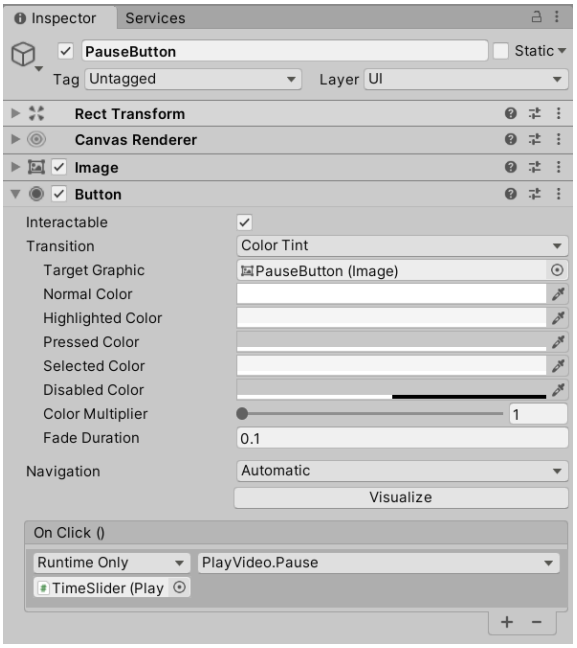


Figure 5.8.6 Inspector of PauseButton game object.

At the PauseButton game object, the Pause method of the PlayVideo script is assigned to the On Click() section as shown in Figure 5.8.6, so that the video will be paused

when the PauseButton is clicked. Similar steps are done for the PlayButton, RestartButton, EnterFullScreenButton and ExitFullScreenButton game objects with their corresponding methods.

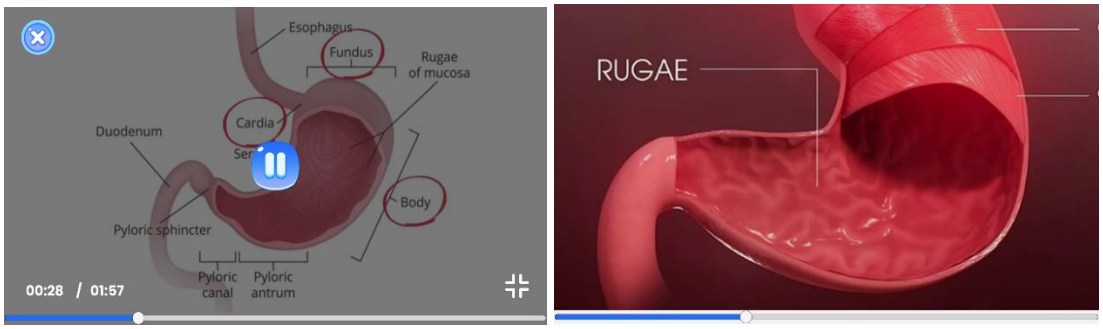


Figure 5.8.7 User interfaces of Video Player Scene.

Figure 5.8.7 shows the user interfaces of the Video Player Scene developed. When the user clicks on the play button at the Topic Information Scene, the user will be navigated to this Video Player Scene. The video will be opened in full screen mode and started immediately. As shown in Figure 5.8.7, inside the video player, the user can perform a few functions, such as play/pause video, restart video when the video ends, dragging the time slider to change the video to the dragged video time, view the total video duration and current video time, and enter/exit full screen mode. Every time when the user taps on the video, all the buttons will be shown/hidden. Lastly, when the user clicks on the close button at the top-left corner of the screen, the video will be close, and the user will be navigated back to the Topic Information Scene.

5.9 Development of Anatomy Puzzle Game Scene

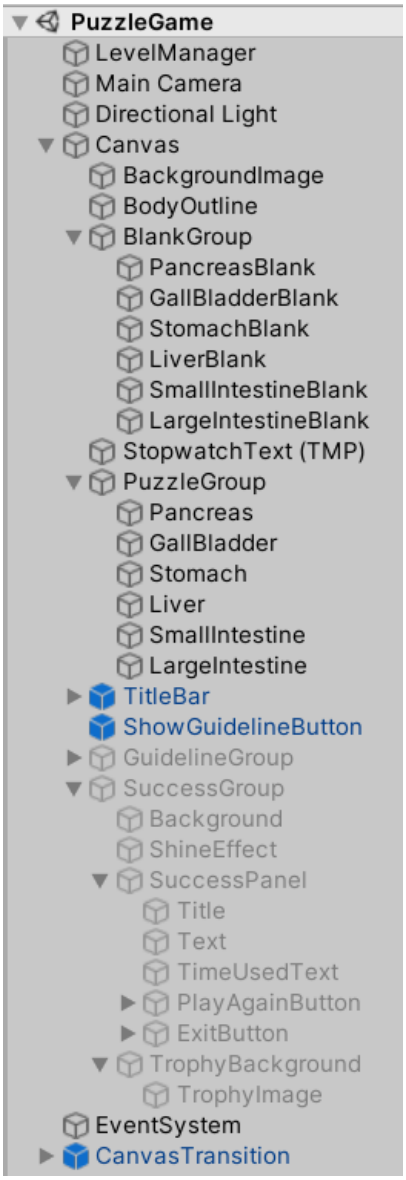


Figure 5.9.1 Hierarchy of Puzzle Game Scene.

To create the Puzzle Game Scene, the game objects as shown in Figure 5.11.2 are added to the scene hierarchy.

Game Object	Function / Description
BodyOutline	The image of the human body outline
BlankGroup	The parent of the blank organs on the human body for the puzzle to be placed on later
StopwatchText (TMP)	Text that shows the stopwatch time, which indicates the current time used while playing the game

PuzzleGroup	The parent containing the anatomy puzzles
ShowGuidelineButton	Button to open and display the dialog box of the guidelines on how to use the AR function
GuidelineGroup	The parent of the guideline dialog box and its background
SuccessGroup	The parent of the success panel and its background
SuccessPanel	The panel that appears when the user successfully completed the game
TimeUsedText	Text that shows the total time used to complete the game
PlayAgainButton	Button to allow user to play again the puzzle game
ExitButton	Button to exit the puzzle game and return to Main Menu Scene

Table 5.9.1 Function / description of some main game objects in Anatomy Puzzle Game Scene.

Puzzle Game Function

```
using UnityEngine;
using UnityEngine.EventSystems;

public class PuzzleGame : MonoBehaviour, IDragHandler, IEndDragHandler
{
    Vector2 organInitialPosition;
    public GameObject organBlank; // correct position for the organ puzzles
    public AudioSource audioSource;
    public AudioClip audioCorrect;
    public AudioClip audioWrong;
    public GameObject successPanel;
    static bool[] organStatus = new bool[6];

    void Start()
    {
        // set the initial position of the organ puzzles
        organInitialPosition = transform.position;
    }

    public void OnDrag(PointerEventData eventData)
    {
        // increase the scale of the organ puzzle
        transform.localScale = new Vector3(1, 1, 1);

        // set the position of organ puzzle according to where it is dragged to
        transform.position = Input.mousePosition;

    }

    public void OnEndDrag(PointerEventData eventData)
    {
        float distance = Vector3.Distance(transform.position, organBlank.transform.position); // distance between current position of the organ puzzle and the correct position

        if (distance < 35) // if organ puzzle is dragged to correct position (within distance of 35 towards the correct position)
        {
            // set the scale and position of the organ puzzle to fit in the correct position
            transform.localScale = organBlank.transform.localScale;
            transform.position = organBlank.transform.position;

            // set and play correct sound effect
            audioSource.clip = audioCorrect;
            audioSource.Play();

            // set status of the organ puzzle to be true
            setPuzzleStatus(true);
        }
```

Figure 5.9.2 Puzzle Game script (Part I).

```
        else // if organ is dragged to wrong position (more than distance of 35 towards the correct position)
        {
            transform.localScale = new Vector3(0.7f, 0.7f, 1); // decrease the scale of the organ
            transform.position = organInitialPosition; // set the position of the puzzle back to initial position

            // set and play wrong sound effect
            audioSource.clip = audioWrong;
            audioSource.Play();

            // set status of the organ puzzle to be false
            setPuzzleStatus(false);
        }
        checkAllPuzzleStatus(); // check the status of all organ puzzles
    }

    private void setPuzzleStatus(bool status)
    {
        if (transform.name == "Liver")
        {
            organStatus[0] = status;
        }
        else if (transform.name == "Stomach")
        {
            organStatus[1] = status;
        }
        else if (transform.name == "Pancreas")
        {
            organStatus[2] = status;
        }
        else if (transform.name == "SmallIntestine")
        {
            organStatus[3] = status;
        }
        else if (transform.name == "LargeIntestine")
        {
            organStatus[4] = status;
        }
        else
        {
            organStatus[5] = status;
        }
    }
```

Figure 5.9.3 Puzzle Game script (Part II).

```
    private void checkAllPuzzleStatus()
    {
        for(int i = 0; i < 6; i++)
        {
            if(organStatus[i] == false) //if one of the organ puzzle status is false
            {
                break;
            }
            else
            {
                if(i == 5) // if all organ puzzle status is true (all dragged to the correct position)
                {
                    successPanel.SetActive(true); // set the succesPanel to be active
                    resetAllPuzzleStatus(); // reset all the status of organ puzzle
                }
            }
        }
    }

    private void resetAllPuzzleStatus()
    {
        for(int i = 0; i < 6; i++)
        {
            organStatus[i] = false;
        }
    }
}
```

Figure 5.9.4 Puzzle Game script (Part III).

Figure 5.9.2 to Figure 5.9.4 shows the Puzzle Game script. The OnDrag() is called when the user drags the anatomy puzzle, while the OnEndDrag() is called when the user drops the anatomy puzzle. The setPuzzleStatus() will set the status of the puzzle. If the status is set to true, it means that the puzzle has been dragged to the correct position. If the status is set to false, it means that the puzzle has not been dragged to the correct position.

Besides that, checkAllPuzzleStatus() will check the status of every puzzle. If all puzzle is set to true, which means all the puzzle has been dragged to the correct position, then the success panel will be set to active and displayed to the user. Lastly, the resetAllPuzzleStatus() will reset all the puzzle status to be false.

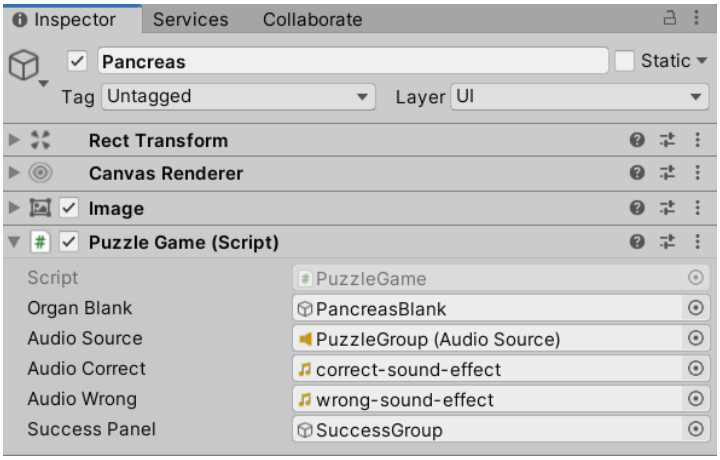


Figure 5.9.5 Inspector of Pancreas game object.

The Puzzle Game script is added to every anatomy puzzle game object. For example, Figure 5.9.5 shows the Puzzle Game script is added to the Pancreas game object. The audio source, audio clips and all the required game object are assigned to the script by drag and drop.

Stopwatch Function

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

public class Stopwatch : MonoBehaviour
{
    public static bool stopwatchActive = true;
    float currentTime;
    public TextMeshProUGUI currentTimeText;

    // Start is called before the first frame update
    void Start()
    {
        currentTime = 0;
        stopwatchActive = true; // start the stopwatch
    }

    // Update is called once per frame
    void Update()
    {
        if (stopwatchActive == true)
        {
            currentTime = currentTime + Time.deltaTime; // update the current time of stopwatch
        }
        TimeSpan time = TimeSpan.FromSeconds(currentTime);
        currentTimeText.GetComponent<TextMeshProUGUI>().text = time.ToString(@"mm\:ss\:fff"); // set the time displayed with proper format
    }
}
```

Figure 5.9.6 Stopwatch script.

Figure 5.9.6 show the Stopwatch script that is used to update the stopwatch time and set it to be displayed to the users.

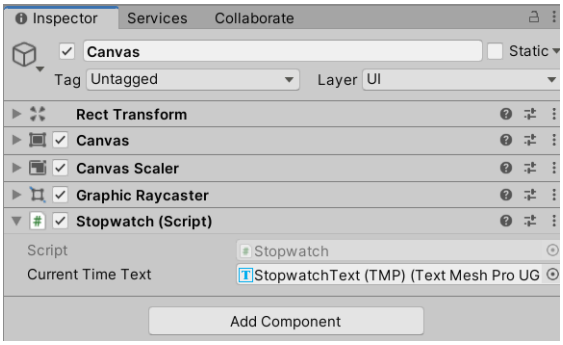


Figure 5.9.7 Inspector window of Canvas game object.

The Stopwatch script is added to the Canvas game object. Once the user enters the Puzzle Game Scene, the Stopwatch script will be called to start the stopwatch.

Display Success Panel Function

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

public class SuccessPanel : MonoBehaviour
{
    [SerializeField]
    GameObject successPanel, exitButton, playAgainButton, shineEffect, trophy, title, text, background;
    public TextMeshProUGUI currentTimeText;
    public Text timeUsedText;

    void Start()
    {
        // stop the stopwatch that counts the total time used to complete the game
        Stopwatch.stopwatchActive = false;

        // set the total time used to complete the game
        timeUsedText.text = "Total Time Used: " + currentTimeText.GetComponent<TextMeshProUGUI>().text;

        // fade in background
        LeanTween.alpha(background.GetComponent<RectTransform>(), 1f, .5f);

        // rotate the shine effect image
        LeanTween.rotateAround(shineEffect, Vector3.forward, -360, 10f).setLoopClamp();

        // scale the trophy image and move it upwards
        LeanTween.scale(trophy, new Vector3(1.5f, 1.5f, 1.5f), 2f).setDelay(.5f).setEase(LeanTweenType.easeOutElastic).setOnComplete(GameComplete);
        LeanTween.moveLocal(trophy, new Vector3(0f, 340f, 2f), .7f).setDelay(2f).setEase(LeanTweenType.easeInOutCubic);
        LeanTween.scale(trophy, new Vector3(1f, 1f, 1f), 2f).setDelay(1.7f).setEase(LeanTweenType.easeInOutCubic);
    }

    void GameComplete()
    {
        // move the success panel from bottom to center
        LeanTween.moveLocal(successPanel, new Vector3(0f, -37f, 0f), 0.7f).setDelay(.5f).setEase(LeanTweenType.easeOutCirc);

        // scale the buttons
        LeanTween.scale(playAgainButton, new Vector3(1f, 1f, 1f), 2f).setDelay(.8f).setEase(LeanTweenType.easeOutElastic);
        LeanTween.scale(exitButton, new Vector3(1f, 1f, 1f), 2f).setDelay(.9f).setEase(LeanTweenType.easeOutElastic);

        // fade in the texts
        LeanTween.alphaText(title.GetComponent<RectTransform>(), 1f, .5f).setDelay(1f);
        LeanTween.alphaText(text.GetComponent<RectTransform>(), 1f, .5f).setDelay(1.1f);
        LeanTween.alphaText(timeUsedText.GetComponent<RectTransform>(), 1f, .5f).setDelay(1.2f);
    }
}
```

Figure 5.9.8 Success Panel script.

Furthermore, Figure 5.9.8 shows the Success Panel script. This script sets the total time used to complete the game to be shown at the success panel. It also defines all the animation when the success panel is pop up and displayed to the user.

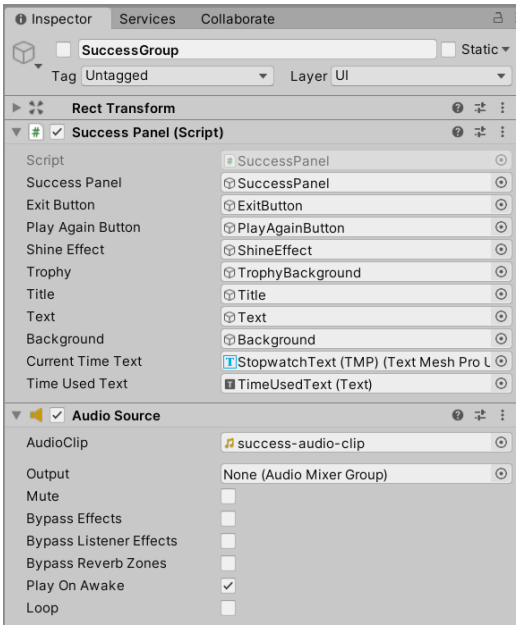


Figure 5.9.9 Inspector of Success Group game object.

Figure 5.9.9 shows the inspector window of the Success Group game object. The Success Panel script is added, and the necessary game objects are dragged in. Furthermore, an audio source with the success audio clip is added too.

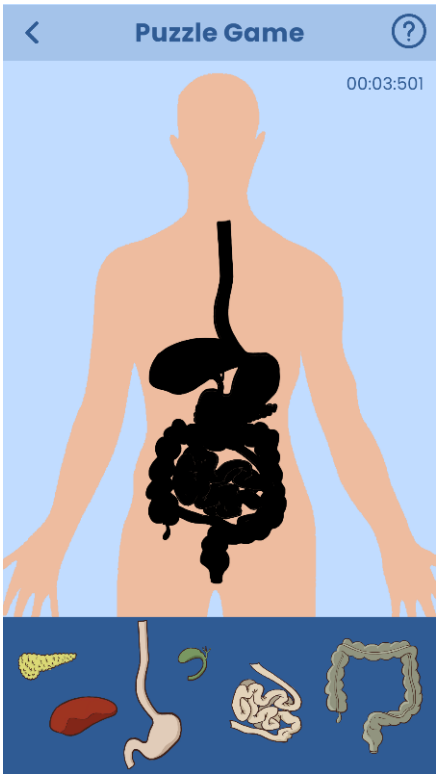


Figure 5.9.10 User interface of Puzzle Game Scene.

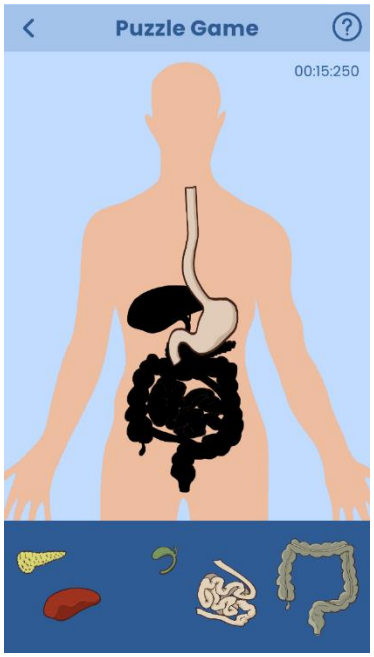


Figure 5.9.11 User interface of Puzzle Game Scene when puzzle is dragged.

Figure 5.9.10 and Figure 5.9.11 shows the user interface of Puzzle Game Scene developed. Once the user enters this scene, the stopwatch on the top right corner will start. The user can drag and drop the anatomy puzzle from the blue container at the bottom of the screen towards the human body at the middle of the screen. If the puzzle is dragged to the correct position, the puzzle will stay at its current position. If the puzzle is dragged to the wrong position, the puzzle will return to its original position.

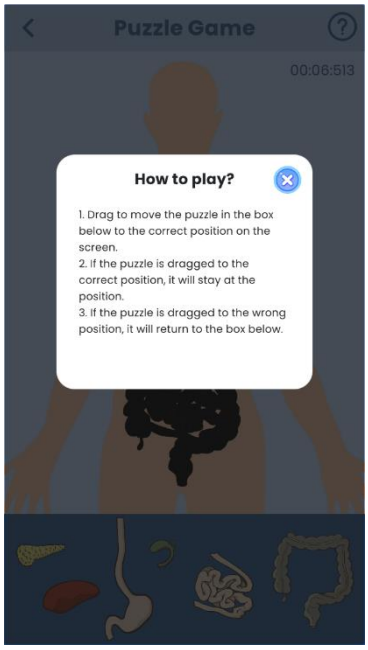


Figure 5.9.12 Instruction panel of Puzzle Game Scene.

If the user can click on the help button at the top-right corner of the screen, the instruction panel on how to play the game will be displayed as shown in Figure 5.9.12.

Figure 5.9.13 Success panel of Puzzle Game Scene.

After the user successfully dragged all the anatomy puzzle to the correct position, a success panel, with the time used to complete the game, will pop out to congratulate the user and let the user to make selection to play again or exit to main menu as shown in Figure 5.9.13.

5.10 Build Configuration

5.10.1 Build Application on Android Device

Before building the completed application, the scenes should be added first. To add build scenes, go to File > Build Settings.

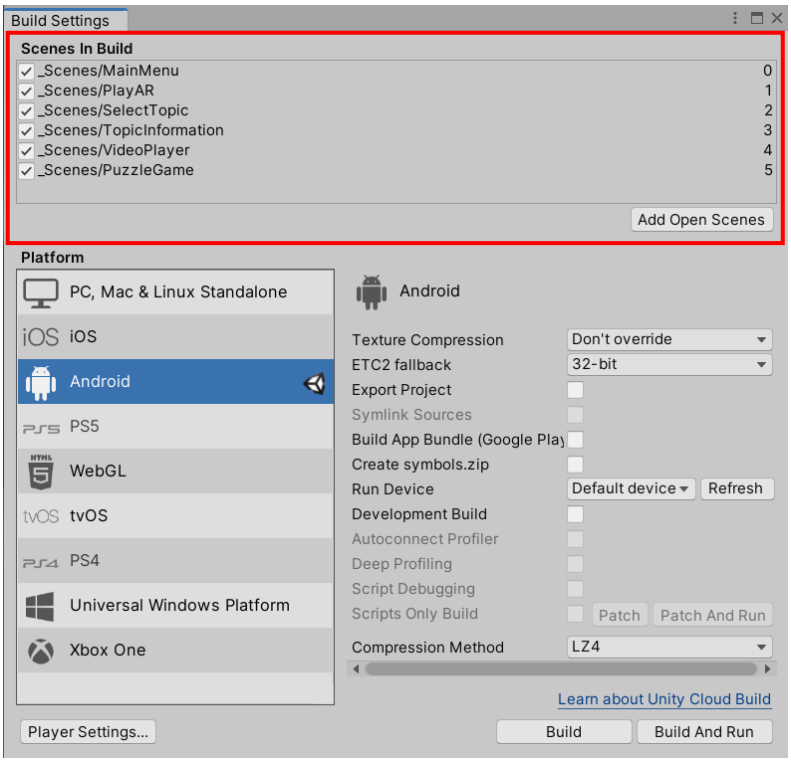


Figure 5.10.1.1 Scenes in build in build settings.

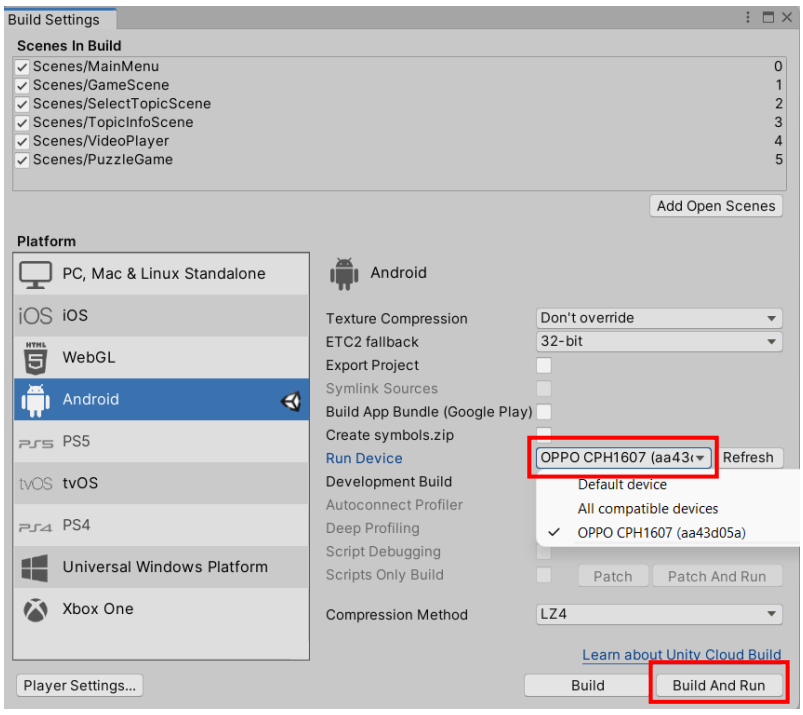


Figure 5.10.1.2 Selecting run device and build the scenes.

Then, drag the scenes to be built into the Scenes in Build section, and arrange the sequence of Scenes as shown in Figure 5.10.1.1. After that, under the Platform section, select Android, then click Switch Platform if it is not yet switched to Android. Then, connect an Android mobile device to the computer using a USB cable, and enable the developer options and USB debugging in the mobile device settings. After that, as shown in Figure 5.10.1.2, select the run device to be the mobile device connected and click 'Build And Run'. Then, wait for unity to install the APK file onto the mobile device connected. After the unity finished installing the APK file onto the mobile device, the application will be launched automatically on the connected mobile device.

5.10.2 Build Application on iOS Device

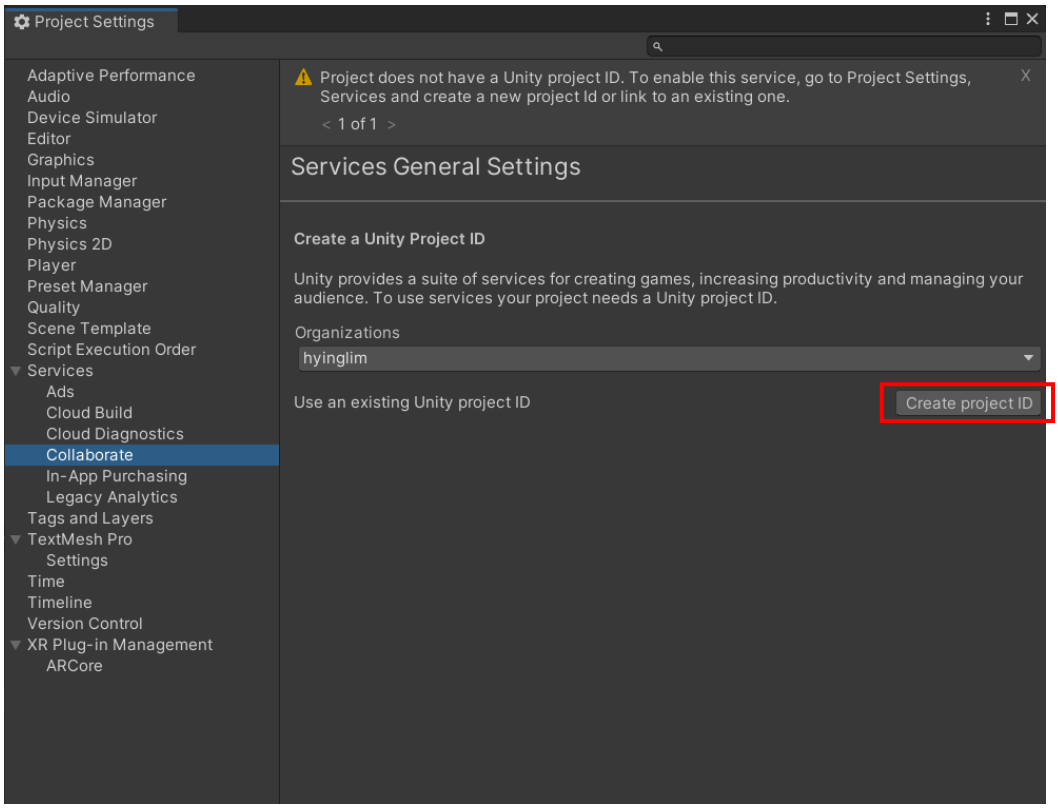


Figure 5.10.2.1 Setting Project ID for Collaborate.

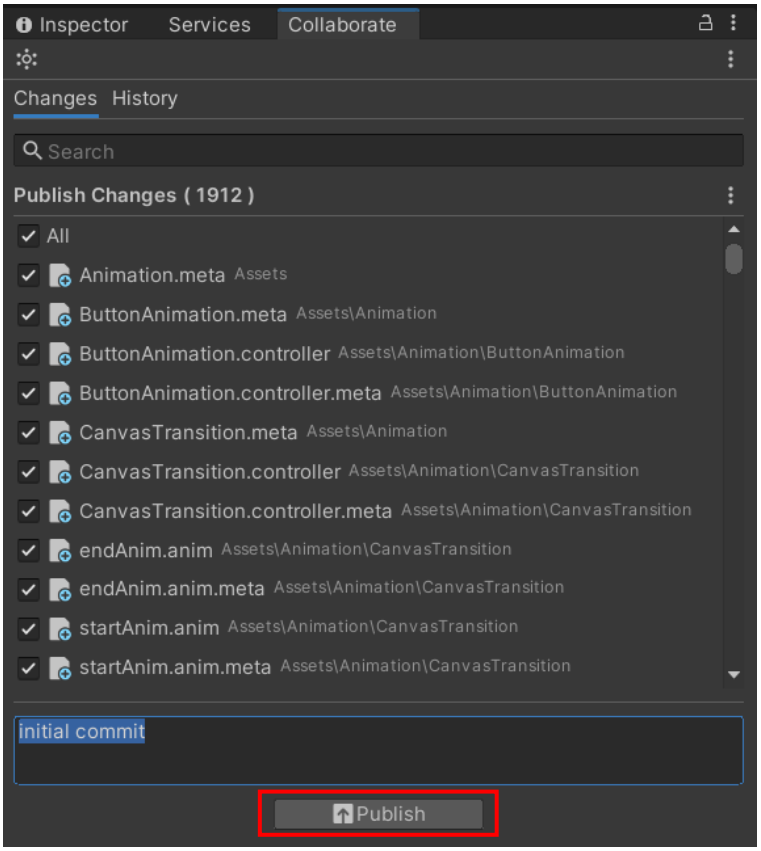


Figure 5.10.2.2 Publishing Unity project to cloud.

To build the completed application onto an iOS device, a macOS operating system environment is needed. In this project, macOS virtual machine is used to build the application on iOS device. To open the Unity Project that is built on the host machine in the virtual machine, one of the quickest ways is linking the project to the cloud through Unity Collaborate. Go to Project Settings > Collaborate, set the project ID as shown Figure 10.2.1. Next, start the Collaborate and publish the project to the cloud, as shown in Figure 5.10.2.2.

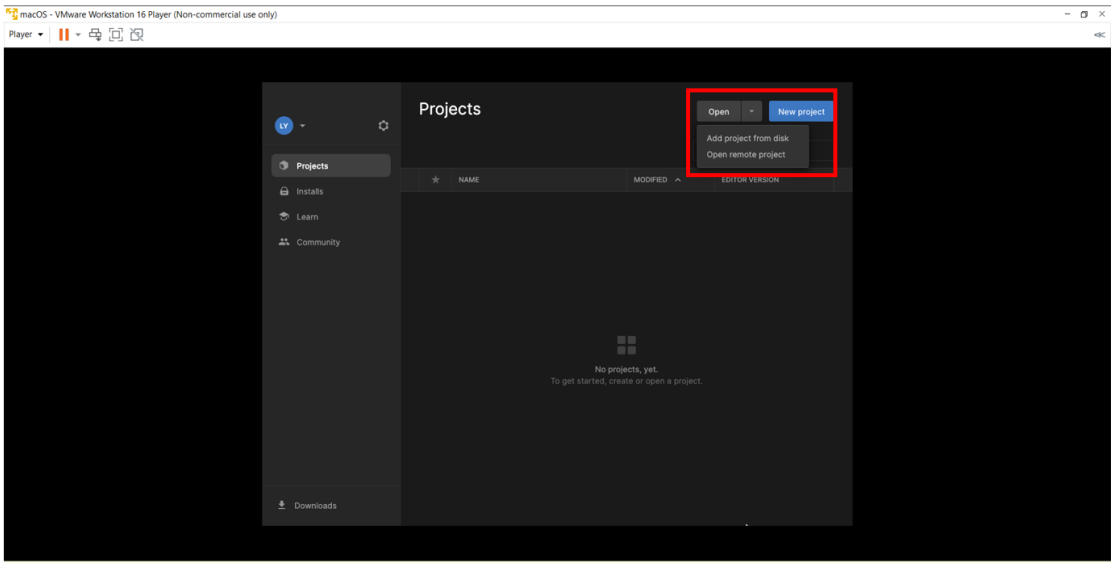


Figure 5.10.2.3 Adding remote project to Unity on macOS (Part I).

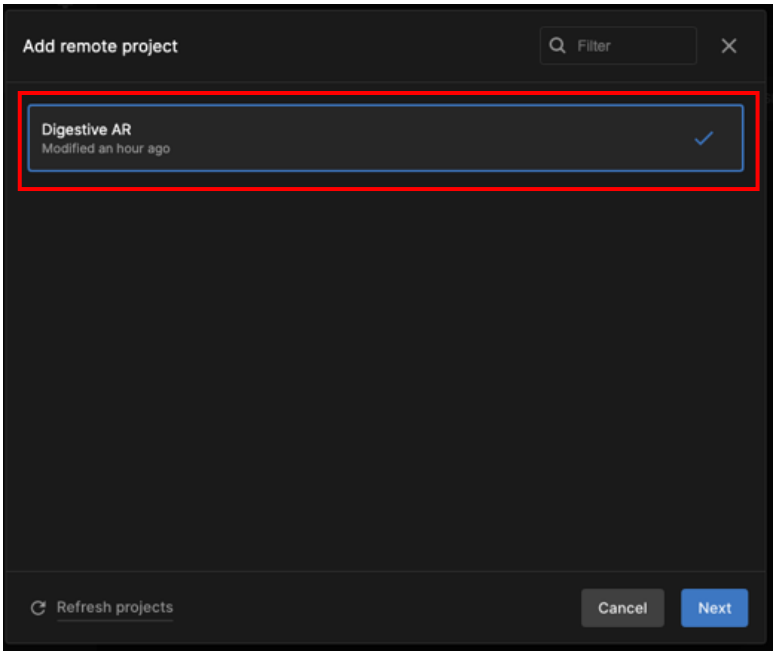


Figure 5.10.2.4 Adding remote project to Unity on macOS (Part II).

After the project is published to the cloud successfully, go to the Unity on the macOS virtual machine. Then, the same account is signed in. The remote project which is added to the cloud previously is added here as shown in Figure 5.10.2.3 and Figure 5.10.2.4.

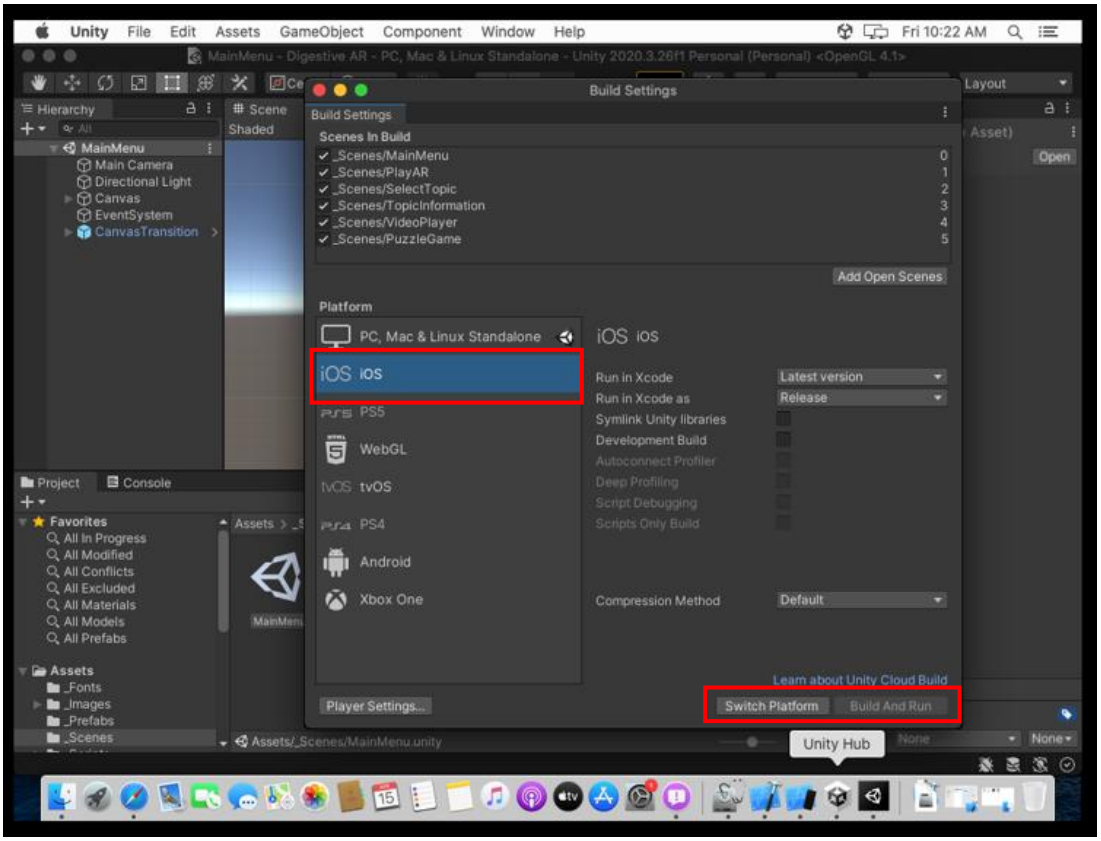


Figure 5.10.2.5 Build and run the project.

After the project is opened successfully, go to File > Build Settings > iOS, then click on ‘Switch Platform’ to switch to iOS platform as shown in Figure 5.10.2.5. Then, click on ‘Build and Run’.

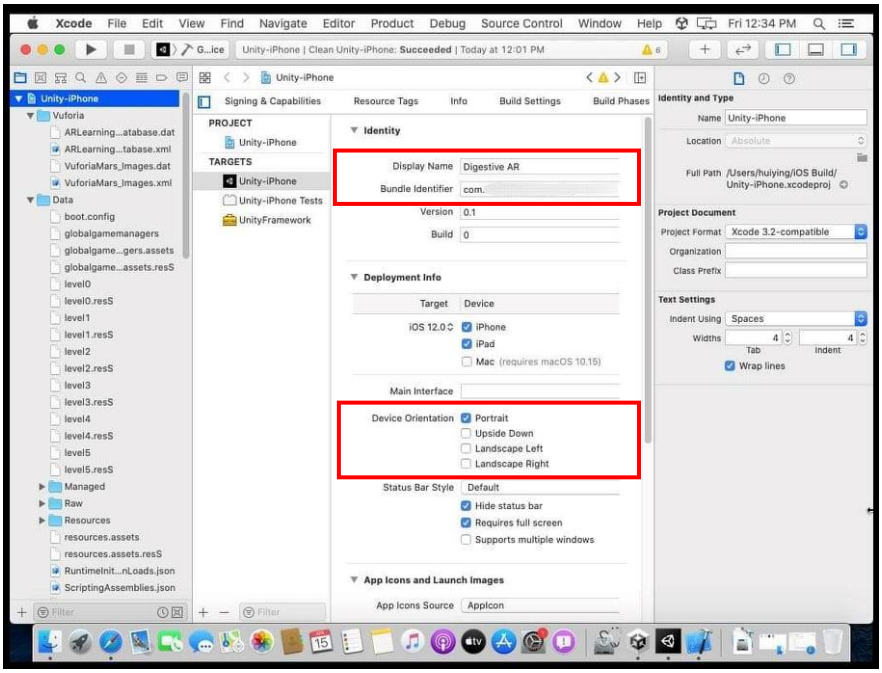


Figure 5.10.2.6 Configuring project settings in Xcode (Part I).

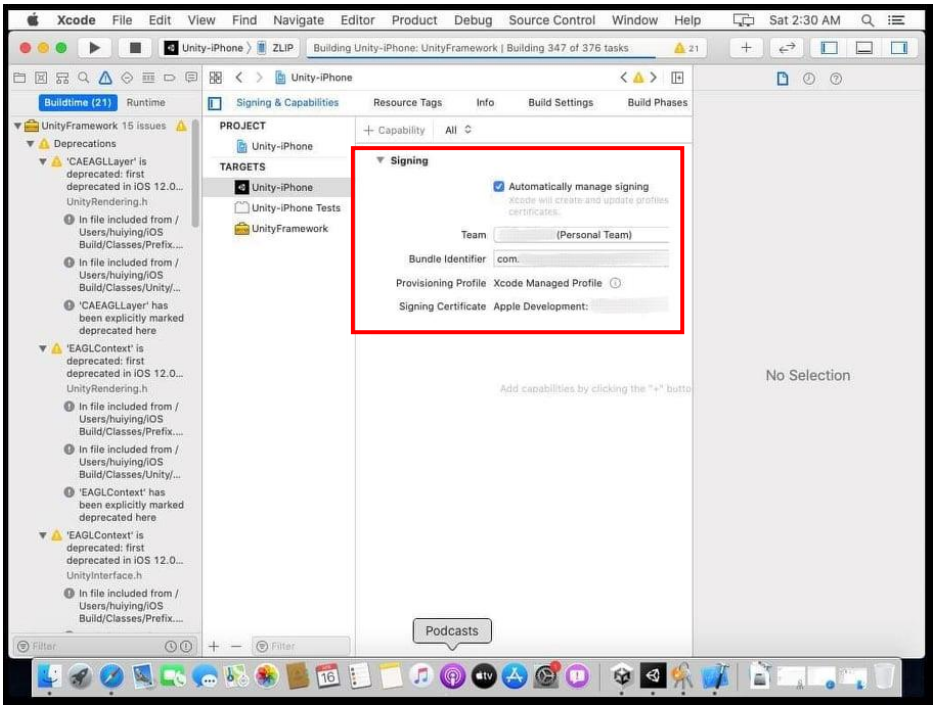


Figure 5.10.2.7 Configuring project settings in Xcode (Part II).

After clicking the build and run in Unity, Xcode will be opened automatically. In Xcode, click on Unity-iPhone > Signing & Capabilities, then select the 'Team' to be the developer ID, and set the bundle identifier with a unique name. Next, enable automatic manage signing, the provisioning profile and signing certificate will then be generated automatically as shown in Figure 5.10.2.6 and Figure 5.10.2.7. After that, an iPhone is connected to the virtual machine using a USB cable. Now, the project is ready to be run and built on the connected iPhone device by clicking on the Play button on the top left corner in Xcode. Xcode will start to build the application onto the connected iPhone. The application will be launched on the iPhone once the project build is finished successfully.

5.11 Concluding Remark

In this chapter, the implementation of the proposed application is described. The procedures to set up Unity and Vuforia Engine, and the steps to add necessary modules for Android and iOS build support are explained. Besides that, the steps to import 3D object, apply AR onto the 3D object with Vuforia Engine, configure build settings and player settings, and develop the application scenes are furthered elaborated. Other than that, the steps to build the application onto mobile devices for testing purposes are also

included. Furthermore, each of the functionality module developed are briefly described with screenshots of the application developed.

CHAPTER 6 SYSTEM EVALUATION

6.1 System Testing

6.1.1 Test Cases for Main Menu

Test Case No.	Test Case Description	Test Data	Expected Result	Actual Result	Pass / Fail
1	Check the response when "Play AR" button is clicked.	Click the "Play AR" button.	The system should navigate the user to the page for AR functionality.	The system navigates the user to the page for AR functionality successfully.	Pass
2	Check the response when "Learn Anatomy" button is clicked.	Click the "Learn Anatomy" button.	The system should navigate the user to the page that displays a list of anatomy topics.	The system navigates the user to the page that displays a list of anatomy topics successfully.	Pass
3	Check the response when "Puzzle Game" button is clicked.	Click the "Puzzle Game" button.	The system should navigate the user to the page that displays anatomy puzzle game.	The system navigates the user to the page that displays anatomy puzzle game successfully.	Pass
4	Check the response when "Exit" button is clicked.	Click the "Exit" button.	The system should display an exit confirmation dialog box.	The system displays an exit confirmation dialog box successfully.	Pass
5	Check the response when "Yes" button of the exit confirmation dialog box is clicked.	Click the "Yes" button of the exit confirmation dialog box.	The system should be exited.	The system is exited successfully.	Pass
6	Check the response when "No" button of the exit confirmation dialog box is clicked.	Click the "No" button of the exit confirmation dialog box.	The system should close the exit confirmation dialog box.	The system closes the exit confirmation dialog box successfully.	Pass

Table 6.1.1.1 Test cases for main menu.

6.1.2 Test Cases for Play AR Functionality

Test Case No.	Test Case Description	Test Data	Expected Result	Actual Result	Pass / Fail
1	Check the response when "Download Marker" link is clicked.	Click the "Download Marker" link.	The system should redirect user to the google drive link that allows user to download marker.	The system redirects user to the google drive link that allows user to download marker successfully.	Pass
2	Check the response when the "Guideline" button is clicked.	Click the "Guideline" button.	The system should display the guideline panel.	The system displays the guideline panel successfully.	Pass
2	Check the response when the "Close Guideline" button is clicked.	Click the "Close Guideline" button.	The system should close the guideline panel.	The system closes the guideline panel successfully.	Pass
3	Check the response when the device camera is pointed to the target marker.	Point the device camera to the target marker to scan it.	The system should display the AR model on the device screen after the marker is detected.	The system displays the AR model on the device screen successfully after the marker is detected successfully.	Pass
4	Check the response when the device camera is not pointed to the target marker.	Point the device camera to other places	The system should prompt the user to point the camera to the target marker.	The system prompts the user to point the camera to the target marker successfully.	Pass
5	Check the response when the "Flashlight" toggle button is clicked.	Click the "Flashlight" toggle button.	The system should automatically switch on or off the flashlight of the user's device.	The system automatically switches on or off the flashlight of the user's device successfully.	Pass
6	Check the response when the gesture of pinching with two fingertips is	Pinch the AR model with two fingertips.	The system should scale the AR model by zooming in and zooming out according to the	The system scales the AR model by zooming in and zooming out according to the	Pass

	performed on the AR model.		user's pinch gesture.	user's pinch gesture successfully.	
7	Check the response when the gesture of dragging with one fingertip is performed on the AR model.	Drag the AR model with one fingertip.	The system should move the AR model to the position according to the user's drag gesture.	The system moves the AR model to the position according to user's drag gesture successfully.	Pass
8	Check the response when the gesture of rotating with two fingertips is performed on the AR model.	Rotate the AR model with two fingertips.	The system should rotate the AR model according to the user's rotate gesture.	The system rotates the AR model according to the user's rotate gesture successfully.	Pass
9	Check the response when the "Settings" toggle button is clicked.	Click the "Settings" toggle button.	The system should open or close the settings menu.	The system opens or closes the settings menu successfully.	Pass
10	Check the response when the "Horizontal Auto Rotate" toggle button is clicked.	Click the "Horizontal Auto Rotate" toggle button.	The system should start or stop auto rotating the AR model horizontally.	The system starts or stops auto rotating the AR model horizontally successfully.	Pass
11	Check the response when the "Vertical Auto Rotate" toggle button is clicked.	Click the "Vertical Auto Rotate" toggle button.	The system should start or stop auto rotating the AR model vertically.	The system starts or stops auto rotating the AR model vertically successfully.	Pass
12	Check the response when the "Organ Segmentation" toggle button is clicked.	Click the "Organ Segmentation" toggle button.	The system should enable or disable the segmentation of the organs.	The system enables or disables the segmentation of the organs successfully.	Pass
13	Check the response when the organ part is tapped.	Tap on the part of the organ to select it.	The system should highlight the selected part and display the selected part name.	The system highlights the selected part and displays the selected part	Pass

				name successfully.	
14	Check the response when the "Show Details" button is clicked	Click the "Show details" button.	The system should display a panel containing the detailed information of the selected part.	The system displays a panel containing the detailed information of the selected part successfully.	Pass
15	Check the response when the "Close Details" button is clicked	Click the "Close Details" button.	The system should close the panel containing the detailed information of the selected part.	The system closes the panel containing the detailed information of the selected part successfully.	Pass
16	Check the response when the "Open Right Navigation Drawer Panel" button is clicked	Click the "Open Right Navigation Drawer Panel" button.	The system should display the right navigation drawer panel.	The system displays the right navigation drawer panel successfully.	Pass
17	Check the response when the toggle checkboxes that show or hide the organ parts is ticked.	Tick the toggle checkboxes that show or hide the organ parts.	The system should show only the organ parts that are ticked.	The system shows only the organ parts that are ticked successfully.	Pass
18	Check the response when the toggle checkboxes that show or hide the organ parts is unticked.	Untick the toggle checkboxes that show or hide the organ parts.	The system should hide all the organ parts that are unticked.	The system hides all the organ parts that are unticked successfully.	Pass
19	Check the response when the screen that is not the right navigation drawer is tapped when the right navigation drawer is opened.	Tap on the screen that is not the right navigation drawer when the right navigation drawer is opened.	The system should close in the right navigation drawer panel.	The system closes the right navigation drawer panel successfully.	Pass

Table 6.1.2.1 Test cases for play AR functionality.

6.1.3 Test Cases for Learn Anatomy Functionality

Test Case No.	Test Case Description	Test Data	Expected Result	Actual Result	Pass / Fail
1	Check the response when one of the topics is clicked.	Click one of the topics.	The system should navigate user to the page that display the selected topic's detailed information.	The system navigates user to the page that display the selected topic's detailed information successfully.	Pass
2	Check the response when the "Open Video" button is clicked.	Click the "Open Video" button.	The system should open the video player in full screen mode and play the video immediately.	The system opens the video player in full screen mode and play the video successfully.	Pass
3	Check the response when the "Zoom Image" button is clicked.	Click the "Zoom Image" button.	The system should open the panel containing the zoomed image.	The system opens the panel containing the zoomed image successfully.	Pass
4	Check the response when the "Close Image" button is clicked	Click the "Close Image" button.	The system should close the panel containing the zoomed image.	The system closes the panel containing the zoomed image successfully.	Pass
5	Check the response when the "Pause" button is clicked.	Click the "Pause" button.	The system should pause the video player.	The system pauses the video player successfully.	Pass
6	Check the response when the "Play" button is clicked.	Click the "Play" button.	The system should resume playing the video player.	The system resumes playing the video player successfully.	Pass
7	Check the response when the time slider is dragged.	Drag the time slider.	The system should change the current video frame playing based on the time slider.	The system changes the current video frame playing based on the time slider successfully.	Pass
8	Check the response when the "Exit Full	Click the "Exit Full Screen" button.	The system should exit the full screen mode and change to	The system exits the full screen mode and changes to	Pass

	Screen" button is clicked.		portrait orientation.	portrait orientation successfully.	
9	Check the response when the "Enter Full Screen" button is clicked.	Click the "Enter Full Screen" button.	The system should enter the full screen mode and change to landscape orientation.	The system enters the full screen mode and changes to landscape orientation successfully.	Pass
10	Check the response when the "Restart" button is clicked.	Click the "Restart" button.	The system should restart the video player.	The system restarts the video player successfully.	Pass
11	Check the response when the "Close Video" button is clicked.	Click the "Close Video" button.	The system should close the video player and return to the anatomy topic information page.	The system closes the video player and returns to the anatomy topic information page successfully.	Pass

Table 6.1.3.1 Test cases for learn anatomy functionality.

6.1.4 Test Cases for Anatomy Puzzle Game Functionality

Test Case No.	Test Case Description	Test Data	Expected Result	Actual Result	Pass / Fail
1	Check the response when the anatomy puzzle is dragged and dropped to the correct position.	Drag and drop the anatomy puzzle to the correct position.	The system should play a sound effect to indicate that it is correct, and the anatomy puzzle should stay at the position.	The system plays a sound effect to indicate that it is correct, and the anatomy puzzle stays at the position successfully.	Pass
2	Check the response when the anatomy puzzle is dragged and dropped to the wrong position.	Drag and drop the anatomy puzzle to the wrong position.	The system should play a sound effect to indicate that it is wrong, and the anatomy puzzle should return to the initial position.	The system plays a sound effect to indicate that it is wrong, and the anatomy puzzle return to the initial position successfully.	Pass
3	Check the response when all the anatomy	All the anatomy puzzle is	The system should pop out a success panel.	The system pops out a success panel successfully.	Pass

	puzzle is being put to the correct position.	being put to the correct position.			
4	Check the response when the "Play Again" button is clicked.	Click the "Play Again" button.	The system should restart the puzzle game and stopwatch that calculates the time used to complete the game.	The system restarts the puzzle game and stopwatch that calculates the time used to complete the game successfully.	Pass
5	Check the response when the "Exit" button is clicked.	Click the "Exit" button.	The system should return to the main menu.	The system returns to the main menu successfully.	Pass

Table 6.1.4.1 Test cases for anatomy puzzle game functionality.

6.2 Survey Questionnaire

A survey is conducted to collect and study the feedback on the AR application developed. The survey consists of 15 questions and the target audience is university students. Google Form, which is a free online tool, is used to create the survey questionnaire because it is easy to use and able to analyze the results in real-time [23]. A total of 15 university students are invited to use the AR application developed, then the survey questionnaire is distributed to them to collect their feedback. The sample survey questionnaire is as shown in Appendix A.

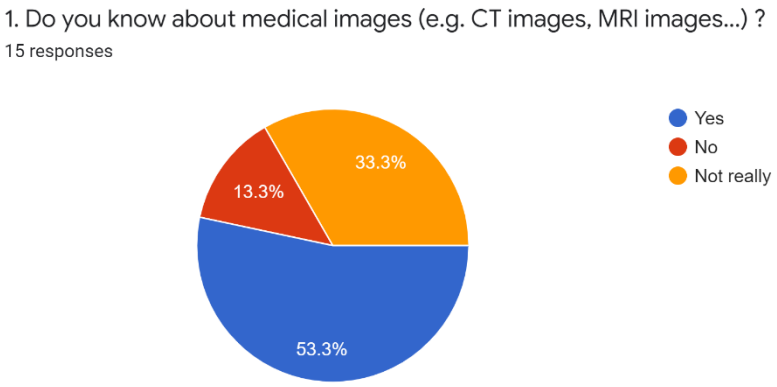


Figure 6.2.1 Result of Question 1.

Question 1 is to determine whether the respondents have the knowledge about medical images such as CT images and MRI images. Figure 6.2.1 shows that 53.3% of the respondents know about medical images, 13.3% of the respondents do not know about medical images, and the remaining 33.3% do not really know about medical images.

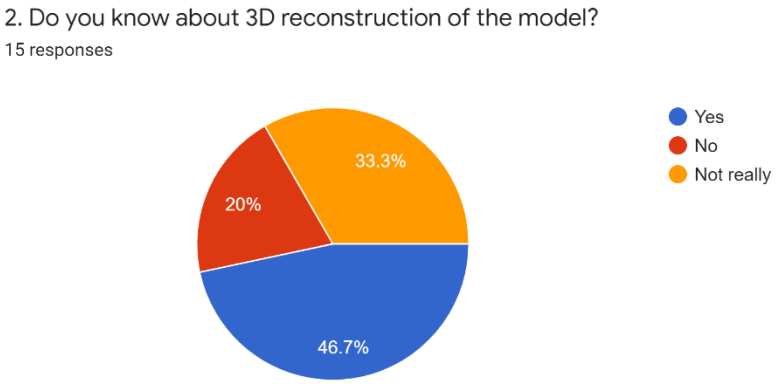


Figure 6.2.2 Result of Question 2.

Question 2 is to find out whether the respondents have the knowledge about 3D reconstruction of the model, which is applied in this project to create the 3D model of the human digestive system. According to Figure 6.2.2, it is shown that 46.7% of the respondents know about 3D model reconstruction, 20% of the respondents do not know about 3D model reconstruction, and the remaining 33.3% do not really know about 3D model reconstruction.

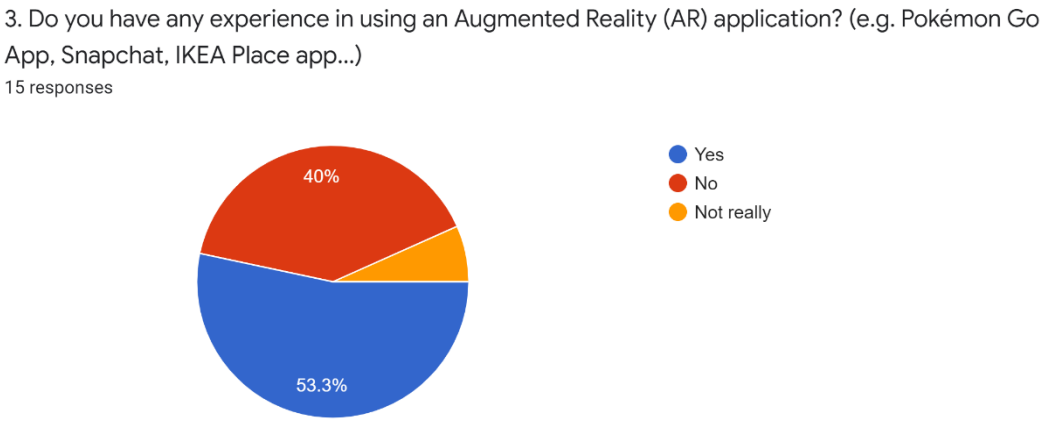


Figure 6.2.3 Result of Question 3.

The purpose of Question 3 is to determine whether the respondents have experience in using an AR application. Based on Figure 6.2.3, it is noticed that 53.3% of the respondents have experience in using an AR application, 40% of the respondents do not have any experience in using an AR application, and the remaining 6.7% do not really used an AR application before.

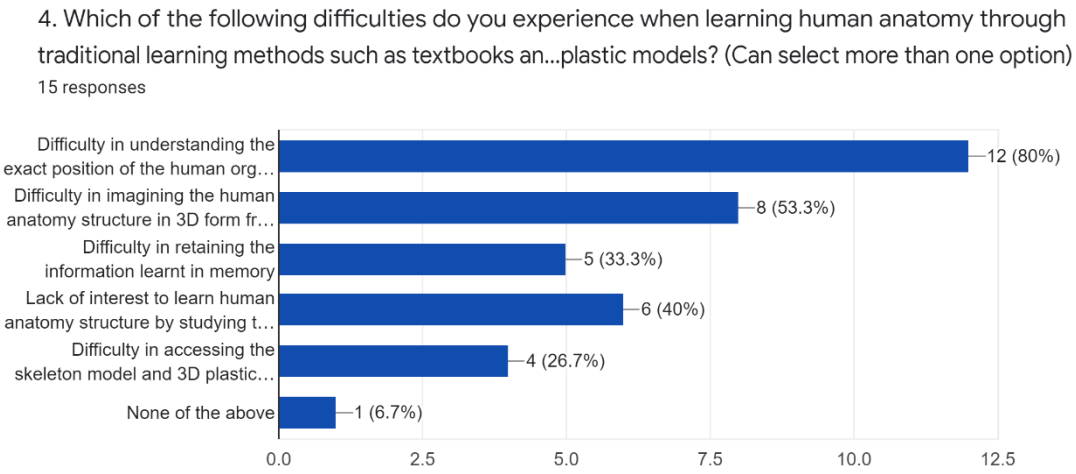


Figure 6.2.4 Result of Question 4.

Question 4 is a multiple-select question to find out whether the respondents face any difficulties when learning human anatomy through traditional learning methods such as textbooks and 3D plastic models. According to the result obtained in Figure 6.2.4, it is revealed that the most common difficulty faced is the difficulty in understanding the exact position of the human organs through text descriptions (12 votes), followed by difficulty in imagining the human anatomy structure in 3D form from a 2D picture (8 votes), lack of interest to learn human anatomy structure by studying textbooks (6 votes), difficulty in retaining the information learnt in memory (5 votes), and lastly difficulty in accessing the skeleton model and 3D plastic models which can only be accessed during operating hours of the laboratory (4 votes). Additionally, there is one respondent do not face any difficulties when learning human anatomy through traditional learning methods.

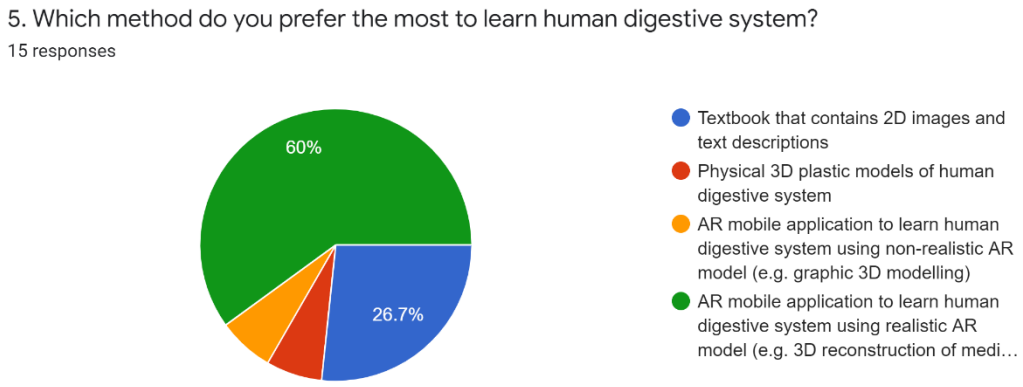


Figure 6.2.5 Result of Question 5.

The purpose of Question 5 is to determine the preferred learning method to learn human digestive system. According to Figure 6.2.5, 60% of the respondents prefer using AR mobile application with realistic AR model such as 3D reconstruction of medical images to learn human digestive system. Then, 26.7% of the respondents prefer using textbook that contains 2D images and text descriptions, 6.7% of the respondents prefer using physical 3D plastic models of the human digestive system, and the remaining 6.7% respondents prefer using AR mobile application with non-realistic AR model such as graphic 3D modelling.

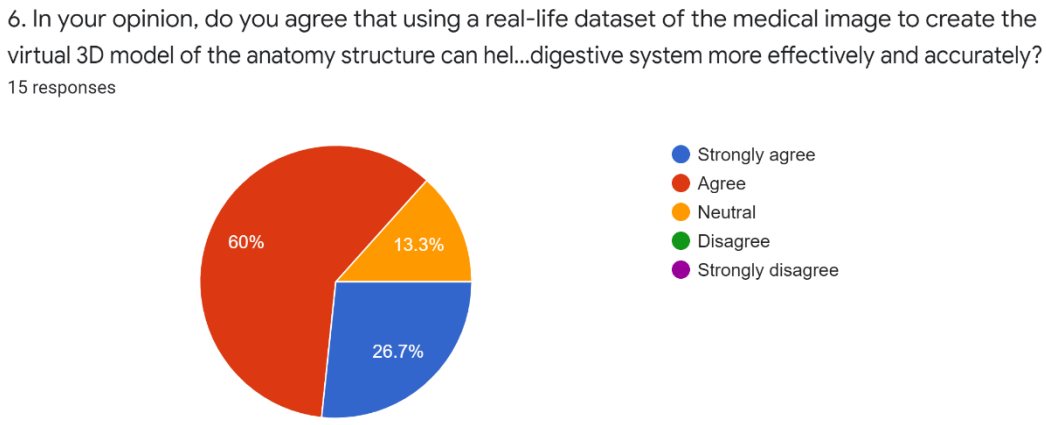


Figure 6.2.6 Result of Question 6.

Question 6 collects the opinion of the respondents on whether they agree that using a real-life dataset of the medical image to create the virtual 3D model of the anatomy structure can help them to learn human digestive system more effectively and

accurately. As shown in Figure 6.2.6, 60% of the respondents agree with the statement, 26.7% of the respondents strongly agree with the statement, and 13.3% respondents are neutral with the statement.

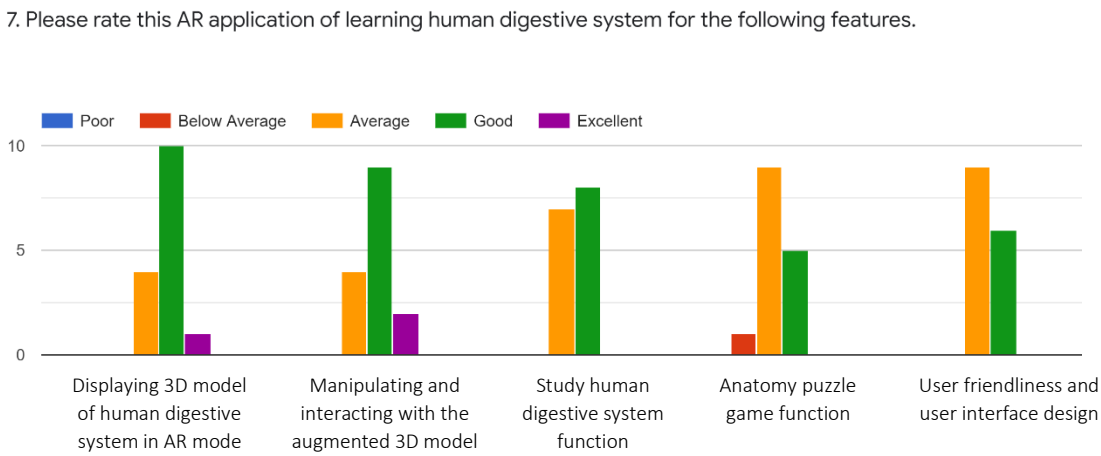


Figure 6.2.7 Result of Question 7.

Next, Question 7 is a multiple-select matrix question that requires the respondents to rate the features of this AR application. Figure 6.2.7 shows the result obtained for Question 7. For the feature of displaying 3D model of human digestive system in AR mode, most of the respondents voted the feature as good (10 votes), followed by 4 votes of average, and 1 vote of excellent. For the feature of manipulating and interacting with the augmented 3D model, most of the respondents voted good (9 respondents), followed by 4 votes of average and 2 votes of excellent. For the feature of study human digestive system function, 8 respondents voted it as good, whereas the remaining 7 respondents voted it as average. For the feature of anatomy puzzle game function, 9 respondents voted it as average, followed by 5 votes of good and 1 vote of below average. Lastly, for the feature of user friendliness and user interface design, 9 respondents voted average, and 6 respondents voted good.

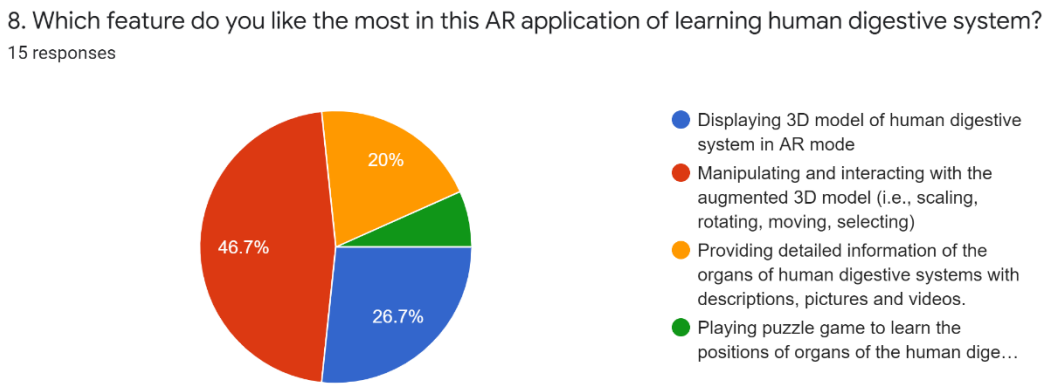


Figure 6.2.8 Result of Question 8.

Question 8 is to acquire the feedback of the respondents on which feature they like the most in this AR application. Based on Figure 6.2.8, it is found that most of the respondents like the feature of manipulating and interacting with the augmented 3D model the most (46.7%), followed by the feature of displaying 3D model of the human digestive system in AR mode (26.7%), feature of providing detailed information of the organs of human digestive systems with descriptions, pictures, and videos (20%), and lastly the feature of playing puzzle game to learn the positions of organs of the human digestive system (6.7%).

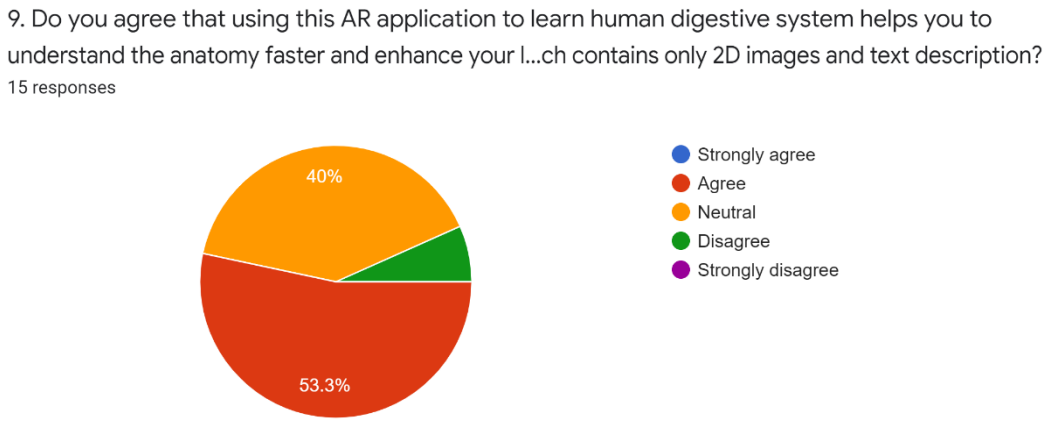


Figure 6.2.9 Result of Question 9.

Question 9 collects the opinion of the respondents on whether they agree that using this AR application to learn human digestive system helps them to understand the anatomy faster and enhance your learning process compared to using textbook which contains

only 2D images and text description. As shown in Figure 6.2.9, 53.3% of the respondents agree that the application helps them to understand anatomy faster, 40% respondents are neutral, and the remaining 6.7% disagree.

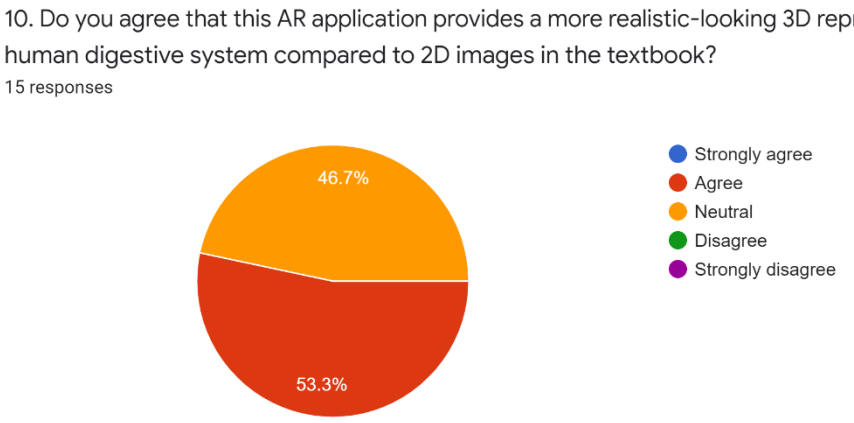


Figure 6.2.10 Result of Question 10.

The purpose of Question 10 is to gather the opinion of the respondents on whether they agree this AR application provides a more realistic-looking 3D representation of the human digestive system compared to 2D images in the textbook. According to the result obtained as shown in Figure 6.2.10, 53.3% of the respondents agree that this AR application provides a more realistic-looking 3D representation of the human digestive system, while the remaining 46.7% respondents are neutral.

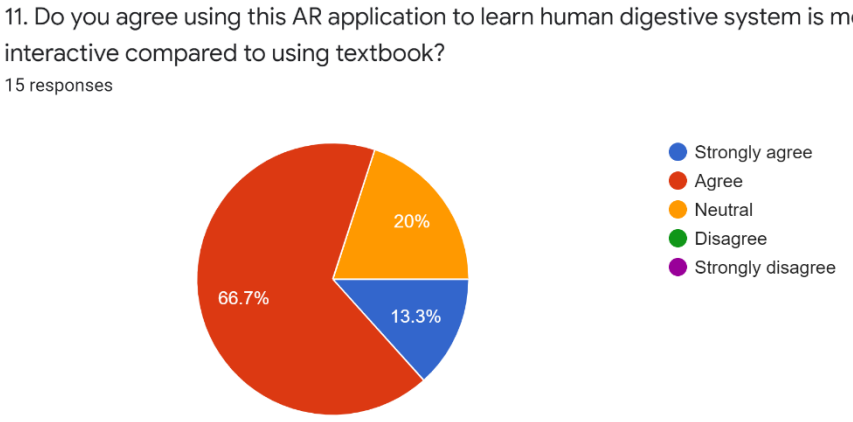


Figure 6.2.11 Result of Question 11.

Question 11 collects the opinion of the respondents on whether they agree that using this AR application to learn human digestive system is more engaging and interactive compared to using textbook. Based on the result obtained as shown in Figure 6.2.11, 66.7% of the respondents agree that using this AR application to learn human digestive system is more engaging and interactive, 20% respondents are neutral, and the remaining 13.3% respondents strongly agree with the statement.

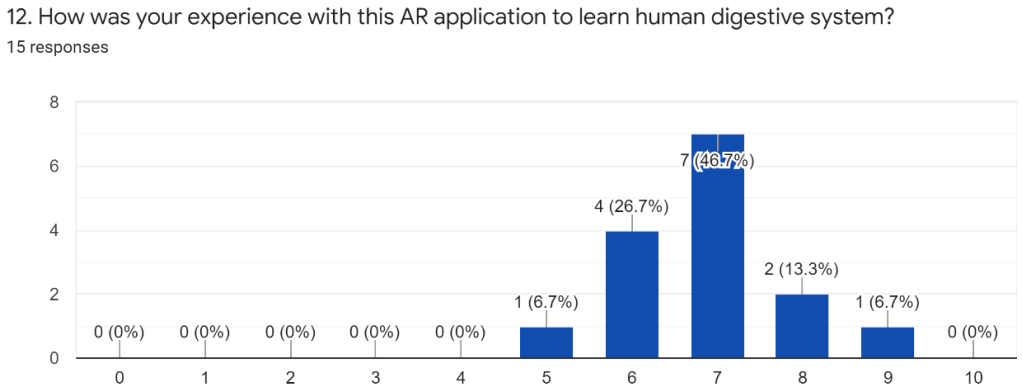


Figure 6.2.12 Result of Question 12.

Question 12 is a rating question to find out the respondents' experience in using this AR application to learn human digestive system, with the choice of rating from 1 (Very Unsatisfied) to 10 (Very Satisfied). Based on Figure 6.2.12, it is found that in overall, the respondents are having good experience with the AR application because the rating is from 5 to 9. Most of the respondents voted a rating of 7 for this question.

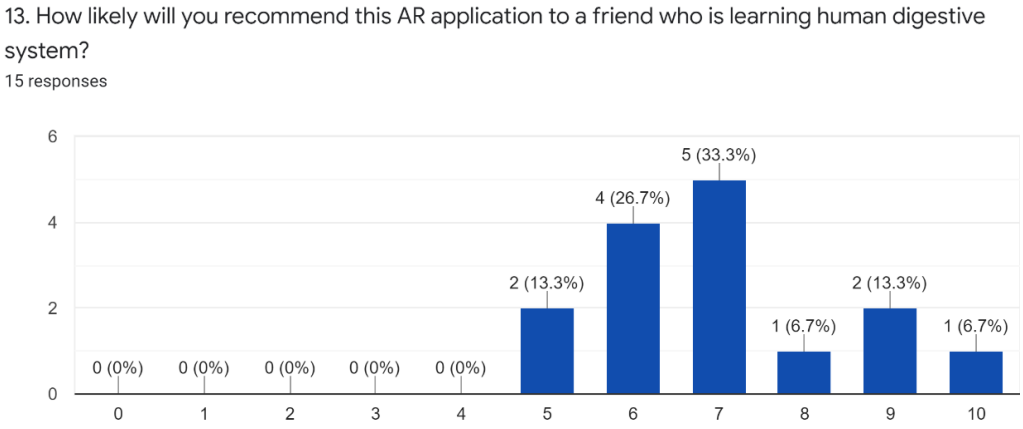


Figure 6.2.13 Result of Question 13.

Next, Question 13 is a rating question to investigate how likely the respondents will recommend this AR application to a friend who is learning human digestive system, with the choice of rating from 1 (Very Unlikely) to 10 (Very Likely). According to Figure 6.2.13, it is found that the respondents are likely to recommend the application to their friends because the rating is from 5 to 10. Most of the respondents voted a rating of 7 for this question.

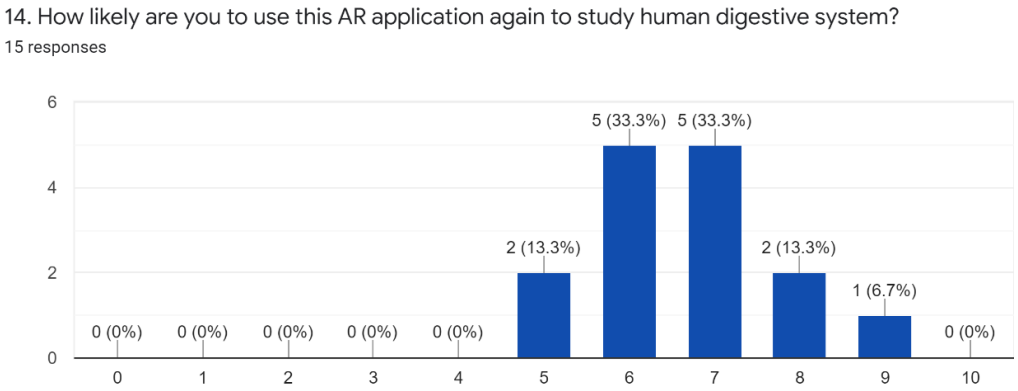


Figure 6.2.14 Result of Question 14.

Question 14 is another rating question to examine how likely the respondents will use this AR application again to study human digestive system, with the choice of rating from 1 (Very Unlikely) to 10 (Very Likely). Based on Figure 6.2.14, the rating is from 5 to 9 and most of the respondents voted a rating of 6 and 7 for this question. Hence, it can be concluded that most of the respondents are likely to use this AR application again.

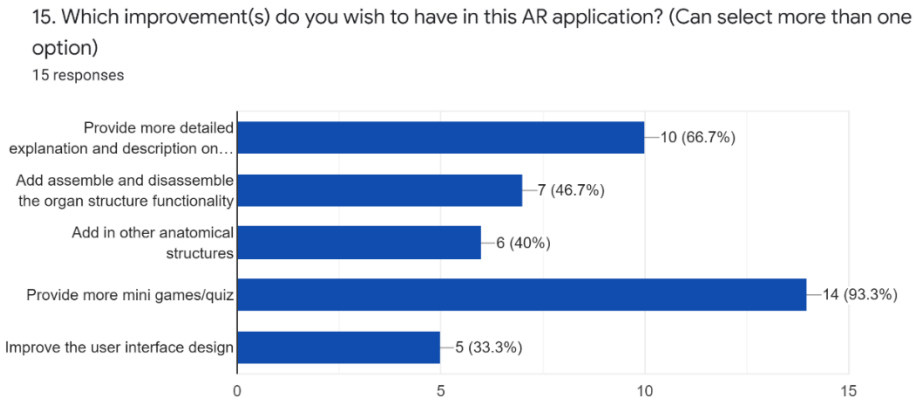


Figure 6.2.15 Result of Question 15.

Finally, Question 15 is a multiple-select question to collect feedback of the respondents on which improvements they wish to have in this AR application. According to the result obtained in Figure 6.2.15, it is discovered that most of the respondents suggest providing more mini games or quizzes in the application (14 votes). Besides that, the respondents also suggest providing more detailed explanation and description on the human digestive system (10 votes), followed by the suggestion to add the assemble and disassemble organ structure functionality (7 votes), add in other anatomical structures (6 votes) and lastly, improve the user interface design (5 votes).

6.3 Objectives Evaluation

The proposed application has achieved the objectives stated in Chapter 1:

- The proposed system enhances the learning process and increase learning outcome about the human digestive system through the augmented 3D model.
- The proposed system provides a more realistic-looking 3D representation of the human digestive system.
- The proposed system provides a more engaging and interactive method of learning human digestive system.

6.4 Concluding Remark

In this chapter, the system testing performed on the proposed application is explained. Test cases for each functionality of the proposed application and the results of the test cases are defined. After that, a survey is conducted towards the university students in UTAR, which is the target user of the application, to collect their feedback on the application developed. The results obtained from the survey are optimistic as most of the respondents are satisfied with the application. After completing and passing the system testing, it can be concluded that the proposed application has achieved the three objectives of the project, which are enhancing the learning process, providing a more realistic-looking 3D representation of human digestive system, and providing a more engaging and interactive method of learning human digestive system.

CHAPTER 7 CONCLUSION AND RECOMMENDATION

7.1 Brief Summary

Conventional anatomy education has a lot of limitations and weaknesses. The main problem with conventional anatomy education is the difficulty of visualising 3D anatomy from 2D images in textbooks. Students find it difficult to understand the anatomy, especially the human digestive system, which is one of the most complex human body systems. Other than that, conventional anatomy education provides limited access to the learning materials in laboratory such as human skeleton models and anatomical models. In this proposed project, an effective anatomy learning application using AR technique will be developed to solve the problems faced by undergraduate students in faculty of science when learning human digestive system. The application will enhance the learning process of the students, by visualizing the 3D organs using the AR technique. The three main modules in the application are the AR module, learn anatomy module, and anatomy puzzle game module.

7.2 Novelties and Contributions

The proposed application greatly improves the learning process and learning outcome of the students. It helps the university students to understand the anatomy of human digestive system faster and easier. It provides a realistic-looking, accurate and detailed 3D representation of the human digestive system because the 3D model is reconstructed based on CT images. The accuracy of details is important so that the students can get precise information of the anatomical knowledge and learn the exact position of each structure of the organs. Using this AR application, the students can interact with the augmented 3D model to learn the anatomy structure, which is more fun and exciting compared to traditional learning methods. They can also play anatomy puzzle game for entertainment, and at the same time learning the position of human digestive organs in the human body. In addition, the application can be easily accessed by the students anytime and anywhere using their smartphones. Hence, the students can revise the subject regularly and this will help them to retain long-lasting knowledge.

7.3 Future Work

The current proposed application only focuses on the middle parts of the human digestive anatomy, which are the liver, pancreas, stomach, and gall bladder. However, the application will be further enhanced by integrating with the upper part (mouth, oesophagus) and lower part (large intestine, small intestine) of the human digestive system, to produce a complete human digestive system. The final application will be delivered for the use of faculty of science students in University Tunku Abdul Rahman to learn the human digestive anatomy. The future improvement of this application is more features and functions which are helpful for learning the anatomy can be included. For example, assembling and disassembling the AR model, displaying the internal view of the organs, showing the movement of food through the digestive tract and adding more mini games and quizzes. Besides that, the details and accuracy of the 3D model can be further improved. Other than that, the organs can be divided into more segments so that the students can learn more details about the structure of the organs.

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APPENDIX A

1. Do you know about medical images (e.g. CT images, MRI images...)?

   [ ] Yes
   [ ] No
   [ ] Not really

2. Do you know about 3D reconstruction of the model?

   [ ] Yes
   [ ] No
   [ ] Not really

3. Do you have any experience in using an Augmented Reality (AR) application? (e.g. Pokémon Go App, Snapchat, IKEA Place app...)

   [ ] Yes
   [ ] No
   [ ] Not really

4. Which of the following difficulties do you experience when learning human anatomy through traditional learning methods such as textbooks and 3D plastic models? (Can select more than one option)

   [ ] Difficulty in understanding the exact position of the human organs through text descriptions
   [ ] Difficulty in imagining the human anatomy structure in 3D form from a 2D picture
   [ ] Difficulty in retaining the information learnt in memory
   [ ] Lack of interest to learn human anatomy structure by studying textbooks
   [ ] Difficulty in accessing the skeleton model and 3D plastic models which can only be accessed during operating hours of the laboratory.
   [ ] None of the above

5. Which method do you prefer the most to learn human digestive system?

   [ ] Textbook that contains 2D images and text descriptions

   [ ] Physical 3D plastic models of human digestive system

   [ ] AR mobile application to learn human digestive system using non-realistic AR model (e.g. graphic 3D modelling)

   [ ] AR mobile application to learn human digestive system using realistic AR model (e.g. 3D reconstruction of medical images)

6. In your opinion, do you agree that using a real-life dataset of the medical image to create the virtual 3D model of the anatomy structure can help you learn human digestive system more effectively and accurately?

   [ ] Strongly agree

   [ ] Agree

   [ ] Neutral

   [ ] Disagree

   [ ] Strongly disagree

7. Please rate this AR application of learning human digestive system for the following features.

	Poor	Below Average	Average	Good	Excellent
Displaying 3D model of human digestive system in AR mode					
Manipulating and interacting with the augmented 3D model (i.e., scaling, rotating, moving, selecting)					
Study human digestive system function					
Anatomy puzzle game function					

User friendliness and user interface design					

8. Which feature do you like the most in this AR application of learning human digestive system?

   [ ] Displaying 3D model of human digestive system in AR mode
   [ ] Manipulating and interacting with the augmented 3D model (i.e., scaling, rotating, moving, selecting)
   [ ] Providing detailed information of the organs of human digestive systems with descriptions, pictures and videos.
   [ ] Playing puzzle game to learn the positions of organs of the human digestive systems

9. Do you agree that using this AR application to learn human digestive system helps you to understand the anatomy faster and enhance your learning process compared to using textbook which contains only 2D images and text description?

   [ ] Strongly agree
   [ ] Agree
   [ ] Neutral
   [ ] Disagree
   [ ] Strongly disagree

10. Do you agree that this AR application provides a more realistic-looking 3D representation of the human digestive system compared to 2D images in the textbook?

    [ ] Strongly agree
    [ ] Agree
    [ ] Neutral
    [ ] Disagree
    [ ] Strongly disagree

11. Do you agree using this AR application to learn human digestive system is more engaging and interactive compared to using textbook?

    [ ] Strongly agree
    [ ] Agree
    [ ] Neutral
    [ ] Disagree
    [ ] Strongly disagree

12. How was your experience with this AR application to learn human digestive system?

	0	1	2	3	4	5	6	7	8	9	10	
Very Unsatisfied	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	Very Satisfied

13. How likely will you recommend this AR application to a friend who is learning human digestive system?

	0	1	2	3	4	5	6	7	8	9	10	
Very Unlikely	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	Very Likely

14. How likely are you to use this AR application again to study human digestive system?

	0	1	2	3	4	5	6	7	8	9	10	
Very Unlikely	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	Very Likely

15. Which improvement(s) do you wish to have in this AR application? (Can select more than one option)

    [ ] Provide more detailed explanation and description on the human digestive system

    [ ] Add assemble and disassemble the organ structure functionality

    [ ] Add in other anatomical structures

    [ ] Provide more mini games/quiz

    [ ] Improve the user interface design

    [ ] Other: _____

WEEKLY LOG

FINAL YEAR PROJECT WEEKLY REPORT
(Project II)

Trimester, Year: Jan, 2022	**Study week no.:** 2
Student Name & ID: Lim Hui Ying 18ACB04180	
Supervisor: Dr Sayed Ahmad Zikri Bin Sayed Aluwee	
Project Title: AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images	

1. WORK DONE
[Please write the details of the work done in the last fortnight.]

The software to be used, Unity is set up, and additional modules are added to Unity. Vuforia Engine is also installed into the Unity. The project is created in Unity, and player settings and build settings are configured so that the application can be run on Android device. Work done is documented into the project report Chapter 5 – system implementation. Besides that, the introduction, problem statement, project scope and objective, contribution, literature review from FYP1 report is refined.

2. WORK TO BE DONE

The work to be done in the following two weeks are the user interface of the main menu, and play AR module, importing the human digestive system 3D object done from FYP1 and a target marker image into Unity, function to scan marker and display AR model, function to interact with AR model, and testing and also fixing bugs of the functions built.

3. PROBLEMS ENCOUNTERED

The content of the report needs to be refined.

4. SELF EVALUATION OF THE PROGRESS

I should spend more time in doing the project.

Sayed

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT
(Project II)

Trimester, Year: Jan, 2022	**Study week no.:** 4
Student Name & ID: Lim Hui Ying 18ACB04180	
Supervisor: Dr Sayed Ahmad Zikri Bin Sayed Aluwee	
Project Title: AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images	

1. WORK DONE
[Please write the details of the work done in the last fortnight.]

The user interface of main menu, and play AR module is done. Human digestive system 3D object done from FYP1, and a target marker image is imported into Unity. Function to scan marker and display AR is done. Function to interact with the AR model, such as rotate, move, and scaling is done. Testing and fixing bugs of the functions are performed.

2. WORK TO BE DONE

The work to be done in the following two weeks are the function to select and highlight the part of the AR model, function to show or hide selected part of the AR model, function to view details of selected part, function to enable and disable flashlight when scanning marker, function to enable and disable segmentation of the organ model, function to display guideline to download marker and also testing and fixing bugs of the functions built.

3. PROBLEMS ENCOUNTERED

Difficulty in creating aesthetic and appropriate user interface design.

4. SELF EVALUATION OF THE PROGRESS

I should spend more time in learning to develop the necessary functions.

Sayed

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT
(Project II)

Trimester, Year: Jan, 2022	**Study week no.:** 6
Student Name & ID: Lim Hui Ying 18ACB04180	
Supervisor: Dr Sayed Ahmad Zikri Bin Sayed Aluwee	
Project Title: AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images	

1. WORK DONE
[Please write the details of the work done in the last fortnight.]

Function to select and highlight the part of the AR model is done. Function to show or hide selected part of the AR model is done. Function to view details of selected part is done. Function to enable and disable flashlight when scanning marker is done. Function to enable and disable segmentation of the organ model is done. Function to display guideline to download marker is done. Testing and fixing bugs of the functions are performed.

2. WORK TO BE DONE

The work to be done in the following two weeks are creating the user interface of the learn anatomy module, building the function to select topic and view topic information to learn the human digestive system organs, function of the video player for playing videos of human digestive system organs, and also testing and fixing bugs of the module created. The work done should also be documented into the project report.

3. PROBLEMS ENCOUNTERED

Difficulties in learning to develop the functions of the applications.

4. SELF EVALUATION OF THE PROGRESS

I should spend more time in learning to develop the necessary functions.

Sayed

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT
(Project II)

Trimester, Year: Jan, 2022	**Study week no.:** 8
Student Name & ID: Lim Hui Ying 18ACB04180	
Supervisor: Dr Sayed Ahmad Zikri Bin Sayed Aluwee	
Project Title: AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images	

1. WORK DONE
[Please write the details of the work done in the last fortnight.]

The user interface of the learn anatomy module is done. Function to select topic and view topic information to learn the human digestive system organs are done. Function of the video player for playing videos of human digestive system organs is done. Testing and fixing bugs of the module are performed. Work done is documented into the project report Chapter 5 – system implementation.

2. WORK TO BE DONE

The work to be done in the following two weeks are creating the user interface and function of the anatomy puzzle game module, and also testing and fixing bugs of the module built. Besides that, the work done should be documented into the project report. Other than that, the draft project report must be completed and submitted to supervisor by Friday of week 10.

3. PROBLEMS ENCOUNTERED

A lot of documentation part need to be refined and improve the writing.

4. SELF EVALUATION OF THE PROGRESS

I need to put more effort in developing the application.

Sayed

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT
(Project II)

Trimester, Year: Jan, 2022	**Study week no.:** 10
Student Name & ID: Lim Hui Ying 18ACB04180	
Supervisor: Dr Sayed Ahmad Zikri Bin Sayed Aluwee	
Project Title: AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images	

1. WORK DONE
[Please write the details of the work done in the last fortnight.]

The user interface and function of the anatomy puzzle game module is done. Testing and fixing bugs of the module is performed. Work done is documented into the project report Chapter 5 – system implementation. System design in the project report is refined. Complete the draft project report and submit the draft project report to supervisor on Friday of week 10.

2. WORK TO BE DONE

Perform system testing and fix for bugs in the application. Do a survey questionnaire to gather student's perception on the application developed.

3. PROBLEMS ENCOUNTERED

Difficulties in obtaining suitable image resource for the puzzles in the puzzle game interfaces.

4. SELF EVALUATION OF THE PROGRESS

I need to spend more time on doing my project.

Sayed

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT
(Project II)

Trimester, Year: Jan, 2022	**Study week no.:** 12
Student Name & ID: Lim Hui Ying 18ACB04180	
Supervisor: Dr Sayed Ahmad Zikri Bin Sayed Aluwee	
Project Title: AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images	

1. WORK DONE
[Please write the details of the work done in the last fortnight.]

System testing and fixing for bugs in the application are performed. A survey is performed to target users to collect their feedback after using the application. Final checking on report and application are done.

2. WORK TO BE DONE
Submit the report on Friday of Week 13. Then, start to prepare for presentation.

3. PROBLEMS ENCOUNTERED

Difficulties in fixing some bugs in the application.

4. SELF EVALUATION OF THE PROGRESS

I should spend more time on doing my project.

Sayed
Supervisor's signature

Student's signature

POSTER

AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images

Introduction

This project delivers an interactive AR learning application about the human digestive system. The 3D model is reconstructed based on CT images so that students can get precise information of the human anatomy.

Problem Statement

- Difficulty of learning human anatomy through traditional learning methods
- Lack of accuracy and realistic looking of the 3D human anatomy
- Lack of interaction in traditional learning methods

Project Scope

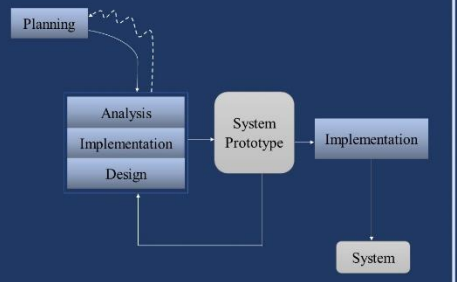
- Focus anatomy parts → liver, stomach, pancreas, gall bladder
- 3 Main Modules → AR module, Learn anatomy module, Anatomy puzzle game module

Project Objective

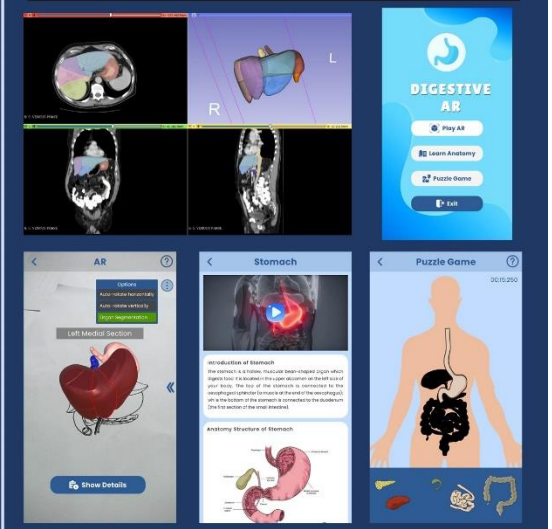
- To enhance the learning process and increase learning outcome
- To provide a more realistic-looking 3D representation of the human digestive system
- To provide a more engaging and interactive method of learning human digestive system

Methodology

- Rapid Application Development (RAD) based methodology



Results



Conclusion

In conclusion, the proposed application solves the difficulties faced by students to learn anatomy, by visualising the human digestive system in augmented 3D model. The application will enhance the learning process of the students and provide a more fun and interactive learning method.

By: Lim Hui Ying *Supervisor: Dr Sayed Ahmad Zikri bin Sayed Aluwee*

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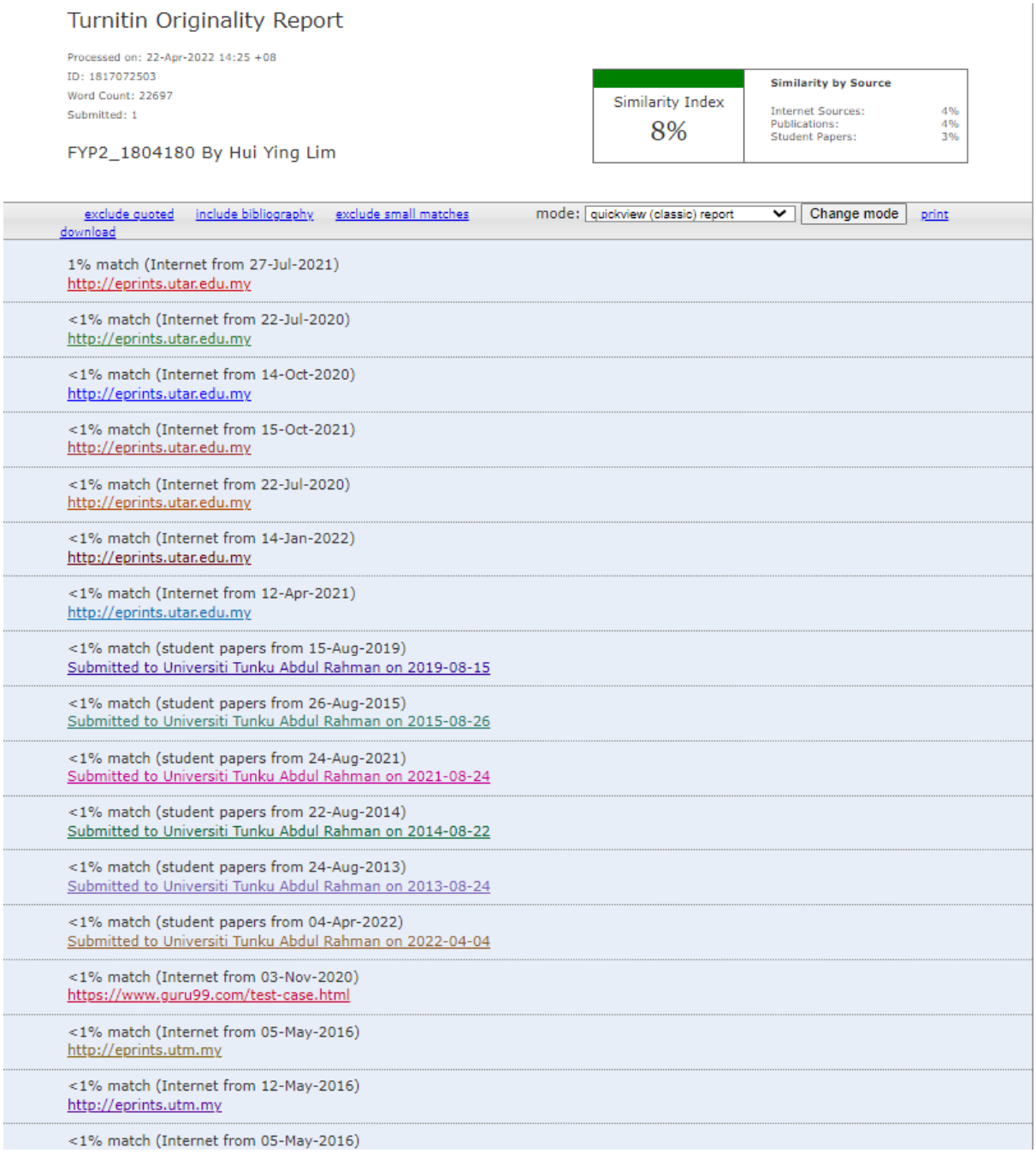

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FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

Full Name(s) of Candidate(s)	Lim Hui Ying
ID Number(s)	18ACB04180
Programme / Course	Bachelor of Computer Science (HONOURS)
Title of Final Year Project	AR Learning Application of Parts of Human Digestive System Based on 3D Reconstruction of CT Images

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Based on the above results, I hereby declare that I am satisfied with the originality of the Final Year Project Report submitted by my student(s) as named above.

Sayed

Signature of Supervisor

Name: SAYED AHMAD ZIKRI BIN SAYED ALUWEE

Date: 22/4/2022

Signature of Co-Supervisor

Name: _____

Date: _____

FYP2 CHECKLIST

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FACULTY OF INFORMATION & COMMUNICATION TECHNOLOGY
(KAMPAR CAMPUS)

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Student Name	Lim Hui Ying
Supervisor Name	Dr Sayed Ahmad Zikri bin Sayed Aluwee

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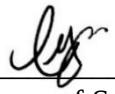

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