CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Methodology

This research will adopt the following steps in order to be completed. The steps that will be carried out are as follows:

1. Literature Review

The literature review is comprised of gathering, reading, and comprehending works of literature from several resources such as scientific journals, conference papers and textbooks. This process aims to enhance the theoretical knowledge regarding the human visual system, colour science, colour vision deficiency, virtual reality, Unity, HMSAM (Hedonic-Motivation System Adoption Model), and the Likert scale. All the information gathered will be used as the base reference for building the application.

2. System Design

The system design step starts with specifying the workflow of the application, followed with flowchart creation, user interface design, asset usage planning, and questionnaire design based on HMSAM.

3. Implementation

The application will be developed with Unity and will contain matrix transformations needed to achieve the desired colour from the colour space

4. Testing and Evaluation

The testing phase is carried out to ensure the program works as expected and can produce accurate results. This step also involves the debugging of the source code. Furthermore, an evaluation is carried out by comparing the testee' vision condition and the output produced by the application.

5. Report Creation

As the final step in this research, report creation will be carried out throughout the research process. The report should cover all aspects of the study and be written according to the Informatics Department's appropriate guideline.

3.2 System Analysis and Design

DichromaVR is a single-player virtual reality-based game that tests whether the player has a colour vision deficiency, particularly dichromatism. The game will be comprised of two tests. The first is based on the Ishihara test to detect red-green colour blindness, and the second one is based on the D15 Farnsworth-Munsell test to detect the severity and type of dichromatism.

In the first test, the player will be given nine questions. In each question, they will be faced with four different coloured gemstones and a box. Their goal is to pick which gemstone's colour is most similar to the box. The colours chosen for each question is based on the theory that states people with colour blindness are more sensitive to saturation.

1. Reference Object Colour

   The colour of the box that acts as a reference.

2. Answer Object Colour

   The colour attached to one of the four gemstones. This is the correct colour of choice because it has a similar hue but different saturation with the reference object.

3. Neutral Object Colour

   A neutral colour is seen as different to people with colour blindness. This colour acts as a parameter to check whether the player understands the test or not. If they keep choosing neutral colours, it means they do not understand the premise of the test and will be asked to take the test again.

4. First and Second Choice Colour

   These are the colours that are attached to two of the four gemstones. They are the colour of choice for colour blind players because it has a similar saturation but different hue with the reference object.

The colours are adapted from the previous table about the Ishihara Colours in Table 2.2, and the colour pairings for each question are shown in Table 3.1 below. Since people with colour deficiency is more likely to choose the object that is most similar in saturation, while people with normal colour vision is more likely to choose the object that is most similar in hue. The colours are chosen manually by comparing the hue and saturation values of each colour.

At the end of the test, they will be shown their result. There are three possible results; Normal Vision, Slight Red-Green Colour Deficiency, and Strong Red-Green Colour Deficiency. After pressing 'A', they will move on to the second test.

In the second test, they will be presented with 15 differently coloured and randomly arranged cubes in front of them. Their goal is to arrange them in the correct order beginning from the pilot cube, which serves as the initial starting point. The goal is simple. They have to place the cube they think is most similar in hue to the pilot cube, place it next to it, and continue to do so until they feel like they have arranged the cubes correctly. After they're done, they can see the result.

For both tests, the player can navigate through the virtual world space using the left stick to move around and use the headset for rotating left and right. To do actions required by the game, the player must press either the 'A', 'B' or 'X' buttons respective to the actions they can perform as shown on screen.

Table 3.1 Colour Pairings in Ishihara Test Based on Hue and Saturation

Q	Reference Object Colour			Answer Object Colour			First Choice Colour			Second Choice Colour		
1		**1**			**2**			**8**			**9**	
	H	S	V	H	S	V	H	S	V	H	S	V
	94.86	52.98	43.75	71.13	39.99	41.05	54.09	49.25	42.18	49.84	66.22	44.97
2		**3**			**4**			**10**			**16**	
	H	S	V	H	S	V	H	S	V	H	S	V
	68	46.03	41.12	65.59	45.93	40.95	41.6	45.92	45.28	24.01	72.54	61.61
3		**6**			**7**			**13**			**15**	
	H	S	V	H	S	V	H	S	V	H	S	V
	57.55	55.05	41.53	54.67	51.45	42.16	35.05	71.1	53.19	24.91	43	57.16
4		**12**			**14**			**21**			**22**	
	H	S	V	H	S	V	H	S	V	H	S	V
	42.44	58.23	46.9	37.07	88.7	56.54	19.8	78.45	69.1	21.61	86.61	72.46
5		**18**			**20**			**23**			**26**	
	H	S	V	H	S	V	H	S	V	H	S	V
	23.83	79.48	65.36	19.37	72.79	65.91	18.34	82.14	73.59	14.15	82.65	80.26
6		**21**			**22**			**5**			**13**	
	H	S	V	H	S	V	H	S	V	H	S	V
	19.8	78.45	69.1	21.61	86.61	72.46	63.69	55.38	41.16	35.05	71.1	53.19
7		**24**			**11**			**19**			**25**	
	H	S	V	H	S	V	H	S	V	H	S	V
	17.35	81.97	74.83	44.83	64.02	46.79	19.29	71.78	65.37	17.1	86.94	79.6
8		**16**			**7**			**12**			**14**	
	H	S	V	H	S	H	S	V	H		H	S
	24.01	72.54	61.61	54.67	51.45	42.16	42.44	58.23	46.9	37.07	88.7	56.54
9		**17**			**25**			**1**			**2**	
	H	S	V	H	S	H	S	V	H		H	S
	18.14	69.64	64.94	17.1	86.94	79.6	94.86	52.98	43.75	71.13	39.99	41.05

3.2.1 Flowcharts

A Main Menu Flowchart

The app will begin from the lobby. Before starting the tests, the player

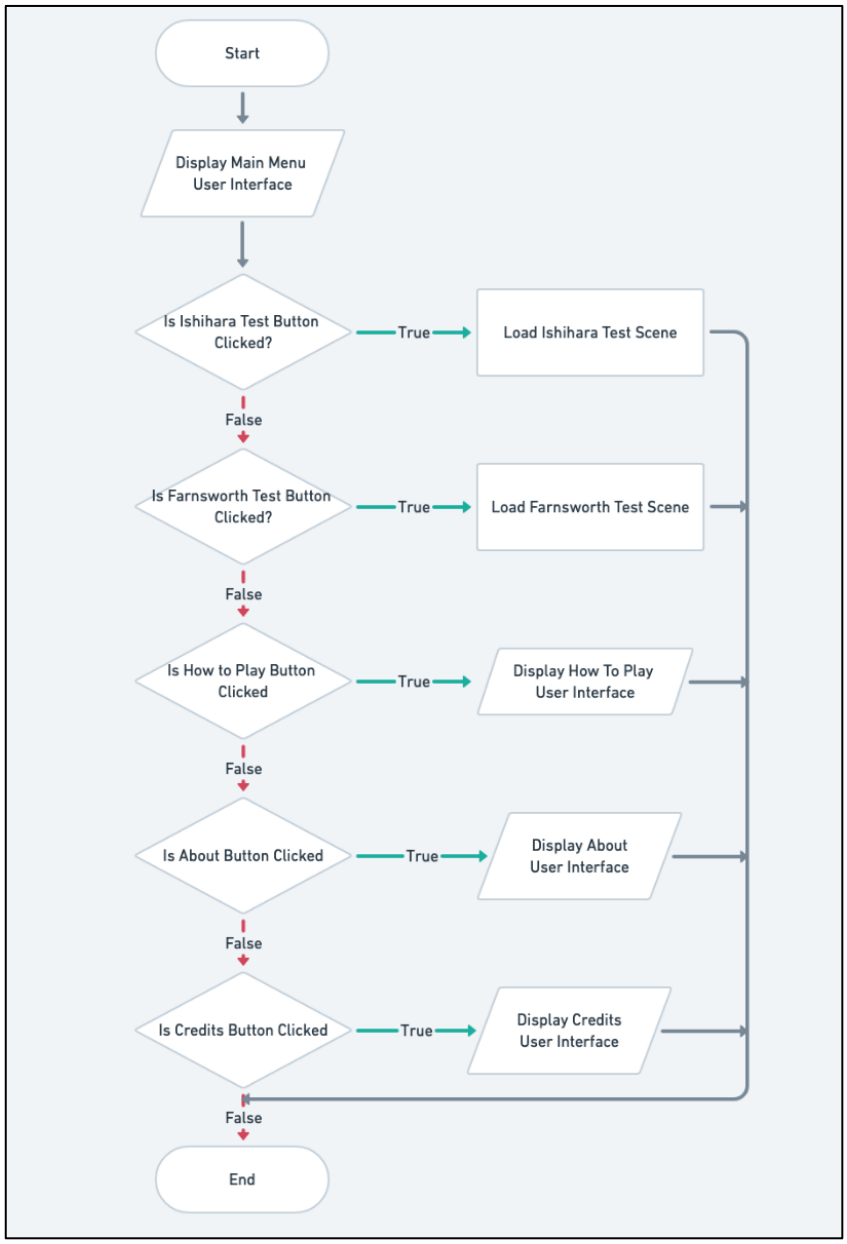

Figure 3.1 Main Menu Flowchart

The app will begin from the lobby. Before starting the tests, the player can adjust the focus on their headset accordingly, try moving around with the controller, and get comfortable with the rotation. There are four options available to choose from in the main lobby: Ishihara Test, D15 Farnsworth Test, How to Play, About, and Credits. If the player decides on the Ishihara Test, they will be brought to the Ishihara Test scene. If the player chooses the D15 Farnsworth Test, they will be brought to the Farnsworth Test scene. But, if the player chooses how to play or about or credits, they will remain in the current scene, and they will be shown the panel of information they chose to see. It is worth noting that the player will be asked to choose to Ishihara test first from the start.

B Ishihara Test Flowchart

B.1 IshiharaTestMain Module

Figure 3.2 shows the IshiharaTestMain Module flowchart. This module is responsible for the whole game. It checks whether the player has entered the question area or not. Once the player enters, it will call on the SpawnQuestion module to instantiate the question. After that, this module will store the answer so later the CalculateIshiharaResult module can calculate it. Once the player completes all question, this module will load the D15 Farnsworth Test scene.

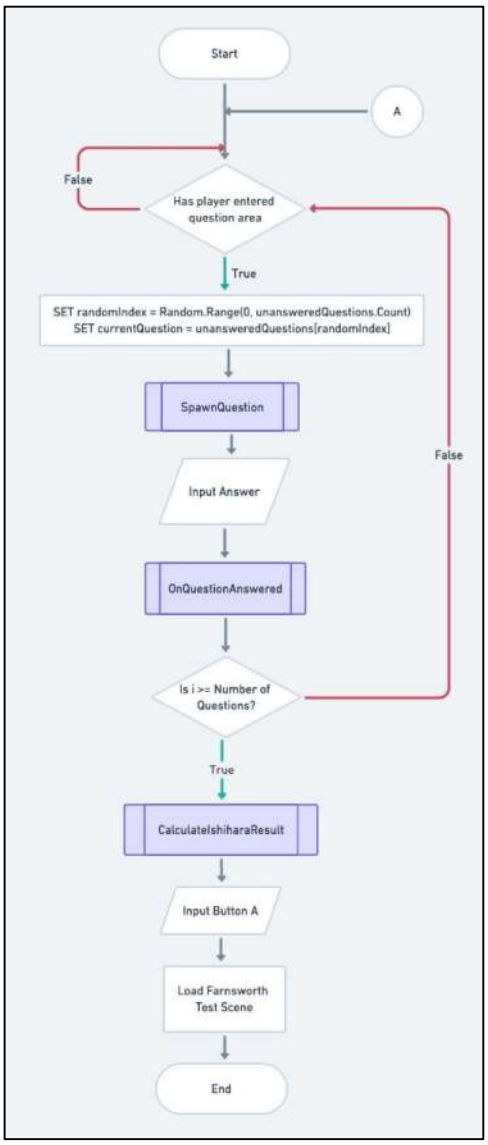

Figure 3.2 IshiharaTestMain Module Flowchart

B.2 SpawnQuestion Module

This module is responsible for spawning the game objects related to the question: reference, answer, first choice, second choice, and neutral game objects. This module calculates the position, rotation, and direction for instantiating these game objects. Furthermore, it also calls the ShuffleOptions module to randomise the order of the options. Figure 3.3 shows the SpawnQuestion Module flowchart.

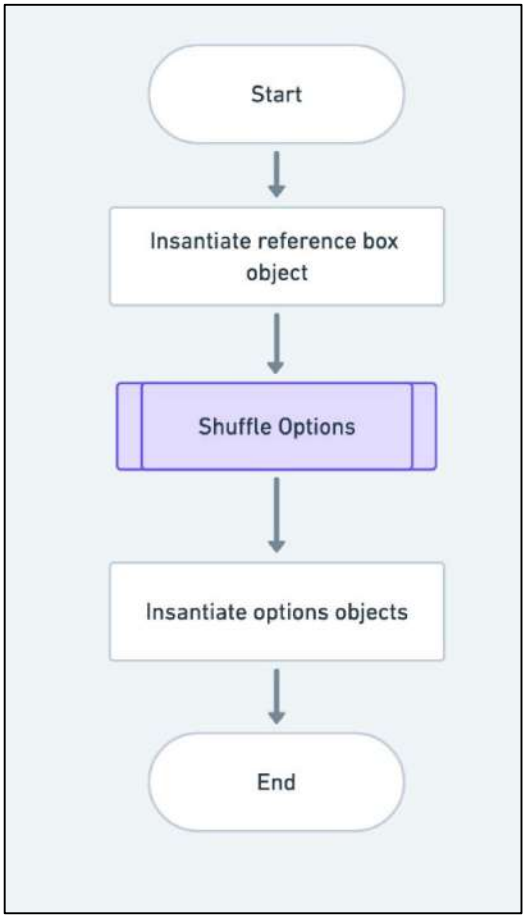

Figure 3.3 SpawnQuestion Module Flowchart

B.3 ShuffleOptions Module

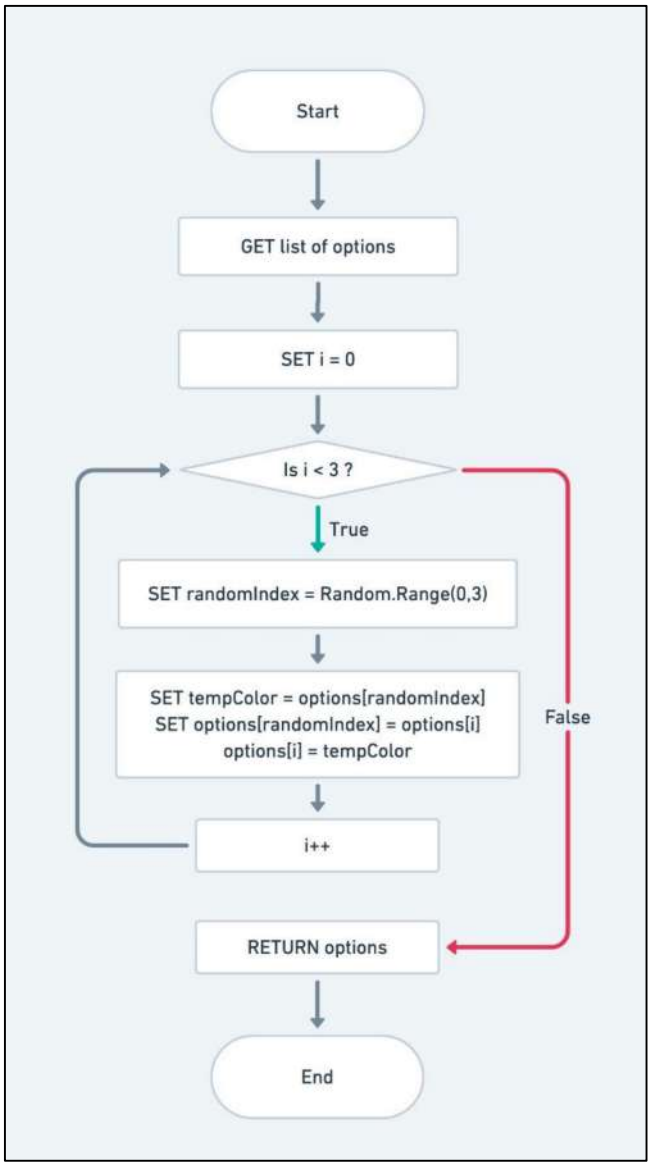

Figure 3.4 Shuffle Options Flowchart Module

Each question has four options and must be shuffled so that the correct answer does not stay in the same position for every question. This ShuffleOptions module is called to do that. Figure 3.4 shows the ShuffleOptions Module flowchart.

B.4 OnQuestionAnswered Module

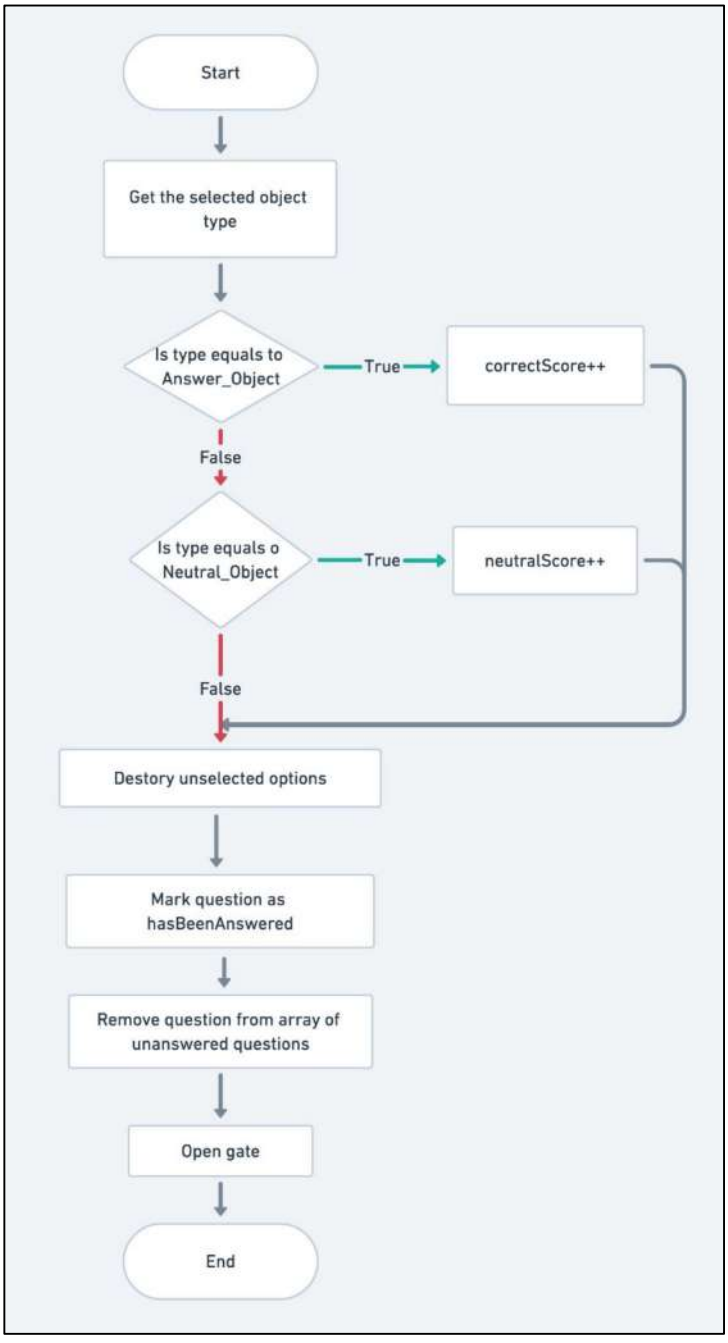

Figure 3.5 OnQuestionAnswered Flowchart Module

This module's main task is to check whether the player has correctly or incorrectly chosen the answer. This module stores the answers and keeps track of the correct and neutral scores. After that, it destroys the unselected options to prevent double response and marks the question as has been answered and removes it from the array of unanswered questions. It then tells the respective gate on that question area to open and make way for the player to continue. Figure 3.5 shows the OnQuestionAnswered Module flowchart.

B.5 CalculateIshiharaResult Module

After the player has finished answering all nine questions, they will see a fireplace to obtain their result. There are two possible outcomes. If the neutral score (the score incremented every time the player chooses a neutral object) has exceeded the threshold, they will be asked to play the game again as it shows they are not cooperative or do not understand the goal clearly. The reason is that yellow appears the same for both red-deficient and green-deficient. Other than that, they will be shown their result and asked to move on to the D15 Farnsworth Test. Figure 3.36shows the CalculateIshiharaResult Module flowchart.

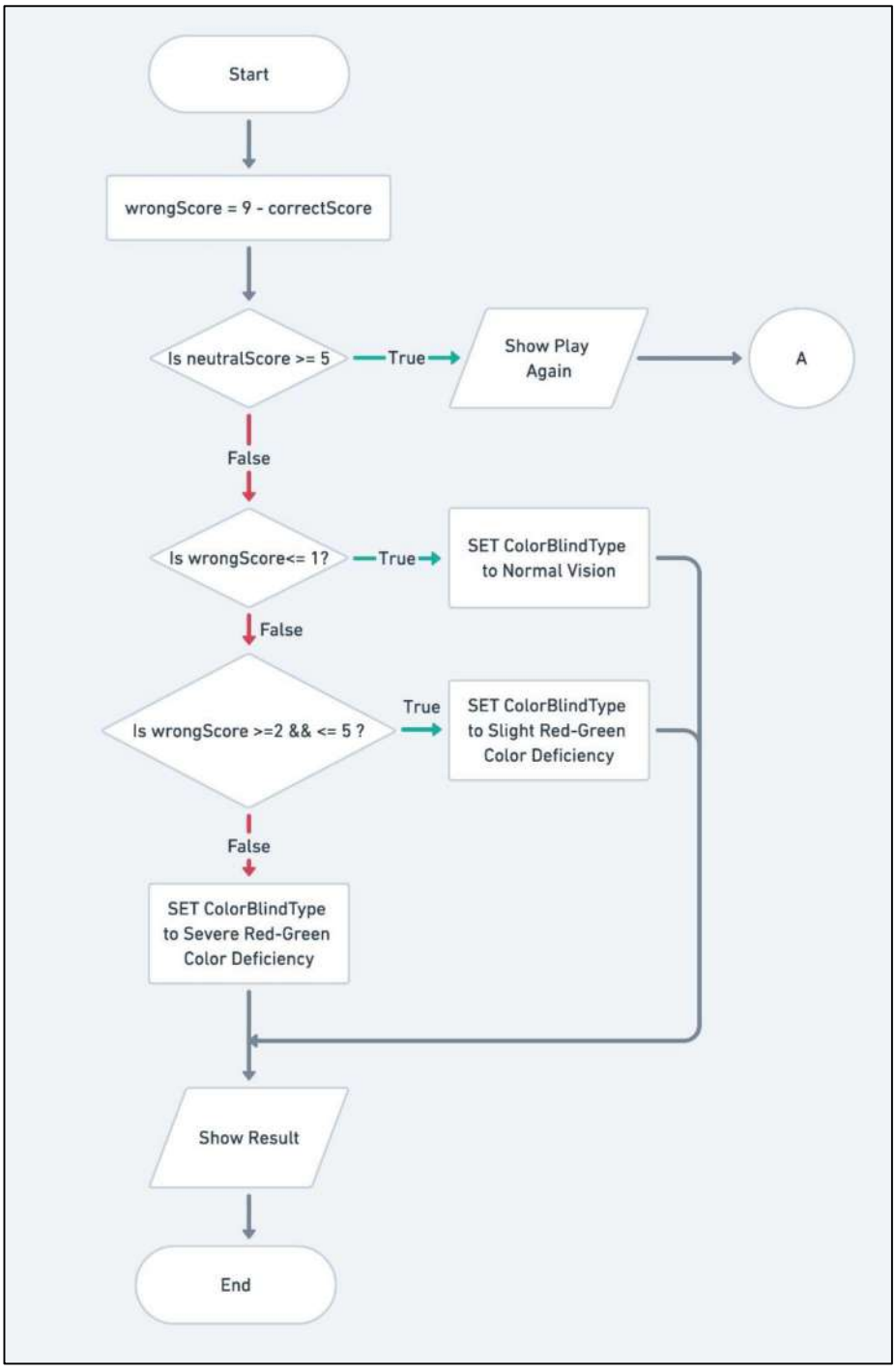

Figure 3.6 CalculateIshiharaResult Module Flowchart

C D15 Farnsworth-Munsell Test Flowchart

C.1 FarnsworthTestMain Module

This module is responsible for calling the SpawnCubes module and check whether the player's raycast has detected any game object in front of it. This module also determines what actions are available for the player to perform for them to arrange the cubes based on the player's condition. The three available actions are pickup, swap, and drop. It also checks whether the player wants to finish and call the RunChecker module to begin processing the result. It then displays the result, and once the player is finished, it will bring them back to the Main Lobby scene and means the test is completed. Figure 3.7 shows the FarnsworthTestMain Module flowchart.

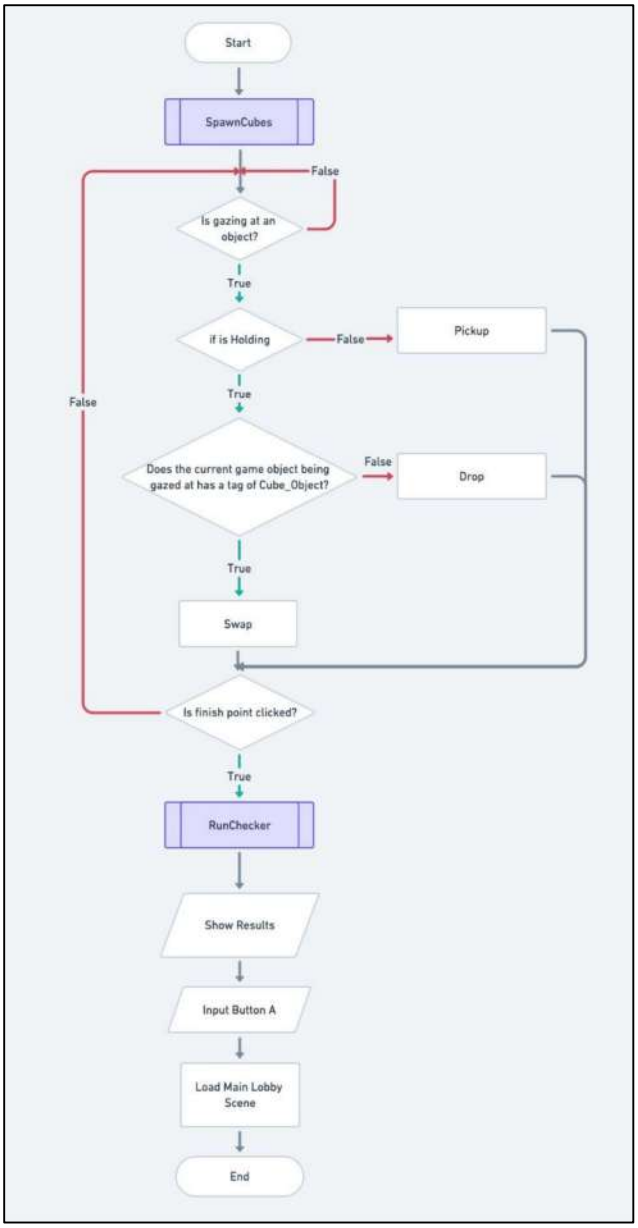

Figure 3.7 FarnsworthTestMain Module Flowchart

C.2 SpawnCubes Module

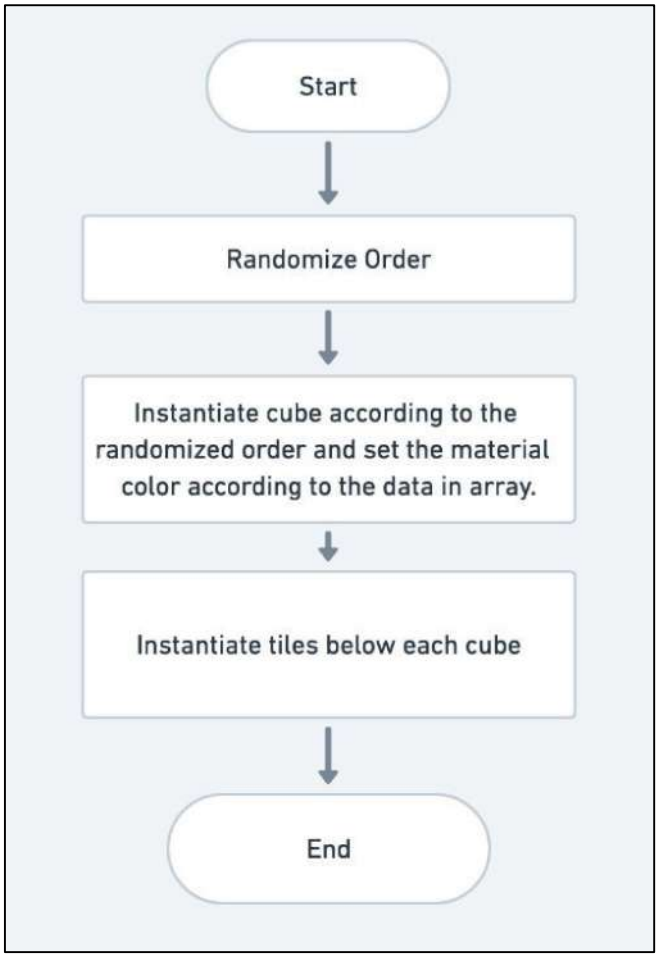

Figure 3.8 SpawnCubes Module Flowchart

This module is responsible for spawning the cubes and their trays and converting the RGB data each cube has into the colour attached to the cube's material. This module also shuffles the order of the cube. Figure 3.8 above shows the SpawnCubes Module flowchart.

C.3 RunChecker Module

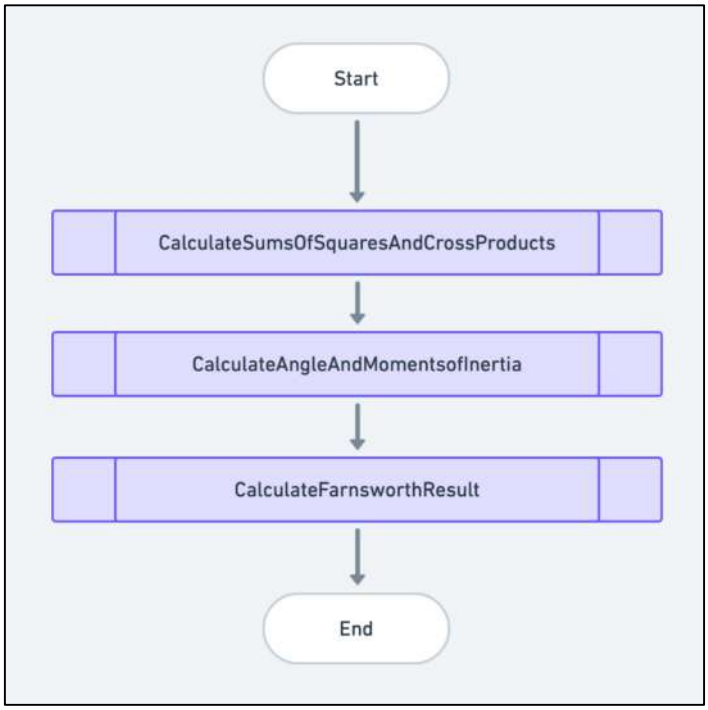

Figure 3.9 RunChecker Module Flowchart

Once the player is done arranging, this module is called and proceeds to calculate the result. This module fetches the arrangement of the player and calculates the result with the help of three other submodules, CalculateSumsofSquaresAndCrossProducts, CalculateAngleAndMomentsOfInertia, and CalculateFarnsworthResults. Figure 3.9 shows the RunChecker Module flowchart.

C.4 CalculateSumsOfSquaresAndCrossProducts Module

This module is responsible for calculating the vector difference for each coordinate (u and v), then from that, we can get the sums of squares and cross-product that later can be used to calculate the next module. Figure 3.10 shows the CalculateSumsOfSquares Module flowchart.

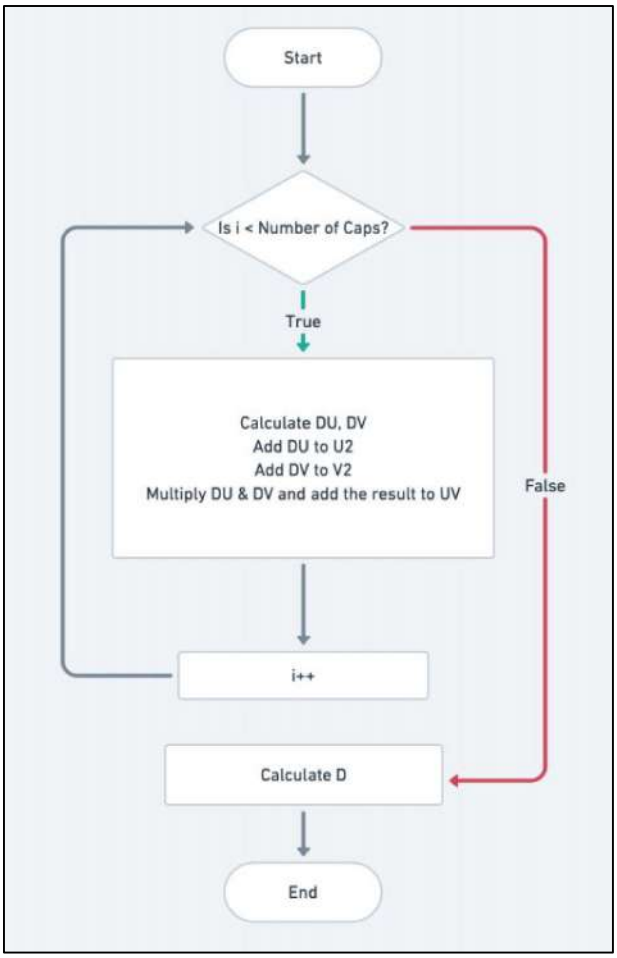

Figure 3.10 CalculateSumsOfSquares Module Flowchart

C.5 CalculateAngleAndMomentsOfInertia Module

This module is responsible for calculating the four main variables needed to calculate the six indicators in determining the colour-blind type. The variables are; major and minor angle as well as major and minor moment. Figure 3.11 shows the CalculatEAnglesAndMomentsOfInertia Module flowchart.

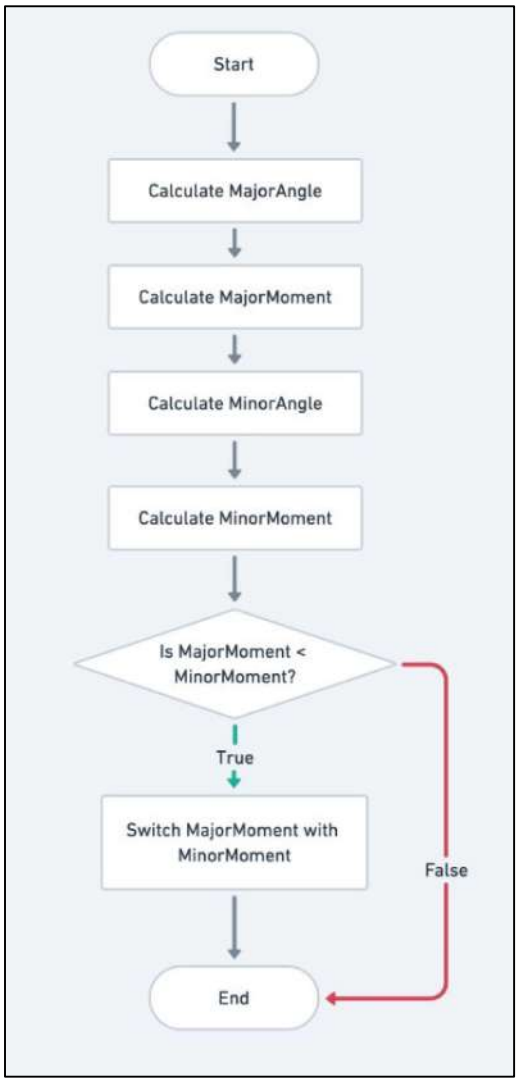

Figure 3.11 CalculateAnglesAndMomentsOfInertia Module Flowchart

C.6 CalculateFarnsworthResult Module

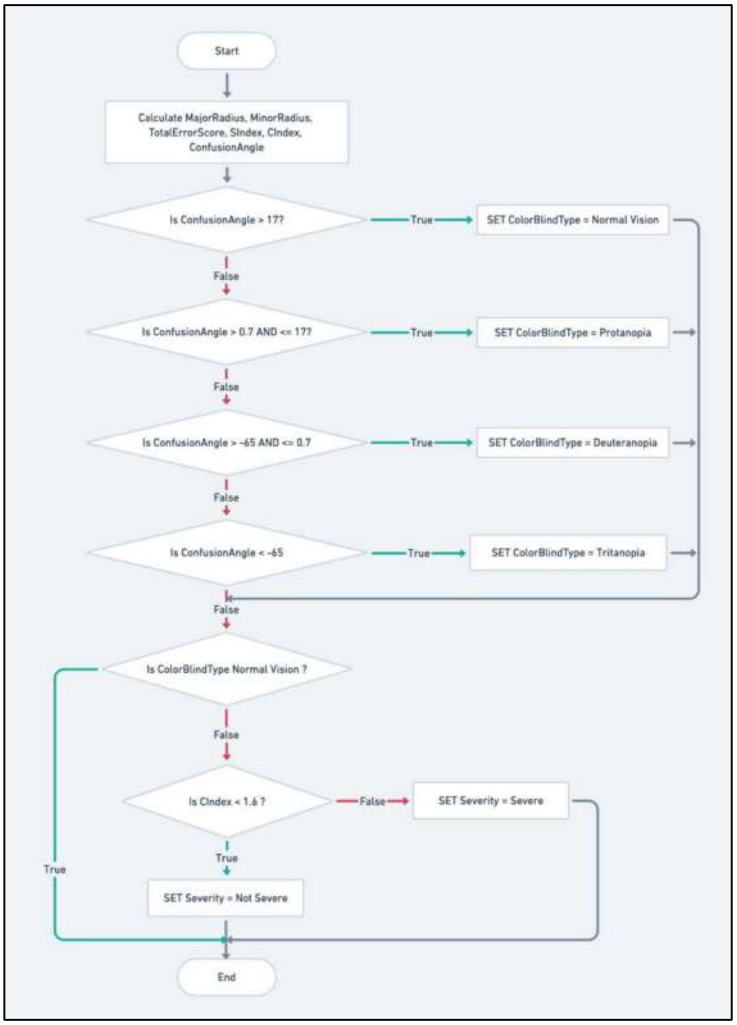

Figure 3.12 CalculateFarnsworthResult Module Flowchart

This final module is responsible for calculating the six factors Vingrys and King-Smith previously proposed: confusion angle, major radius, minor radius, total error score, s-index, and c-index. These variables are detrimental to what type of colour blindness the person is suffering from and how severe it is. Figure 3.12 shows the CalculateFarnsworthResult Module flowchart.

3.2.2 Application User Interface Design

Designing the application is needed to help ease out the development process. The design starts from the main lobby, The Ishihara Test, and D15 Farnsworth-Munsell Test.

A Main Lobby

In the main lobby, players are presented with scenery similar to the ones they will see on the test. The purpose is for them to get used to the view of the game and so that they can adjust their sight focus in using the VR headset.

A.1 Main Menu Panel

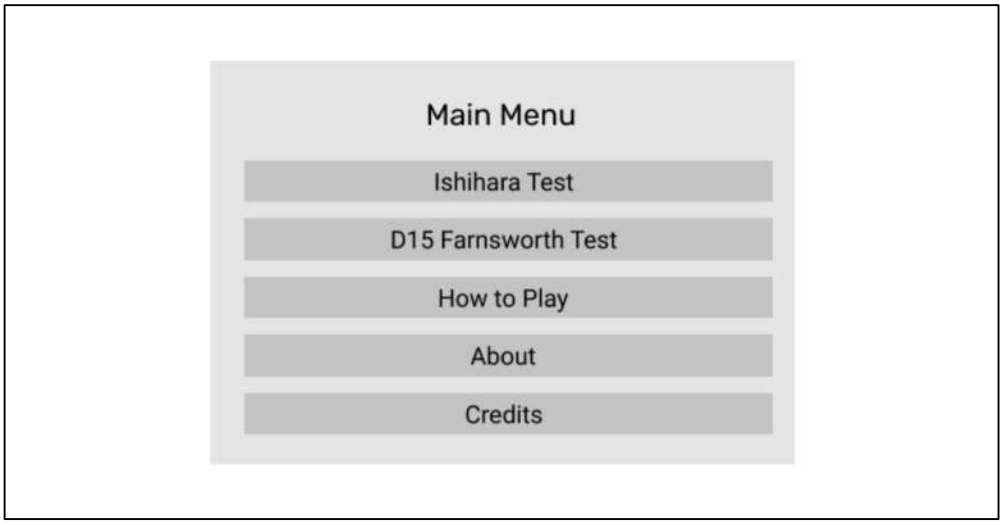

Figure 3.13 MainMenuUI Design

In the main menu, there are five buttons present; *Ishihara Test*, *D15 Farnsworth Test*, both used to pick the test they will take, *How to Play,* which displays a series of instructions on how to navigate through the game, *About* which contains the information regarding the game, and *Credits* which contains the list of asset and

their creators used in the game. By default, players are asked to choose the Ishihara when starting the game. Figure 3.13 shows the design for the MainMenuUI.

A.2 How to Play Panel

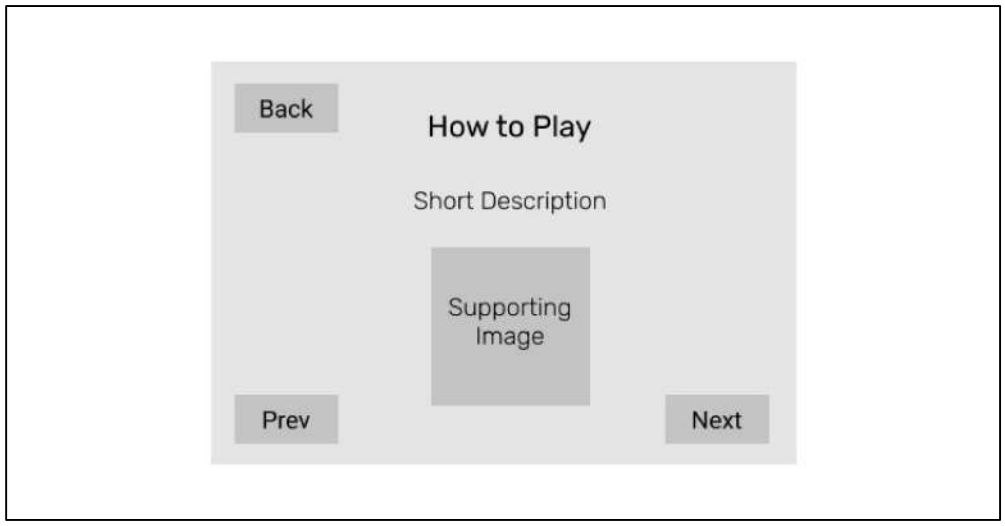

Figure 3.14 HowtoPlayUI Design

How to Play panel shows the player the step-by-step instructions of each test and how to use both the headset and controller to move around the virtual world. This panel can be accessed by gazing at the How to Play button on the Main Menu Panel. Players can navigate to the next or previous steps using the respective buttons on the bottom of the panel. They can also go back to Main Menu Panel through the Back button on the top left. Figure 3.14 shows the HowtoPlayUI design.

A.3 Credits Panel

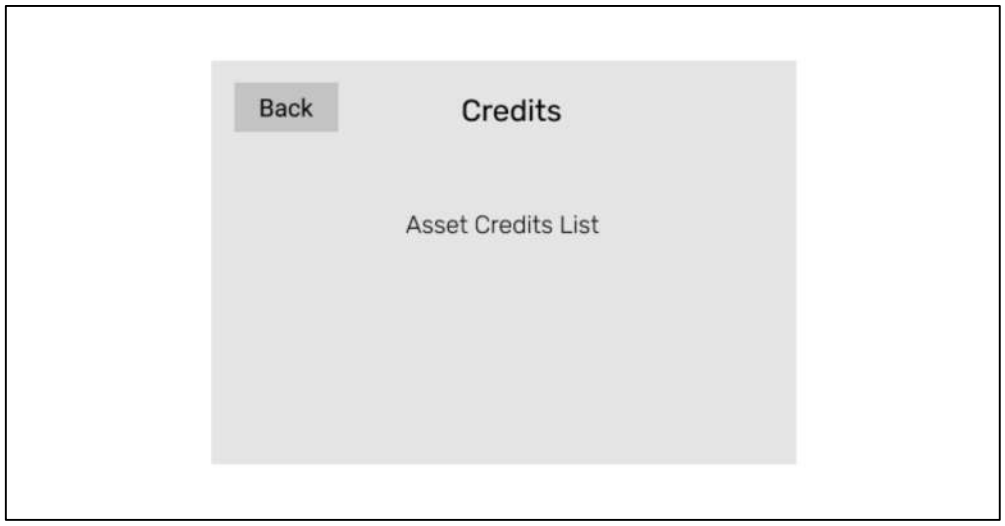

Figure 3.15 CreditsUI Design

The credits panel will show the list of creators, along with their assets that have been used in this game. This panel can be accessed by gazing at the Credits button on the Main Menu panel. Figure 3.15 shows the CreditsUI design.

A.4 About Panel

The about panel displays information about the developer and supervisors of this game as well as the institution logo. This panel can be accessed by gazing at the About button on the Main Menu Panel. Figure 3.16 shows the AboutUI design.

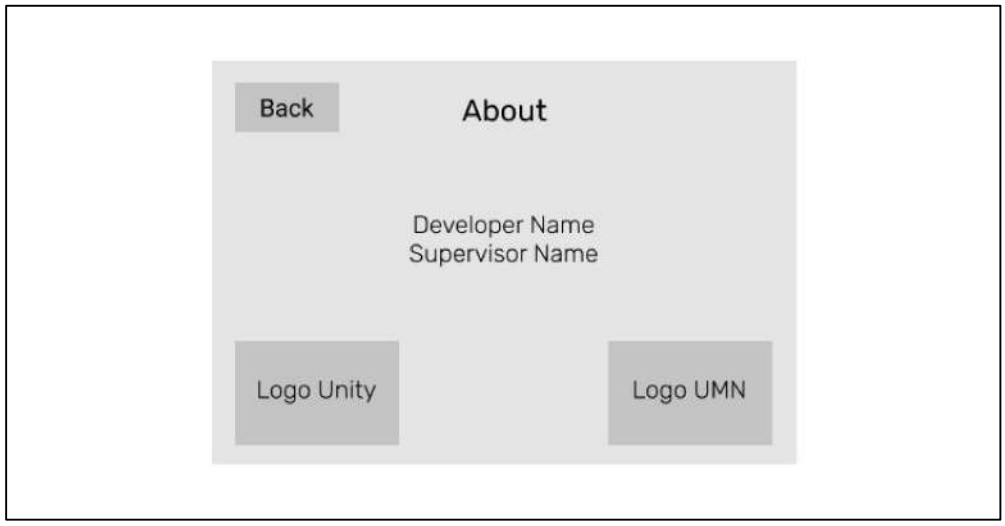

Figure 3.16 AboutUI Design

B Ishihara Test

For the Ishihara, test players will have to answer nine questions to get the result of whether they might suffer from colour blindness or not.

B.1 Question Design

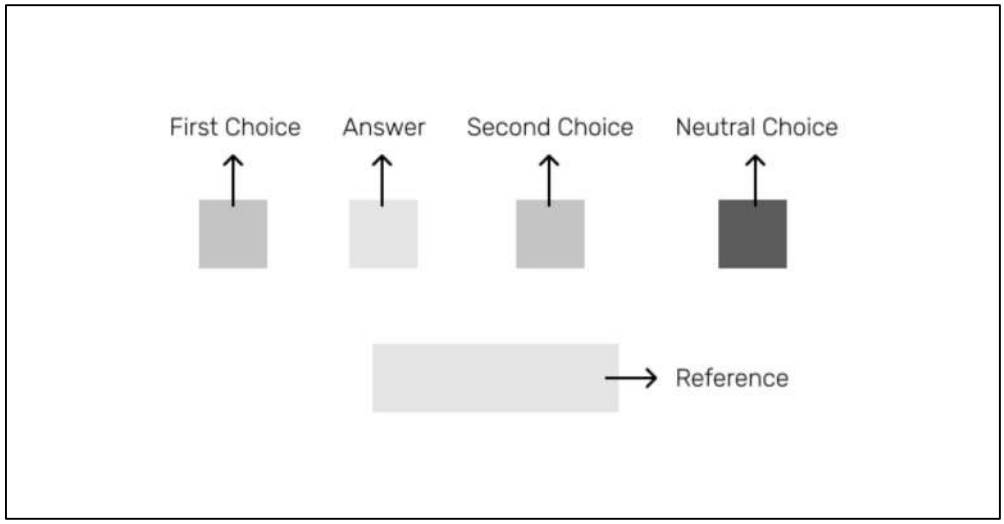

Figure 3.17 IshiharaTestQuestionDesign UI

As mentioned, there are nine questions in total, and each question is designed as portrayed in Figure 3.17. Players will be presented with five objects, one box and four gemstones. The player must pick one of the four gemstones that is most similar in colour to the box.

B.2 Result Panel

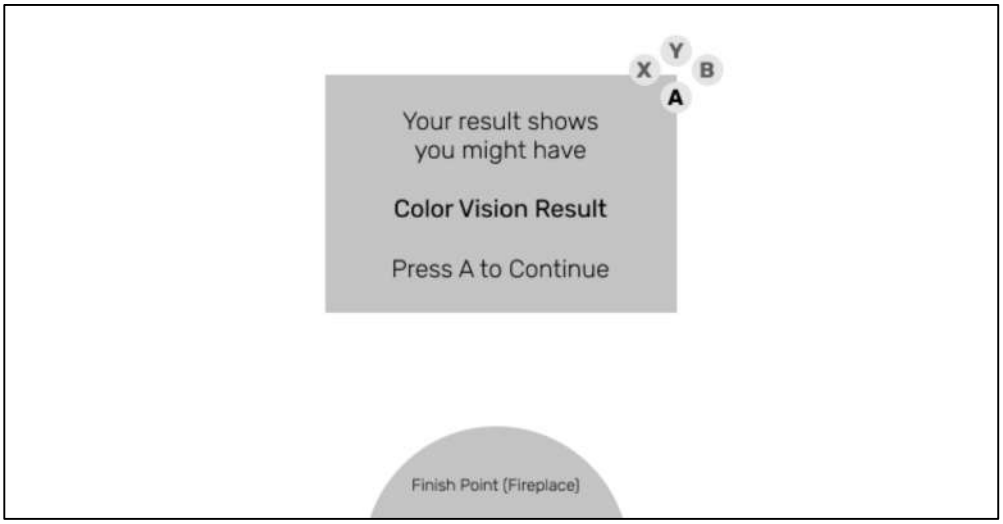

Figure 3.18 IshiharaTestResultUI Design

After the player has finished answering all nine questions, they will see a finish point that will show a panel of their result. Figure 3.18 shows the IshiharaTestResultUI design.

C Farnsworth Test

C.1 Question Design

Figure 3.19 FarnsworthTestQuestionUI Design

At the beginning of the test, players will be presented with 16 differently coloured cubes. One of which is the *Pilot* cube that serves as a starting or reference colour, and the rest of the fifteen cubes are randomly arranged in tray 1 to 15. The goal of the player is to arrange the cubes based on their hues. Figure 3.19 shows the FarnsworthTestQuestionUI design.

C.2 Pickup Action

The first way for a player to arrange the cubes is by picking them up. The pickup action can be done when the player is not holding any other cube in their hands. The player can only hold one cube at a time. To pick up, the player needs to simply stare at the cube of their choice until the pickup prompt panel is visible, and they can press the A button on the Xbox controller.

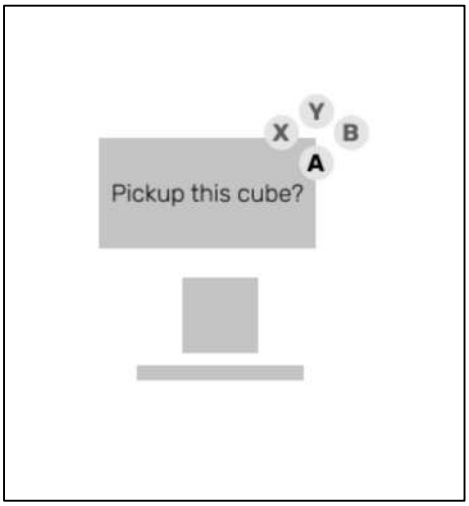

Figure 3.20 PickupActionUI Design

C.3 Swap Action

The second way for a player to arrange the cubes is by swapping them. The swap action can be done when the player is holding a cube in their hands. To swap, the player needs to simply stare at the cube of their choice until the swap prompt panel is visible, and they can press the B button on the Xbox controller. This will swap the cube they were holding with the one they were gazing at. Figure 3.21 shows the SwapActionUI design.

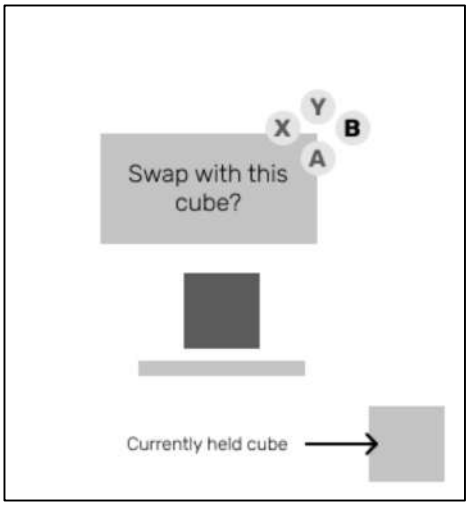

Figure 3.21 SwapActionUI Design

C.4 Drop Action

The third and final way for a player to arrange the cubes is by dropping them. The drop action can be done when the player is holding a cube in their hands and is gazing at an empty tray. To drop, the player needs to simply stare at the empty tray until the pickup prompt panel is visible, and they can press the X

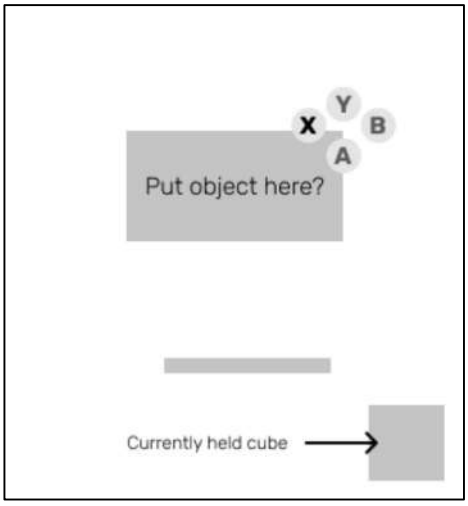

Figure 3.22 DropActionUI Design

button on the Xbox controller. Figure 3.16 shows the DropActionUI design.

C.5 Result Panel

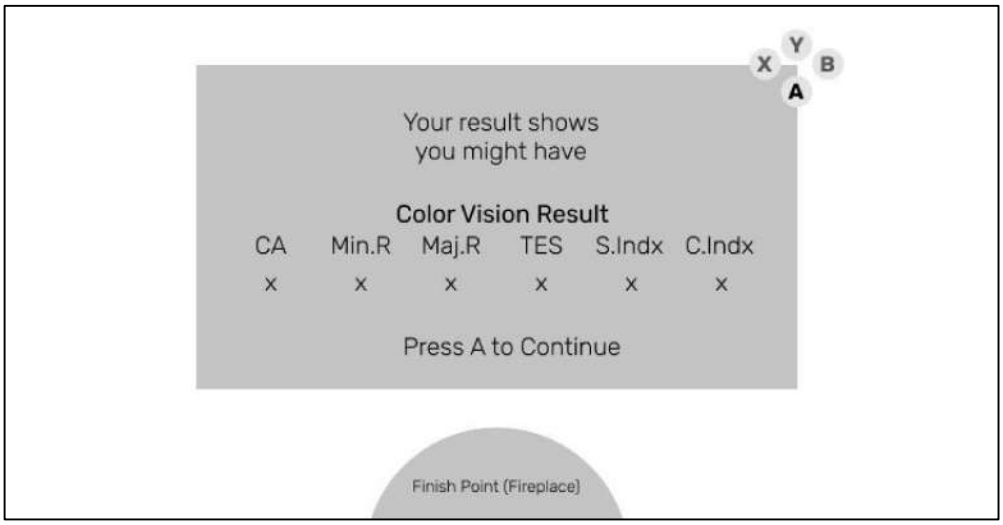

Figure 3.23 FarnsworthTestResultUI Design

To the left of the Pilot cube, there will be a finish point same as the one in the Ishihara test. After the player feels like they are finished arranging the cubes, they can go to the finish point to get their result. The resulting panel will show the final result along with the variable values. CA stands for ConfusionAngle, Min. R stands for Minor Radius, Maj. R stands for Major Radius, TES stands for Total Error Score, S.Indx stands for S-Index, and C.Indx stands for C-Index. Figure 2.23 shows the FarnsworthTestResultUI design.

3.2.3 Application Asset List Plan

Table 3.2 Application Asset List

Asset Name	Function	Source
Modular Terrain Pack Simple Low Poly Nature Pack	Terrain & Environment	Itch.io Unity Asset Store
Modular Asset Staging Tool	Environment creation tool	Itch.io
Low Poly Gems Pack Low Poly Pack -Environment Lite	Objects	Itch.io Unity Asset Store
Rubik Typeface	Font	Google Fonts
Gaze UI for Canvas	Raycast for GUI Components	Unity Asset Store
Abstraction Ludum Dare	Audio	Itch.io

3.3 Questionnaire Design

The questionnaire will consist of questions from the HMSAM (Hedonic-Motivation System Adoption Model) method. Aside from that, the questionnaire also asks for a brief profile about the user and whether each test has shown a correct result. Each statement from the HMSAM method will have six options scaled in the following manner and with their respective scores:

1 = Strongly disagree, with a score of 1

2 = Disagree, with a score of 2

3 = Slightly disagree, with a score of 3

4 = Slightly agree, with a score of 4

5 = Agree, with a score of 5

6 = Strongly Agree, with a score of 6

However, some statements are negated; thus the score will be inverted as well such that they will be like this:

1 = Strongly disagree, with a score of 6

2 = Disagree, with a score of 5

3 = Slightly disagree, with a score of 4

4 = Slightly agree, with a score of 3

5 = Agree, with a score of 2

6 = Strongly Agree, with a score of 1

Using an even-numbered scale forces the respondents to choose which side they are more likely to lean towards on.