ELEN4012A Group 17: A Virtual Reality Platform for Body Dysmorphic Disorder Therapy

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Abstract: This investigation focuses on the technical and functional feasibility of a Virtual Reality platform developed to study cognitive patterns in individuals with Body Dysmorphic Disorder. The system was created using Unity3D and deployed onto the Meta Quest 2. Users are able to customise an avatar to their self-image and embark into a virtual restaurant with ambiguous social cues which the user is required to interpret negatively or as benign. The interpretations are then exported to a dashboard for data capture. The system uses core features such as avatar customisation, first-person embodiment, interaction with avatars, and self-reflection with the user's customised avatar, which guides the user through the scenario. All core mechanisms were successfully operational however, the system is strained by an average of 82.54% graphics usage, a 24.66 frame rate due to the scene complexity, and 37.80°C hardware temperature, indicating thermal and rendering limitations. The project successfully established a functional and feasible prototype. Future work must prioritise rendering optimisation and integrating gaze tracking for research usage and to support scalable virtual reality therapeutic interventions.

Key words: Virtual Reality, Body Dysmorphic Disorder, Unity3D, Avatars, Embodiment, Prototype

1. Introduction

Body Dysmorphic Disorder (BDD) is a mental health disorder marked by an excessive focus on perceived flaws in appearance and the negative interpretation of ambiguous social cues [1]. This report discusses how a virtual reality (VR) platform can be developed in order to study the behavior and cognitive patterns of individuals suffering from BDD. The aim of the VR platform is to enable users to participate in interactive social scenarios and to customise a 3D avatar that reflects their self-perception, thereby allowing researchers to visually assess their self-image. The objective of the investigation is to determine the technical feasibility of the developed system which will indicate if the platform can act as a foundation for psychologists to further examine how individuals perceive their appearance and interpret social cues within social environments. This report first establishes context by covering the research background and existing solutions in Sections 2 and 3. The core of the project is then detailed, with a high-level overview in Section 4 and the methodology in Section 5. The critical evaluation begins with testing the system and its main results in Section 6 and the system is then critically analysed in Section 7. The report concludes by addressing final improvements in Section 8.

2. Background

VR is defined as a computer-generated three-dimensional (3D) simulation of images and sounds, allowing for realistic interaction using specialised electronic equipment, which the Meta Quest 2 (MQ2) has been provided for this investigation [2]. VR provides a subjective sense of immersion and presence, which has been investigated as a therapeutic approach for various mental health disorders, including social anxiety, eating disorders, and multiple phobias [2]. By simulating specific scenarios, treatment can be precisely targeted, as individuals feel immersed and act in the digital world as if it were real, thus living meaningful experiences [3]. The development environment for this project is Unity 3D, a cross-platform game engine, which is widely used for developing interactive 3D and 2D experiences. Its multi-platform compatibility, particularly with VR, allows it to integrate various functions such as a rendering engine, physical engine, script engine, lighting mapping, and scene management. A typical Unity3D program consists of scenes where objects and models, known as GameObjects, are created and controlled using C# and JavaScript scripts, with a main camera allowing the user to control their visual perspective of the scene.

BDD is defined by a preoccupation with perceived, often imagined, defects in one's appearance, commonly involving the skin, hair, nose size, or overall body shape and size [1]. BDD typically begins around age 16 and, while affecting both genders, is more common in women. Individuals often feel ashamed, avoid seeking help, and avoid social situations due to fear of negative judgment, leading to reductions in mental health, social functioning, and quality of life. Furthermore, people with BDD tend to misinterpret neutral emotional expressions as contemptuous or angry, which reinforces feelings of rejection [1]. These patterns highlight the importance of studying perception and interpretation biases to assess future treatment approaches. Existing treatments include pharmacotherapy, Cognitive Behavioral Therapy (CBT), exposure therapy, cosmetic treatments, and Interpersonal Psychotherapy (IPT) [1]. Notably, VR CBT has shown similar therapeutic effects to in-vivo CBT for anxiety disorders, depression, and phobias, demonstrating its potential for various treatments [4].

3. Literature Review

Virtual Reality Exposure Therapy (VRET) which provides a safe, controlled environment to challenge the distorted body image perceptions central to BDD [5].

VRET uses VR to create scenarios that patients typically avoid, such as social situations or viewing themselves, allowing for the restructuring of negative beliefs. Another solution that demonstrates the practical efficacy of using VR as a therapeutic platform for BDD is the PsiousToolSuite [6]. It is a commercial platform that uses a restaurant scenario for exposure therapy related to social and food anxiety, which are comorbid with BDD. By placing the user in a common social trigger environment, the tool provides a virtual scenario of ordering and eating a meal. The patient practices eating and conversing with a virtual person to safely expose them to anxiety triggers and teach them strategies for treating food anxiety.

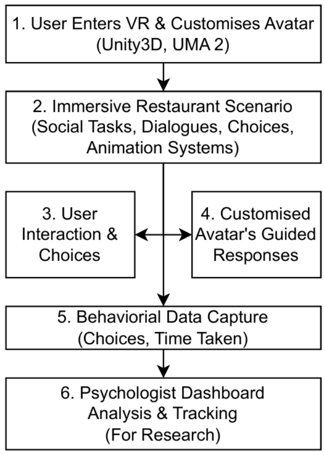

Figure 1 : High Level Diagram of System.

4. High Level Overview

This project focuses on the design and development of a VR platform intended to study the behavior and cognitive patterns of individuals with BDD to support further research.The system allows users to customise a 3D avatar according to their perception of their self-image and interact with other avatars in a first-person perspective. This promotes an immersive embodiment, which is crucial as it generates the "illusion of body ownership" [7]. An interactive social environment, specifically a restaurant scenario as it is a social trigger environment, is designed where social tasks are presented for the user to interpret through selection choices [6]. The platform was developed in Unity3D for optimisation on the MQ2, requiring multiple subsystems for the avatars, dialogues, and animations. After customisation, the user embarks on the restaurant scenario, where integrated social cues, typically interpreted negatively by individuals with BDD, are presented. The patient's behavior and thought pattern are captured based on their interpretation choice. Throughout this gamified scenario, the user's customised avatar guides the conversation to either reframe or reinforce their interpretation, allowing the user to observe a version of themselves interpreting cues positively. This functions as a form of self-to-self interaction, which has been shown to facilitate positive psychological changes, such as increased self-compassion [7]. Finally, the user's selected choices and the time taken to make them are exported to a dashboard for psychologist analysis, and a screenshot of the final avatar is exported to visualise the user's self-image. The system flow is illustrated in Figure 1, highlighting the core subsystems.

5. Methodology

5.1 Creating a Customisable Avatar

The Unity Multipurpose Avatar (UMA) asset, from Unity asset store (UAS), was selected to create a base avatar due to its flexibility in body morphing and included appearance packages. The core avatar was added to the project hierarchy as a dynamic GameObject, requiring bone rigging to map its joints to the animation system. To manage the avatar's generation and runtime rebuilding, including body changes and recreating the default character, the UMA Dynamic Character System (DCS) GameObject was also added. The UMA avatar is composed of two key components, namely the Root object, which is responsible for generating the 3D model with meshes, bones, rigs, positioning and containing animated body parts, and the Renderer object, which controls the visual aspects such as skin, clothing, and hair. These components link the appearance and animation controls to the avatar's body.

5.2 User-Interface (UI) Control for Customisation

The customisation system was built using the UMA framework, which facilitates the real-time editing physical characteristics through DNA parameters without requiring a reload of the avatar's model. This system was designed around interactive UI panels, ensuring a structured user experience. These panels are divided into categories, namely Build, for body morphing, Face, for facial features, Skin color changes, Hair selection, and Wardrobe, with each containing sliders or buttons that correspond to specific DNA values or wardrobe recipes. The Build panel controls height, weight of the arms and legs, leg separation, waist, belly protrusion, gluteus, and cleavage, while the Face panel focuses on forehead, lip, and nose sizes. An 'Apply Changes' button updates the avatar appearance for body modifications. This approach was chosen to prioritise flexibility and technical feasibility within a VR environment while considering the main areas of concern for individuals with BDD. By linking UMA's DNA system to Unity's XR Interaction Toolkit, users make these adjustments using MQ2 controllers, interacting directly with floating panels. The use of sliders, buttons, and real-time visual feedback was implemented to create a sense of control, allowing researchers to visually capture how users perceive changes to their virtual appearance and self-image.

5.3 Dialogue and Choice System

The FS Dialogue and Cutscene System asset from UAS was purchased to manage the interactive conversations, animations, and scenario sequencing between avatars in its cutscene graph tool. This tool uses a node-based interface to create dialogue scripts, manage GameObjects, and trigger character actions without complex programming. In the restaurant scenario, the system triggers contextual events, such as avatar greetings, gestures, and dialogue, based on the user interaction. Each cutscene sequence controls the timing and flow of dialogue, synchronises animations and facial gestures, and ensures that both verbal and non-verbal communication are reactive within the VR environment. The scenario's base logic is controlled through these nodes, where a dialogue node can feed into multiple choice nodes, each displaying the user's interpretation options. After each node, an avatar can perform a movement or animation, or the flow can advance to the next dialogue. The asset was chosen for its efficiency, flexibility, and compatibility with Unity's VR workflow, allowing the project to focus on interactivity rather than building custom dialogue mechanics. Its ability to simplify the coordination of avatar interactions and reduce repetitive coding made it ideal for demonstrating social interpretation scenarios with structured, responsive decision trees based on the user's choices.

5.4 Animation System

The animation system was constructed using Unity's Animator Controller, which functions as a state machine to manage the different animation states and transitions for each avatar. Animation clips, generated by Unity Artificial Intelligence and imported from Mixamo.com, were assigned to specific states within the Controller, coordinating with the avatar's bone rigging to control joint movements. Transitions between these states were managed through transition arrows, which ensure smooth movement and prevent abrupt changes. Key transition controls include 'Exit Time', which returns the avatar to a default state once an animation clip is complete, and 'Loop', which reiterates an animation until a new one is triggered. This setup enhances the realism of the movements. The FS Cutscene System integrates directly with this Animator Controller. An animation node within the cutscene graph assigns an avatar and an animation clip name, which activates once the system reaches that node. This process allows dialogue and animations to be synchronised, ensuring that gestures align with dialogues and situational context. By combining Unity's Animator system with the cutscene tool, the project integrates a dynamic interaction system where the avatar responds to the user's behavior and performs actions correlating to the social cue, thereby enhancing realism, interactivity, and narrative flow within the VR environment.

5.5 Non-Player Characters (NPCs)

Other NPCs were imported from Mixamo to add to the realism of the scenario which includes a waiter, to serve as the host, and ordinary characters sitting and conversing with each other in the restaurant. Each character with a role in the scenario requires its own Animator Controller for different animations however, the ordinary NPCs perform one looped motion and were imported as a character with its motion from Mixamo.com for simplicity.

6. System Testing and Results

This section details a structured investigation undertaken to assess the validity of the designed system. These procedures were crucial for ensuring the VR platform's and system's performance, with each test designed to investigate potential flaws and successes.

6.1 Testing Methodology: Avatar Customisation

This experiment, conducted by systematically setting all avatar body customisation sliders to approximately five discrete values, 0%, 25%, 50%, 75%, and 100%, was performed to validate the functional range and stability of the customisation system. The minimum and maximum percentages are to determine the boundary tests, while the other values are for functionality and rendering testing at their respective values. The primary purpose was to ensure that the sliders correctly apply and render the changes across the spectrum of possible values. The recorded changes at each percentage, as seen in Figure 2, illustrate an increase in body morphology as the DNA parameters increased, demonstrating that the avatar customisation functions as expected without crashes or visual anomalies at its tested points. A similar test was performed for the facial features, skin, wardrobe, and hair, and successfully functions as expected.

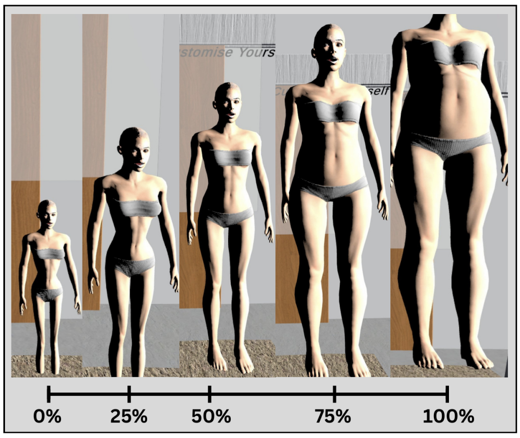

Figure 2 : Increasing sizes in body structure of avatar.

6.2 Testing Methodology: Dialogue System

The functionality of the social interaction system was investigated, which comprises of the coordination between the FS Dialogue and Cutscene System asset and the game logic. By playing through the scenario, the test confirmed that the developed cutscene graph, successfully displays the correct text, allows the user to interactively select choices, and triggers the next intended dialogue or animation sequence. The visual confirmation of this flow ensured that the social cues and subsequent conversations were presented to the user as designed. Figure 3 displays a fragment cutscene graph, illustrating the flow and interaction between dialogue, choice, and animation nodes. The node highlighted in the graph corresponds to the specific scenario event that was visually confirmed to be active and functioning correctly during the system's functional testing.

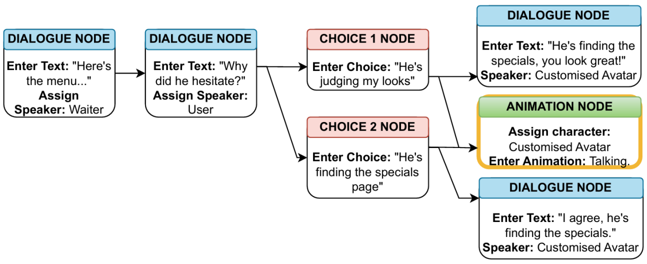

Figure 3 : Cutscene graph with integrated nodes.

6.3 Testing Methodology: Animation System

The integration and synchronisation of the animation system with the narrative flow managed by the cutscene graph was tested and validated. The test confirmed that the animation nodes within the cutscene graph successfully triggered the correct animation clips and transition states from the animator controllers. By visually confirming that animations are called at the correct dialogue triggers, respect exit times or loops, and transition back to the default state, the results demonstrate the functionality of non-verbal social cues, which are essential for creating a realistic and immersive social scenario. The validation of the animation system is shown by the conducted animation test cases shown in Table 1, and were all passed through visual confirmation from the running virtual environment.

6.4 Testing Methodology: Platform Functionality

Functionality test cases were conducted to validate the overall technical feasibility and user experience of the VR platform. The tests, outlined in Table 2, verify the core mechanisms, including the customisation sliders, the immersive first-person embodiment, the transition between scenes, the correct triggering of animations, and the interactive components of the dialogue and choice system. Overall, the functional validation tests

Table 1 : Animation System Test Cases.

Animation Clip	Trigger Event and Expected Behaviour
Default State	Scenario Start or Transition Exit. Loop until next animation triggers.
Walking and Sitting	Dining scene initiates. Avatar walks to table then transitions to sitting down clip.
Talking	Avatar's dialogue appears and animation plays.
Transition Smoothness	Next animation uses exit time of current animation clip . Smoothly transists to next state without visible jump.

show all core features passed their respective procedures however, minor technical notes were noted for the customisation sliders, which were not set to deafult values and did not dynamically update the avatar, the avatar embodiment occasionally showed coordination issues during sitting or standing, and the scene transition showed a deviation in the user's designated spawning point within the restaurant.

Table 2 : Functionality Test Cases.

Feature Tested	Procedure and Expected Result
Avatar Customisation	Moving all DNA sliders changes the Avatar's body morphology.
Avatar Embodiment	Confirm 1st person view, hand movement with controllers, and interactable functionality.
Scene Transition	Click "I am ready!" button to teleport user to restaurant scene in designated position.
NPC Waiter	Waiter performs correct animations, movements, and gestures when scene is triggered.
Customisable Avatar	Customised avatar performs correct animations and gestures when scene is triggered.
Dialogue Progression	Dialogue box with text disappears when clicked on and advances to next cutscene node.
Choice Interaction	Choice UI panel disappears when selected, and corresponding "Avatar Reframe" dialogue node is displayed.

6.5 Testing Methodology: Platform Performance

Performance testing was investigated to determine the rendering scalability and performance limits of the VR environment on the MQ2 by systematically increasing the scene's rendering complexity. The test involved duplicating the restaurant setting, without additional NPCs and systems, 5, 15, and 25 times to measure the impact of an increased object count on the platform's performance. The analysis focuses on three metrics: Average Frame Rate (FPS), which is the primary measure of user experience, Graphics Processing Unit (GPU) Utilisation Percentage, which indicates the rendering bottleneck caused by the increased number of objects, and Sensor Temperature (temp), which reveals if performance degradation is due to thermal throttling. These metrics were measured using the OVR Metrics Tool within the MQ2 and were chosen as they identify any bottlenecks and can compare rendering measurements [8]. The results, shown in Figures 4, 5, and 6, display the complexity range of the platform, providing data on the scalability of expanding to include more scenarios. FPS is calculated using Eq 1 with the Computer Processing Time (CPU) and GPU.

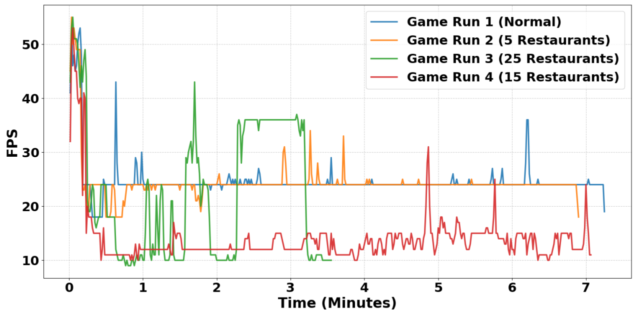

Figure 4 : FPS measurements across four game runs.

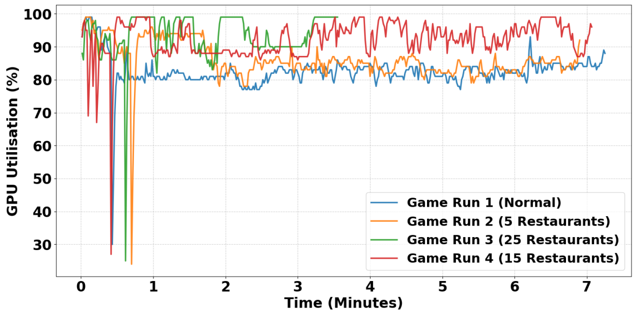

Figure 5 : GPU utilisation across four game runs.

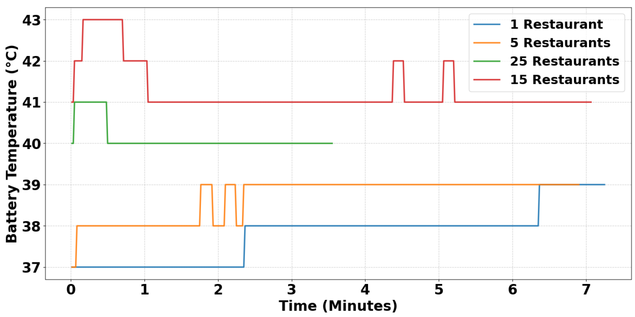

Figure 6 : Device temperature across four game runs.

Using these datasets, the average metrics were calculated, using Eq 2, across each game run to provide a better comparison as outlined in Table 3.

$$FPS = \frac{1}{CPU\ \ TIME + GPU\ \ TIME} \tag{1}$$

$$Mean\ Formula\ \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{2}$$

Table 3 : Average Performance Metrics across four game runs.

Test Condition	FPS	GPU (%)	Device Temp (°C)
Game Run 1 1 Restaurant	24.66	82.54	37.80
Game Run 2 5 Restaurants	24.41	86.05	38.70
Game Run 3 15 Restaurants	22.63	93.41	40.13
Game Run 4 25 Restaurants	14.05	92.24	41.26

As expected, Table 3 shows that as the complexity of the environment increases, the FPS decreases while both the GPU utilisation and device temperature increase. The increased complexity forces the GPU to process more draw calls and vertices per frame, leading to higher GPU utilisation as the system approaches its rendering limit [9]. This usage generates more heat, causing the device temperature to rise. If the temperature exceeds the thermal threshold, the device's hardware is throttled, which is the ultimate cause of the observed FPS decrease [10]. The beginning of the scenario includes instruction pages with less objects and correlates to the spikes in each metric within the first 2 minutes. This was due to less rendering of objects. Finally, the Game Run 4 test was unable to be completed as the MQ2 reached its lowest FPS limit and resulted in glitches. This further proves that exceeded rendering complexity diminishes the platform's performance.

7. Critical Analysis

While the project established a functional VR platform, the prototype phase revealed technical limitations that could impact the user experience and research outcome. The Unity AI proved difficult for generating realistic animations. A partial failure in the custom avatar's bone rigging, specifically the jaw joints, resulted in the avatar having an unnatural open mouth. Furthermore, the non-dynamic customisation of the avatar, requiring an "update" button as body changes did not occur at the same rate as the slider adjustments, is a limitation to the user experience. The environment presented issues with lighting and stability such as the user's avatar shadow distorted the lighting within the scene, and to compensate for this by adding more light, increased the rendering complexity. The height changes of the avatar exceeds the boundaries of the room as seen in Figure 2. Thus, the positioning of the avatar's base alters and distorts the animation clip. The fixed position of the dialogue box, which did not move with the camera, would require the user to navigate towards it so that it is in their peripheral view. Finally, the user's created avatar is not saved after the scenario thus, participants would have to recreate their self-image for each session, introducing a barrier to longitudinal research.

The performance analysis demonstrates the average FPS across all runs is below the required minimum of 72 FPS for a comfortable VR experience without health risks such as motion sickness [8]. The system is limited by the GPU, as the utilisation consistently exceeded the 80% ideal limit [8]. The scalability test confirms this limitation, showing that increasing scene complexity exceeds the GPU to saturation and causes the device temperature to reach the critical 40°C thermal threshold [8]. This heat generation triggers thermal throttling, which reduces the FPS to an unusable 10-15 FPS range and resulted in glitches. This confirms that the system's performance is limited by the device's thermal capacity and requires rendering optimisation and reduction to achieve a stable FPS and user experience.
The system cost is R 7344.00, which is affordable compared to existing VR CBT therapy solutions and includes purchased MQ2 and Unity assets [11].

8. Further Work and Recommendations

Further work could transition the prototype platform to a robust research tool. Technical optimisation is essential, resolving performance issues and rendering improvements, such as implementing Unity's baked lighting and using fewer objects, to mitigate the strain on the MQ2 and prevent overheating. Refine the system by correcting the avatar's open-mouth rigging issue and implementing user profiles to save the customised avatar for each session, which were features omitted due program complexities. The system could involve a male avatar option, although adds to the programming complexity, and integrating gaze tracking, which requires specialised hardware and managing high computational cost to capture the user's visual avoidance. Improving the animation realism, enhancing body rigging, and allowing for more freedom of interpretation choices could expand the platform's usability. Finally, the platform can be verified by psychologists to add more social cues and considering the use of a more powerful VR headset, such as the MQ 3, although would increase budget costs.

9. Conclusion

A VR platform was developed and functionally investigated, thereby establishing a foundation for future psychologist-led research to analyse the behavior and cognitive patterns of individuals with BDD. The project successfully achieved this aim by developing a fully integrated prototype system featuring real-time avatar customisation, a node-based dialogue and animation system, and an interactive choice-based social scenario. Functional testing confirmed that all core mechanisms were operational. However, the system is GPU-bound and limited by the thermal envelope of the MQ2, with the FPS falling into an unusable range under increased load. Therefore, the most important further work must prioritise technical optimisation to ensure a stable frame rate. By addressing these limitations and improvements, the platform can successfully transition from a validated affordable technical prototype to a scalable tool for BDD research.

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Appendices

A Reflection on Group Work

The project was completed in collaboration with Ms Raksha Pai under the supervision of Professor Vered Aharonson.

Table 4 : Task distribution amongst group members.

Task	Rawdah Kurrimboccus	Raksha Pai
Configuring VR to laptops		✓
First-person embodiment		✓
Scene creation and rendering		✓
Customisable avatar	✓	
Animation system	✓	
NPCs	✓	✓
Host avatar	✓	
Dialogue and choice system	✓	
Combining all scenes		✓
Welcome pages		✓
Benchmark testing	✓	✓
Functionality testing	✓	
User experience testing	✓	✓

The success of this investigation was led in a highly structured and consistent collaborative partnership, beginning with an initial meeting with our supervisor to define the project's scope and strategic approach. In this initial session, we discussed potential scenarios, system designs, and existing VR applications, and sought guidance on appropriate testing measures to ensure a rigorous investigation.

The workload was divided on a 50/50 basis, ensuring equitable contribution across all phases of the project, from initial research to documentations. This division was managed through daily meetings held every weekday throughout the 8-week investigation course. These meetings were crucial for discussing workflow progress, refining the division of tasks, and collaboratively creating the system, ensuring both partners maintained a comprehensive understanding of the project's architecture. The project was split into sub-tasks to ensure fairness and decreasing workload and to ensure the project was completed by the deadline. As tasks became increasing complex, both partners would problem solve and collaborate to resolve the complications.

Communication and documentation were prioritised to maintain the project's coherence. Both partners conducted independent research to ensure the project's theoretical and technical foundations were robustly supported. A shared online Google Document was maintained vigorously, which served as the central repository for all research findings, task breakdowns, and project progress. This source ensured transparency and allowed for seamless collaboration. Furthermore, all technical assets, including the final project APK, testing data, performance graphs, and a game walkthrough video, were systematically managed and shared onto a dedicated online GitHub repository.

The project's direction was effectively overseen through weekly updates with our supervisor, who offered crucial external feedback and guidance. Internally, the team adopted a flexible yet disciplined strategy, diligently testing various system designs and revisiting the project's scope on a weekly basis to ensure that the final product remained focused and technically viable. The importance of external peer review was also emphasised through mandatory Friday cohort meetings, which served as a platform to showcase the project's progress, exchange ideas and discuss mitigation strategies for project issues, and obtain constructive feedback from colleagues facing similar challenges. This consistent, structured, and communicative methodology was vital in addressing the complexities of the investigation and in delivering a final working system.

A week was dedicated to collaboratively testing all components and integrated systems. This involved both partners systematically testing every feature against its defined use case, ensuring the functional integrity of the individually created systems within the larger platform. During this week, both partners jointly set up and executed the performance benchmarking tests, ensuring consistency in the data collection methodology. This collaborative testing approach not only validated the system's technical readiness but also served as a final, comprehensive knowledge transfer, ensuring both partners were fully aware of the system's capabilities and limitations before final documentation.

Personal Reflection: The achievements of this project were greatly enhanced by the contributions of my project partner, whose professionalism and dedication were outstanding throughout the investigation. Ms Pai consistently fulfilled all assigned responsibilities, often exceeding the expected scope, which showcased her profound commitment to the project's success. Her creativity and remarkable problem-solving abilities were crucial, especially when addressing intricate technical challenges, and she was always willing to help with any issues or tasks that emerged. In addition to her technical expertise, she demonstrated excellent communication skills, and her collaborative approach provided me with valuable insights into effectively diagnosing problems and gaining a deeper understanding of the system's complexities. Collaborating with her was an exceptionally positive experience, her motivating and inspiring demeanor, along with her steadfast focus on the project, ensured that the entire process was smooth and highly efficient. This collaboration has equipped me with essential teamwork and research skills that I am confident will be a great advantage in my future career and academic pursuits.

B Project Plan

ELEN4012 Investigation Project Plan: A Virtual Reality Mirror System for Body Dysmorphic Disorder Therapy

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Abstract: The proposal of the development of a Virtual Reality mirror system aimed at assisting with Body Dysmorphic Disorder therapy is described in this report. Leveraging a Meta Quest 2 platform, this proposed system enables users to customise an avatar that reflects their perceived body image and interact with socially ambiguous virtual scenarios designed to challenge negative cognitive biases. The system incorporates dynamic embodiment, adaptive narrative feedback loops and therapist-guided avatar transformations to promote healthier self-perceptions. An integrated web dashboard allows for clinical oversight and data-driven insights through Firebase and machine learning support therapeutic personalisation. While direct user testing is not included in this phase, the technical design and implementation aim to demonstrate system feasibility for future human-centred trials.

Key words: Adaptive Narrative Therapy, Avatar Embodiment, Body Dysmorphic Disorder, Cognitive Bias Modification, Inverse Kinematics, Virtual Reality Therapy.

1. INTRODUCTION

Body Dysmorphic Disorder (BDD) is a mental health disorder marked by an excessive focus on perceived flaws in appearance, a condition often perpetuated by ongoing and distressing cognitive biases, especially the negative interpretation of ambiguous social cues [1]. This investigative project aims to explore the potential of Virtual Reality (VR) as an innovative medium to examine and potentially assist in the therapy of BDD using a VR headset with its controllers (Meta Quest 2). The main objectives are to design and create a VR system that includes a dynamic avatar and mirror interface for user embodiment and to employ this platform to provoke and objectively assess interpretation biases and related distress in response to controlled social situations. This report discusses the approach and procedure to the implementation of this VR system. Sections 2 and 3 cover the research background. Sections 4 and 5 outline assumptions and constraints. Section 6 gives a high-level solution overview, with the phased procedure in Section 7. Section 8 provides critical analysis and Section 9 covers project management. Section 10 evaluates risks and impacts with final improvements concluding the report.

2. BACKGROUND

VR is described as a technology which allows participants to immerse themselves as avatars into a virtual world [2]. One of its many uses include Mirror Visual Feedback to treat phantom limb pain for amputees. This involves an illusion technique to manipulate the movement of amputated limbs observed in a virtual mirror. The VR system's controllers track movement of the user's healthy limbs and animates the opposite virtual limb in a mirrored fashion. This tricks the amputee into believing the reflection they observe is their limb moving and being controlled in place of their amputated limb.

Virtual Environments (VEs) consists of crucial elements to mimic a realist setting, such as decor pertinent to the environment, a first-person user perspective, interactions with the environment, and motor tasks [2]. VEs are becoming popular as a human-computer interaction platform for studying human behavioural interventions, including eating disorders, emotional patterns and psychiatric disorders [3]. Clinical use of VEs have shown promising results in reducing anxiety and improving body image [3].

BDD is a chronic mental health condition marked by an intense preoccupation with minor or imagined physical flaws [1]. It typically begins in adolescence and leads to obsessive appearance-related thoughts, compulsive behaviours, and psychosocial impairment. These behaviours include muscle dysmorphia (more common in males), frequent mirror checking, comparing appearances, grooming, and seeking reassurances [1]. BDD significantly impacts the quality of life and may lead to depression, substance abuse, and low self-esteem. Treatments include medication, Cognitive-Behavioural Therapy (CBT), and occasional cosmetic procedures.

CBT for BDD involves motivational enhancement, cognitive restructuring and strategies to challenge self-defeating beliefs about appearance [4]. It fosters self-acceptance, self-esteem and self-compassion, showing greater effectiveness in reducing BDD symptoms and improving quality of life than supportive psychotherapy [4]. Socratic questioning, a CBT technique, helps patients rethink negative thoughts through guided questions and reflective dialogue [1].

3. LITERATURE REVIEW

Studies on using VR as a therapeutic approach for BDD have shown promising results. Experiments used VR to explore fears and threats triggered during social interactions in BDD patients [5]. Participants reported higher discomfort in virtual social scenarios designed to evoke BDD-related interpretations. After each scenario, they answered questions about the perceived social ambiguity, allowing researchers to calculate BDD distress ratings. Findings support VR's potential in BDD treatment, including an avatar-based VR paradigm that allows for the modifications of avatars' appearance in VEs [5]. The study confirmed that social situations trigger BDD distress and that engagement and distraction from compulsions help alleviate symptoms [5].

Another study evaluated the efficacy of VR therapy for the treatment of body image disturbances in female patients with binge eating disorders [6]. This approach allowed for the modification of body image distortions and practice eating control. Through this, participants were found to reduce their binge-eating behaviour, proving that VR therapy was successful in improving their overall psychological state. This also enhanced their body image satisfaction and motivation for a better change. The VR system consisted of interactions with different virtual scenarios and avatar representations. Impaired beliefs and body image flaws are challenged by creating avatars which would allow participants to visualise themselves with different body sizes or races. This resulted in increasing awareness of the participants' own body image. Thus, VR-based avatar modification can be utilised as a therapeutic mechanism to improve body image.

4. ASSUMPTIONS OF INVESTIGATION

- **Therapeutic Efficacy of Embodiment:** Virtual body ownership (embodiment) is a valid and effective therapeutic approach for BDD, leveraging a user's mental connection to a digital avatar to address distorted self-perceptions.
- **Technical Feasibility of Meta Quest 2:** The provided Meta Quest 2 has adequate technical capabilities to render a convincing VR environment and avatar. Additionally, Inverse Kinematics (IK), based on headset and controller tracking, will sufficiently simulate realistic body movements to induce a strong body ownership illusion.
- **System Viability and Functionality:** The VR hardware and software can be developed into a functional and intuitive system. Technical validation, including movement tracking by IK and dynamic avatar adjustment, will use physical surrogates to simulate user presence. This project, by proving technical viability, assumes it lays the groundwork for future human-centric studies and therapeutic applications.
- **Availability of Expert Support:** Occasional support from psychology researchers will be available for clinical scenario design, ethical oversight and interpreting future user feedback.
- **Data Security:** No sensitive patient data will be collected or stored in this project.

5. OUTLINE OF CONSTRAINTS

- **Hardware platform limitations:** The project is limited to the Meta Quest 2 headset. As a standalone device, its processing and graphical power restrict the complexity and visual fidelity of the VR environment and avatar compared to PC-tethered systems.
- **Movement tracking accuracy:** The system relies on the Meta Quest 2's "inside-out" tracking, which only accurately tracks the head and hands. IK estimates the rest of the body, potentially leading to occasional animation inaccuracies.
- **Absence of human subject testing:** A major constraint is the inability to validate embodiment and user perception without human participants. This project focuses solely on technical functionality, meaning that conviction of the body ownership illusion or user avatar perception cannot be measured.
- **Limited real-world applicability:** Without human testing, the system's effectiveness cannot be tested against diverse human body shapes, sizes, or postures. The project is constrained to a generic avatar model and its real-world applicability remains unproven.
- **Lack of subjective feedback:** Without user input, developers must rely on their own observations, limiting user-centred refinement.

6. HIGH LEVEL OVERVIEW OF PROPOSED SOLUTION

This investigative project proposes the development of a VR system designed to investigate and potentially aid in the treatment of BDD. The approach is conceptualised as an interactive, story-driven experience, similar to simulation games where a user guides a character through a narrative. At the beginning of the experience, the user is embodied in a virtual avatar. The primary function of the system is a dynamic mirror, enabling the user to carefully modify the avatar's appearance to reflect their own self-image. This preliminary stage acts to externalise the user's internal body image, establishing an essential baseline for the investigation.

After the avatar customisation, the user will guide their personalised character through a variety of social situations set in a virtual environment, similar to those researched in earlier BDD studies. In this narrative mode, the user will face ambiguous social events and must select from a range of potential actions or responses, thus influencing the immediate result of the interaction. When confronted with these social situations, users are offered choices that represent adaptive and maladaptive or threat-based interpretations. The system is designed to establish a therapeutic feedback loop, where the narrative advances only after an adaptive choice is made. If a user opts for a maladaptive response, the system will not acknowledge this choice. Instead, it will initiate a subtle, supportive intervention from a virtual character, gently encouraging the user to reassess the situation before offering the subsequent choices. This approach to guided therapy seeks to avert the reinforcement of negative thought patterns and actively trains the user in cognitive reappraisal.

The system is intended to incorporate additional virtual, neutral, Non-Player Characters (NPCs) that will respond to user choices in a therapeutically guided manner. The primary aim of these interactions is twofold: firstly, to gather objective behavioural data regarding the user's interpretation biases and patterns of social avoidance; and secondly, to gently challenge negative assumptions while steering the user towards more adaptive social cognitions within a controlled and safe virtual environment. The main focus of the investigation will be to evaluate whether this structured training can effectively influence more adaptive behavioural responses and reduce the user's self-reported distress across repeated trials, thereby offering a novel framework for skill development in the treatment of BDD.

7. METHODOLOGY AND IMPLEMENTATION

The user persona centers on a 17-year-old high school student dealing with social anxiety and body image issues. Their daily environment includes, but is not limited to school settings, peer interactions and self-image challenges. Adaptive experience design allows the player to navigate through given choices all of which impact a "Mood Meter" reflecting confidence and self-esteem. Figure 1 portrays the experience of the user in a particular scenario. The implementation phases with milestones are outlined in this section.

7.1 ***Phase 1:*** *Foundational VR Environment*

This initial phase focuses on establishing the VR development environment and constructing a foundational scene, including avatar embodiment using IK. The aim is to enable an immersive baseline VR experience with basic movement, mirroring and avatar synchronisation.

- VR Development Environment Setup:
Install Unity3D, Meta Quest Developer Hub and the appropriate Meta XR Plugin to enable Meta Quest-specific features after enabling Developer Mode on the Meta Quest 2/3 headset. Unity3D builds the VR environment and handles 3D interaction logic. Meta Quest Developer Hub manages and tests apps on Meta Quest devices. In Unity, configure the project for XR development using the XR Interaction Toolkit which provides prebuilt VR interactions such as movement and object handling.

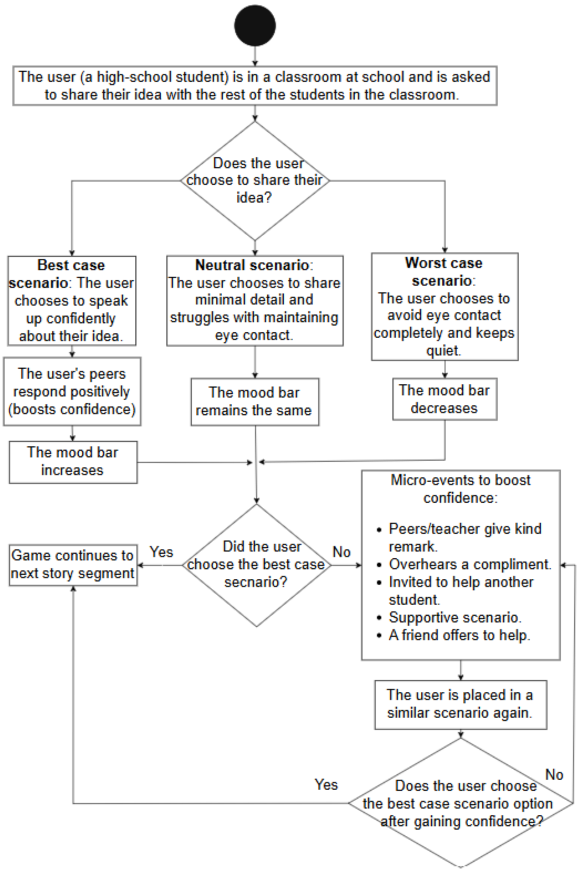

Figure 1 : Narrative loop feedback flowchart

- Initial VR Scene Construction:
Create a simple, neutral 3D scene and add basic player locomotion.

- Development of Avatar and Mirroring System:
The Maximo and Adobe Fuse softwares are widely used for digital avatar development and can be integrated into visual environments for interaction with virtual reality platforms.

- IK Setup:
This is applied for avatar control and mapping of the figure into a virtual world. Unity's Animation Rigging package can be used to map the headset position to the avatar's head and controller positions to the avatar's hands. The embodiment system will be tested by verifying that head and hand movements in VR are accurately mirrored by the avatar. Mannequins will be used to simulate user tracking for testing and visualising avatar movements. The rest of the avatar's body should respond naturally via the IK solver.

7.2 ***Phase 2:*** *Web-Based Management System (React Frontend and Firebase Back-end)*

This phase involves developing a web portal for psychologists to monitor and manage user data, authentication, session tracking and avatar preferences.

- Firebase Project Setup:
Create a new Firebase project on the Firebase Console and enable Firestore Database and Firebase Authentication, lastly, retrieve the project's Firebase configuration credentials. Firebase provides cloud services to manage user authentication and store data in real time. In this setup, it handles user login through Firebase Authentication and stores session, avatar, and interaction data using Firestore Database.

- React Frontend Configuration:
Follow Tailwind CSS's installation guide for React, install the Firebase Software Development Kit (SDK), and initialise Firebase.

- Core App Structure:
Create separate files to manage authentication state and access database queries and updates. Create a routing system between dashboard, user management, avatar customisation, and session viewer.

7.3 ***Phase 3:*** *Advanced VR System Development*

This phase focuses on building the more sophisticated features of the VR application, particularly dynamic avatar customisation, behavioural therapy logic, and scenario-driven interactions. This phase integrates body perception theory, therapist control mechanisms, and emotional feedback loops relevant to BDD treatment.

- Sophisticated Avatar Customisation in VR:
Users create avatars that reflect their perceived body image. This can be done by Ready Player Me SDK or a custom morph shape system allowing real-time adjustments of body features through VR sliders. This avatar data is saved to Firestore under the user's ID, allowing session continuity and psychologist review through the web dashboard.

- Refined IK and Movement Accuracy:
Since Meta Quest 2/3 only tracks head and hands, realistic body movement is achieved through advanced inverse kinematic solvers such as FABRIK for smooth, natural movement. Context-aware IK adjustments are used for sitting or standing. A mannequin rig in the scene can simulate user tracking for testing and motion playback.

- Dynamic Avatar Transformation for Therapy Progression:
Psychologists define *targetAvatarState* values in Firestore. The VR app reads these and gradually interpolates the user's avatar to match, reducing visual shock and supporting exposure therapy. Transformation pacing is entirely therapist-controlled to match user readiness.

- Scenario-Based Therapy with Branching Interactions:
Therapeutic guidance is delivered through structured, interactive scenarios that mirror real-life BDD triggers. Users navigate choices using the VR controller. Dialogue may be static or enhanced for personalised interactions. All user choices, mood changes, and response times are logged to Firestore.

- Adaptive Therapy Progression Loop:
If users choose positive, confident actions, the game advances. If not, the system loops them into similar but supportive scenarios to encourage growth. This adaptive feedback loop continues until consistent healthy decisions are made, after which the therapy progresses.

7.4 ***Phase 4:*** *Machine Learning and Psychologist Integration*

This phase connects the VR system to back-end analytics and enables clinical oversight through secure infrastructure and data-driven insight.

- Firestore Security Implementation:
To protect sensitive user data, implement strict Firebase Firestore security rules for public and private data, as well as data accessible only to psychologists.

- Data Logging and Storage:
Integrate Firebase SDKs to log user interactions, and store session data, choices, and avatar adjustments. Data is written in real time during and after each scenario for further analysis.

- Machine Learning Integration (ML):
The back-end retrieves session logs and avatar changes. Regression or clustering models are used to track behavioural patterns and therapy progression. These models may suggest personalised pacing or flag high-risk behaviour using anomaly detection.

- Psychologist Dashboard Enhancements:
Allow viewing of profiles, logins, and avatar histories. Visualise ML outputs and user progress. Enable psychologists to adjust avatar targets or unlock new scenarios remotely via Firestore. Provide session-based note-taking for clinical documentation.

7.5 ***Phase 5:*** *Testing and Experiments*

This phases includes a testing strategy to validate the system's technical usability and efficacy.

- Unit Testing:
Verify core features including avatar sliders, mirror rendering, and IK mapping within the software using automated and unit testing.

- Integration Testing:
Validate the major system components, from user interaction in VR to data visualisation on the dashboard. Create test scripts to simulate a user workflow and validate input and output data of the pipeline.

- Performance Testing:
Optimise frame rate to ensure comfort and reduce motion sickness. Focus on user experience quality for comfort and performance.

- Security Audits:
Regularly inspect Firestore rules and back-end code for privacy or potential data leakage vulnerabilities.

- Experimental Validation:
Validate the project therapeutic hypotheses through a formal simulated user experiment. Review efficacy of guided feedback loops in choices made by user.

8. CRITICAL ANALYSIS

Significant improvements in body self-perception and self-esteem are expected following the VR intervention. The Mood Meter should show a consistent upward trajectory as participants engage with self-affirming scenarios. Gradual, therapist-guided avatar transformations are expected to reduce the gap between perceived and actual body image. Machine learning analytics should reveal patterns of increased confident behaviours, decreased avoidance in looping scenarios and enhanced mood stability across sessions. Regarding system costs, the Meta Quest 2 will be provided for the duration of the project. All essential softwares, tools and frameworks have free tiers suitable for prototype development and academic use.

9. PROJECT MANAGEMENT

The five development phases are evenly spread across an 8 week period. The workload has been structured to allow parallel progress where possible while maintaining logical dependencies between tasks. Responsibilities are split equally, with each engineering student contributing 50% to the tasks.

10. RISKS AND SOCIOECONOMIC IMPACT

The immersive nature of VR therapy has the potential to induce psychological distress, including anxiety stemming from the personalisation of avatars that may reflect distorted self-images or from encountering social triggers, even within a controlled setting. Additionally, the creation of an excessively supportive virtual environment, where all interactions are positive, might cultivate a misleading sense of reality, leaving users ill-equipped to handle real-world rejection or uncertainty. Technical challenges such as VR motion sickness and unnatural avatar movements resulting from 3-point tracking can further diminish the therapeutic benefits. If implemented successfully, the system could provide scalable and cost-effective access to specialised therapy for BDD. Nevertheless, the high initial costs may limit access for individuals with lower incomes, potentially exacerbating existing inequalities in mental healthcare.

11. FURTHER RECOMMENDATIONS

While using a single user persona is the starting point, the overall game structure stays the same across various users. However, the environments, scenarios and social dynamics will adapt based on age group, gender as well as their occupation. A working adult may face decisions in an office context such as presentation anxiety. Whereas, a younger teen might experience similar choices within a school setting. This ensures that users face relatable challenges, while still benefiting from consistent therapeutic progression.

12. CONCLUSION

This project presents a technically scalable VR framework grounded in psychological theory, targeting BDD through avatar embodiment and CBT. The design aligns with best practices in virtual exposure therapies. VR interventions have shown feasibility, cost-effectiveness, and positive results in body image and anxiety contexts. While clinical testing is not yet feasible, the system's architecture and implementation roadmap establish a robust foundation for future trials and personalised therapy. Pending ethical review and efficacy studies, this system holds promise as a novel, accessible tool for mental health interventions.

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APPENDIX

APPENDIX A

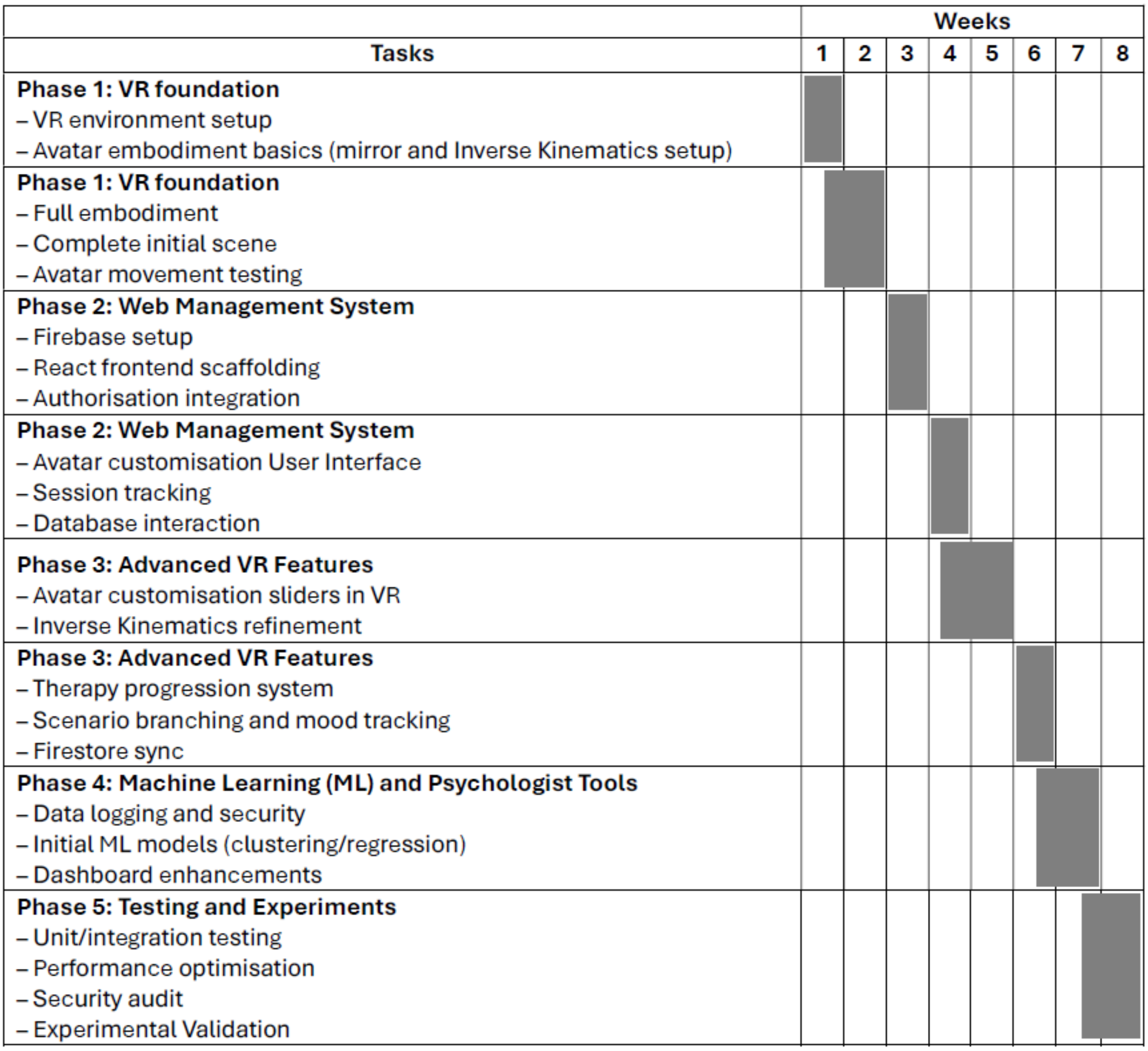

Figure 2 : Gantt chart breakdown for the 8 week project duration

APPENDIX B

Table 1 : Overview of virtual environments, core tasks, and corresponding guided feedback loops designed for the BDD therapy simulation.

Virtual Environment	**Core Task & User Choice**	**Ambiguous Social Trigger & Guided Feedback Loop**
Bedroom with Closet	**Task:** Prepare for the day. **Choice:** Customize avatar's appearance and select an outfit.	**Trigger:** The virtual mirror reflects the user's avatar. **Interaction:** This phase primarily gathers baseline data. The system logs the discrepancy between the default avatar and the user's modifications, as well as clothing choices (e.g., baggy vs. form-fitting) to measure initial body image.
School Bus	**Task:** Find a seat on the partially filled bus. **Choice:** Sit in an empty row alone (avoidant), or sit next to a neutral peer avatar.	**Trigger:** The user must navigate past seated peers to find a spot. **Interaction:** If the user chooses to sit alone, a peer from a nearby seat will turn and offer a supportive invitation which provides a gentle turn towards social integration and reduces the perceived barrier of initiating contact.
School Hallway	**Task:** Navigate from one classroom to another. **Choice:** Walk confidently down the centre of the hall, or walk along the edge to avoid attention.	**Trigger:** The user overhears two NPCs make an ambiguous comment. **Interaction:** If the user chooses the avoidant path along the wall, a friendly peer avatar will approach and interact to provide a positive social buffer and guide the user toward the adaptive behavior of confidently occupying shared space.
Classroom	**Task:** Participate in a class discussion. **Choice:** Answer a question from the teacher confidently, or mumble and avoid eye contact.	**Trigger:** The teacher avatar asks the user a direct, non-threatening question. **Interaction:** If the user avoids answering, the teacher provides supportive scaffolding to reduce perceived pressure and encourage participation. The system logs eye contact and mood data to measure social anxiety.
Cafeteria	**Task:** Select and eat a meal. **Choice:** Choose a balanced meal and sit with others, or choose a low-calorie food option and sit alone.	**Trigger:** An NPC makes an ambiguous comment about the user's food choice. **Interaction:** If the user interprets this as judgment and moves to change their meal, a peer avatar intervenes to compliment the meal and offer to sit with the user. This reframes the comment as neutral and encourages social eating.
Bathroom	**Task:** Take a short break. **Choice:** Briefly check appearance in the mirror and leave, or engage in prolonged, ritualistic checking.	**Trigger:** The user's avatar is faced with its own reflection in the bathroom mirror. **Interaction:** If the user remains fixated on the mirror for a set duration, an external prompt interrupts the compulsion such as an interaction with an avatar.
Gym	**Task:** Participate in a gym class activity. **Choice:** Join the team activity, or feign illness to sit on the sidelines.	**Trigger:** The coach announces the start of a team-based game. **Interaction:** If the user chooses avoidance, the coach avatar approaches them to lower the barrier to entry and encourages participation in a less intimidating, step-by-step manner.

C Online GitHub Repository

The project's full implementation can be accessed at: `https://github.com/Rawdahh/Investigation-Project--A-Virtual-Reality-Mirror-System-for-BDD-Therapy`

D Flow Diagram of Virtual Reality Platform Architecture

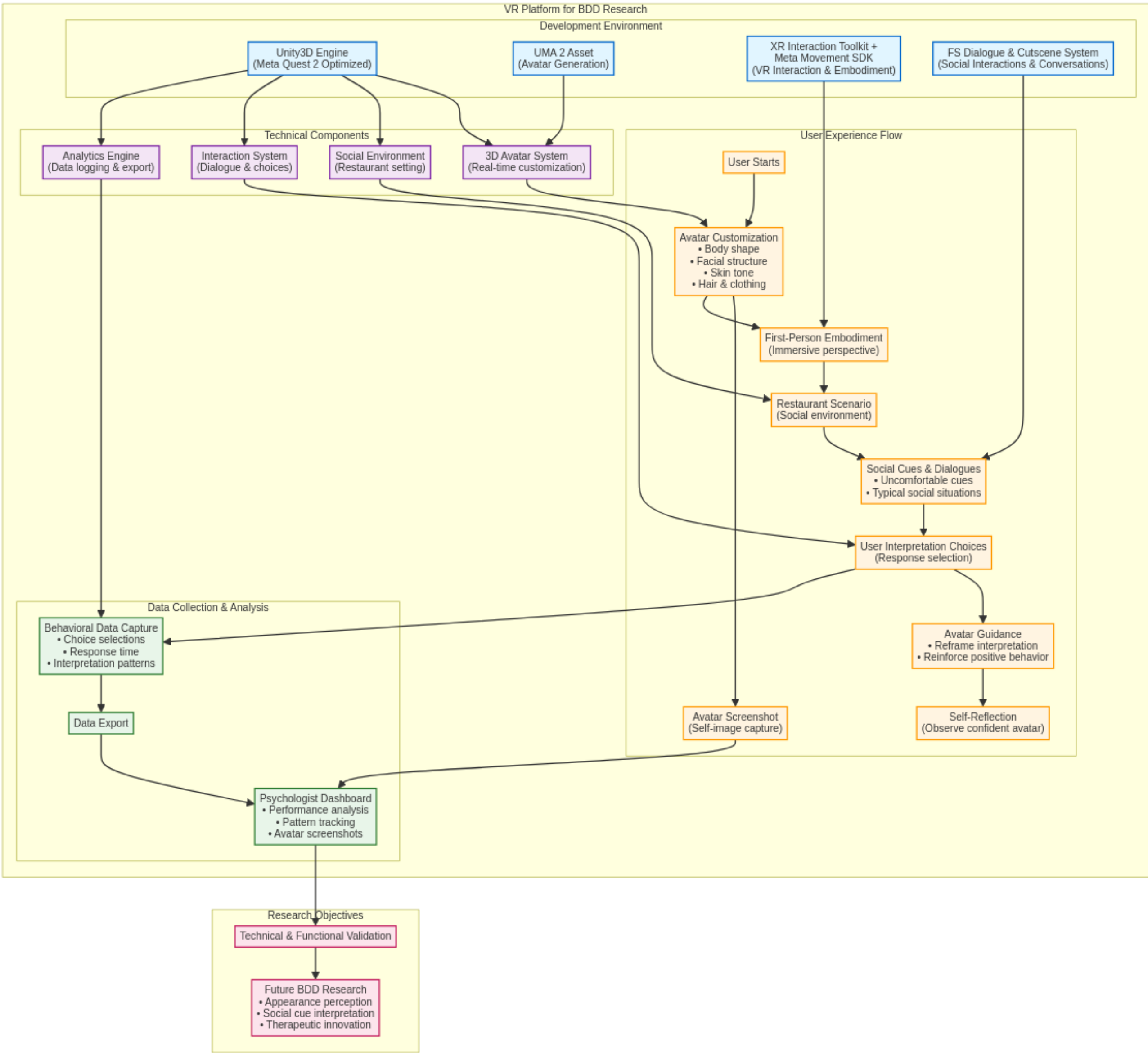

Figure 7 : Design architecture and sequence of events of VR system.

E Flow Diagram of Dialogue and Choice System

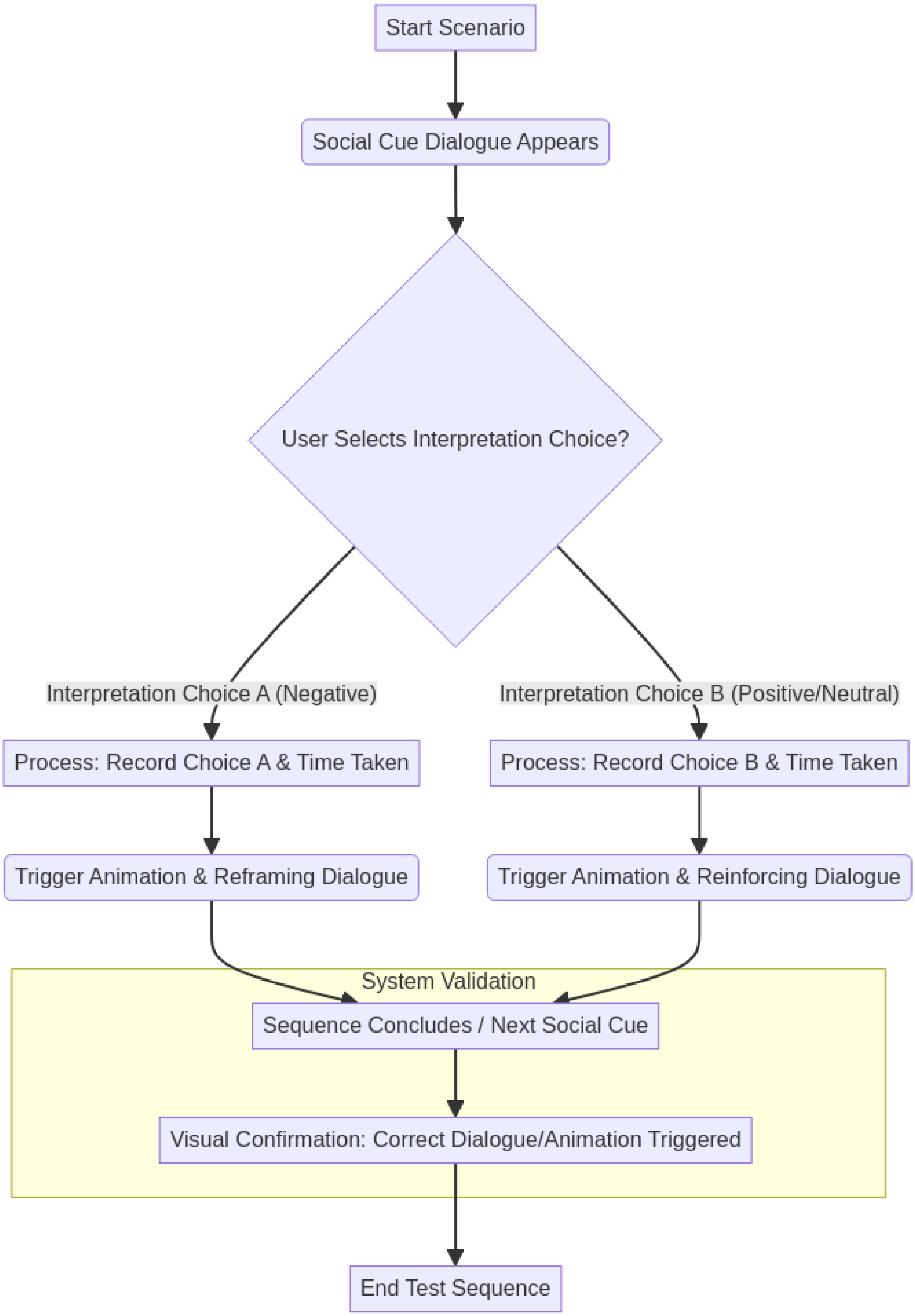

Figure 8 : Testing procedure of dialogue and choice system designed for the virtual social scenario.

F Avatar Customisation Panels

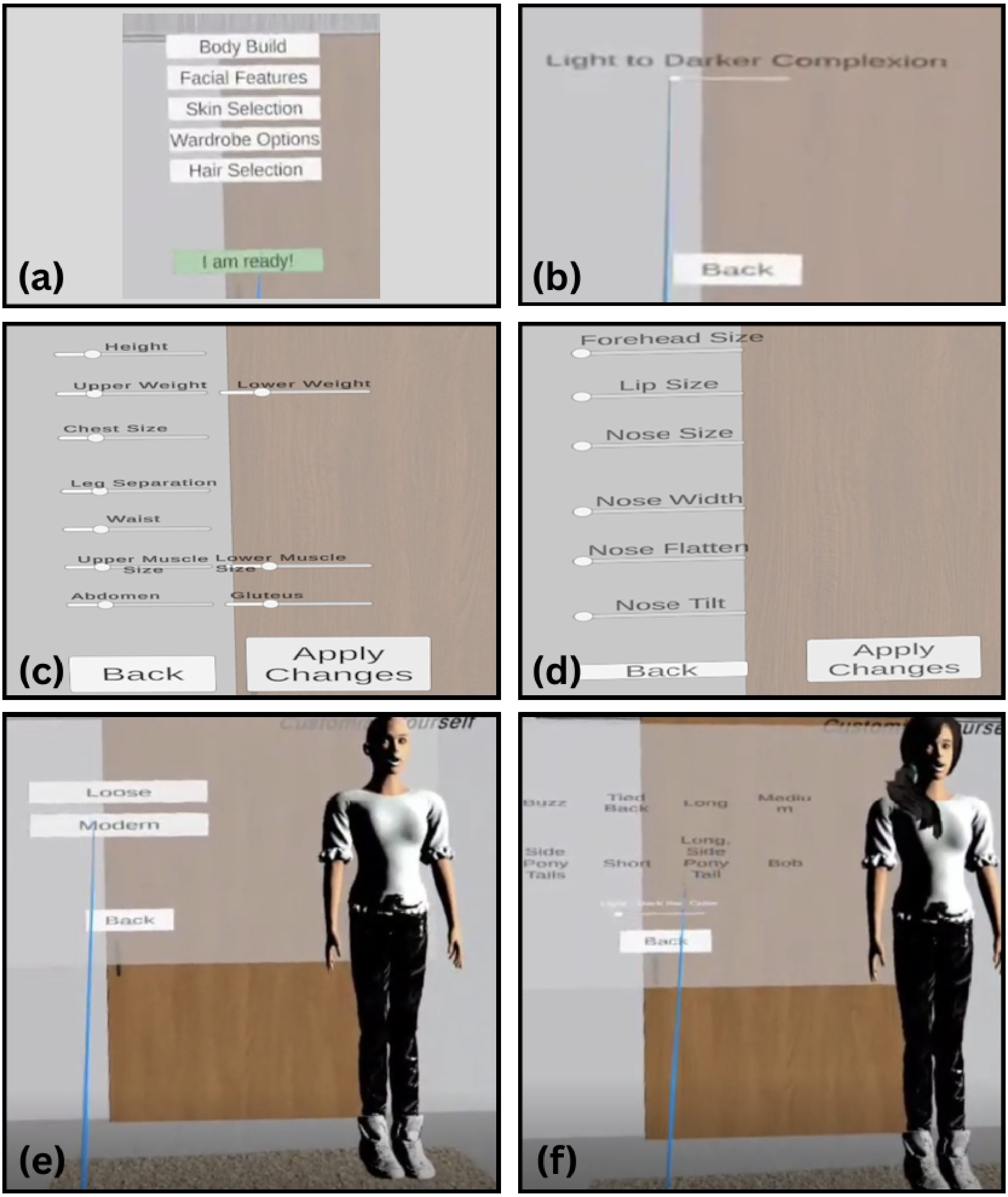

Figure 9 : Developed customisation panels include (a) Main Menu, (b) Skin Panel, (c) Body Panel, (d) Facial Features Panel, (e) Wardrobe Panel, and (f) Hair Panel.

G Animator Controller and Animation clips

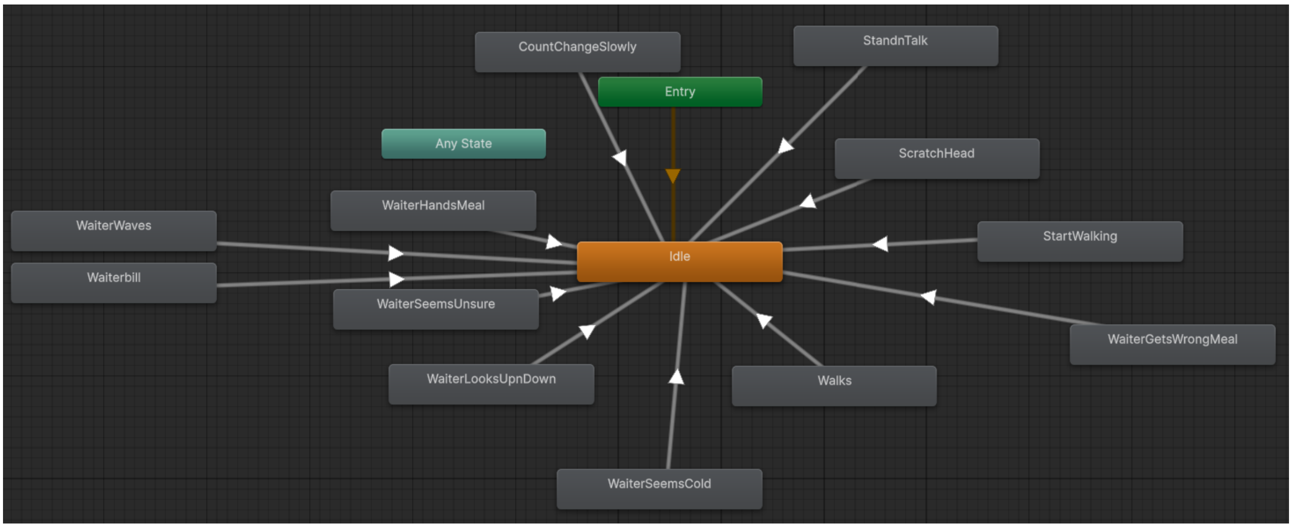

Figure 10 : Character Animator Controller with transitions between animations

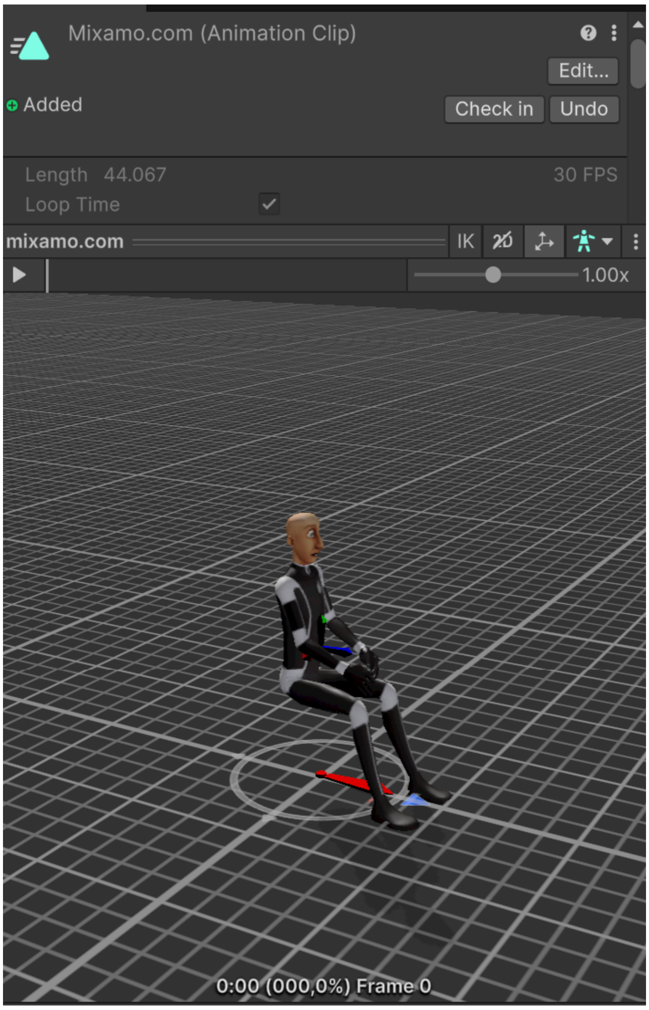

Figure 11 : Editing animation clip

H FS Dialogue and Cutscene Asset

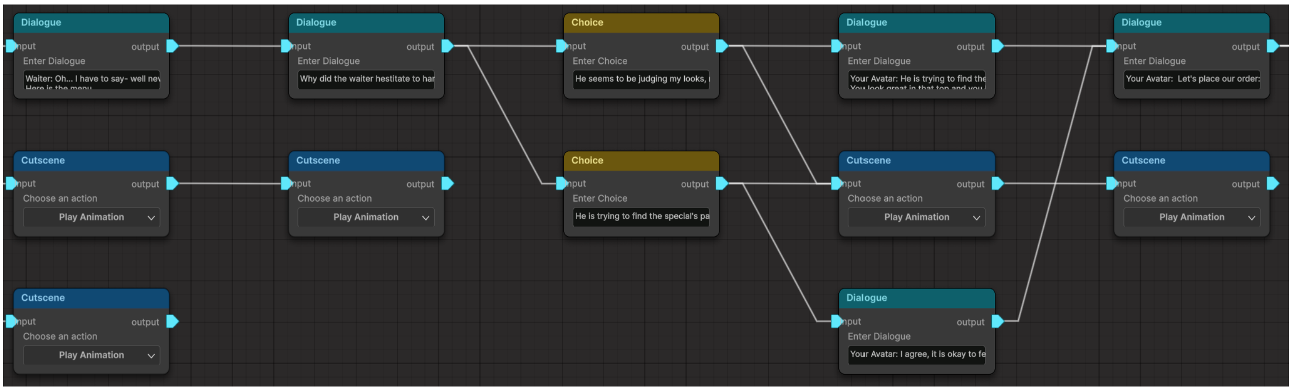

Figure 12 : Created cutscene graph with different nodes.

I Cohort Minute Meetings

The following pages to follow are the minutes taken from the weekly cohort meetings.