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.

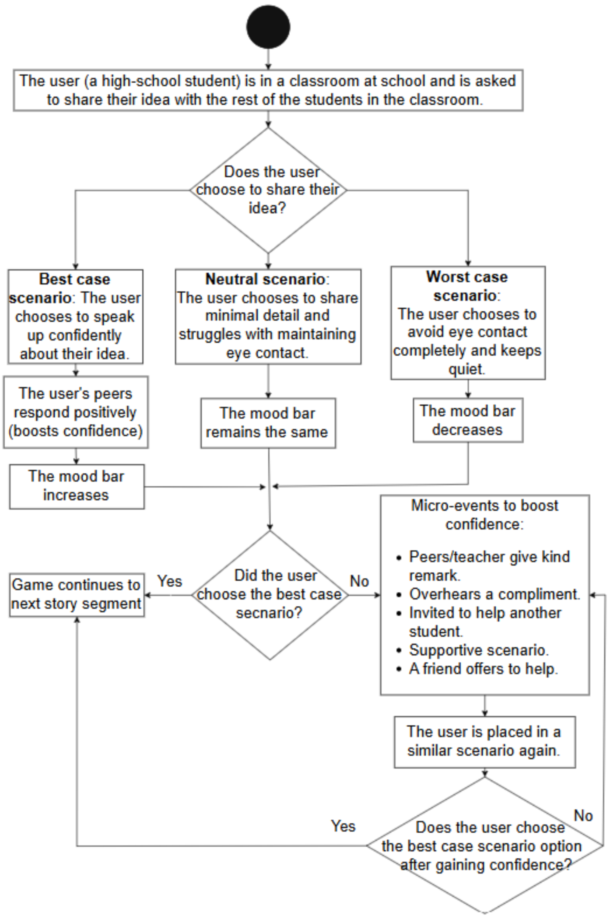

Figure 1 : Narrative loop feedback flowchart

- 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

Tasks	Weeks							
	1	2	3	4	5	6	7	8
Phase 1: VR foundation – VR environment setup – Avatar embodiment basics (mirror and Inverse Kinematics setup)								
Phase 1: VR foundation – Full embodiment – Complete initial scene – Avatar movement testing								
Phase 2: Web Management System – Firebase setup – React frontend scaffolding – Authorisation integration								
Phase 2: Web Management System – Avatar customisation User Interface – Session tracking – Database interaction								
Phase 3: Advanced VR Features – Avatar customisation sliders in VR – Inverse Kinematics refinement								
Phase 3: Advanced VR Features – Therapy progression system – Scenario branching and mood tracking – Firestore sync								
Phase 4: Machine Learning (ML) and Psychologist Tools – Data logging and security – Initial ML models (clustering/regression) – Dashboard enhancements								
Phase 5: Testing and Experiments – Unit/integration testing – Performance optimisation – Security audit – Experimental Validation								

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.