

SpaceRehab: A VR-Based Space Rehabilitation Experience for Hand Therapy on Meta Quest

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Abstract—SpaceRehab is a virtual reality rehabilitation platform developed in Meta Quest that transforms traditional upper-extremity hand-therapy exercises into immersive gameplay experiences within a space-themed environment. Inspired by clinical rehabilitation assessments such as the 9-Hole Peg Test, Box and Block Test, and Action Research Arm Test (ARAT), the project integrates fine and gross motor skill exercises into engaging VR mechanics. The system combines hand tracking, gesture-based interaction, and low-gravity environmental simulation to improve user engagement and rehabilitation adherence while maintaining measurable therapeutic tasks.

The project was designed as an interdisciplinary collaboration combining engineering, game development, and artistic design. SpaceRehab incorporates Unity XR Hands, XR Interaction Toolkit, custom gesture recognition systems, and immersive environmental assets to create a functional rehabilitation experience that balances accessibility, technical robustness, and gameplay immersion.

I. INTRODUCTION

Traditional rehabilitation exercises can become repetitive and reduce patient motivation over time. Virtual reality presents an opportunity to transform therapy into an engaging and interactive experience while preserving clinically relevant therapeutic movement patterns. SpaceRehab explores how immersive technology can improve rehabilitation engagement by embedding therapy tasks into a futuristic space mission environment.

The project was developed in Meta Quest using Unity and focuses on hand-tracking-based interaction without requiring external controllers. Users perform therapeutic actions naturally through gesture-driven gameplay mechanics while navigating a space environment.

II. ELEVATOR PITCH

A VR space adventure in Meta Quest that transforms clinical hand rehabilitation exercises into immersive gameplay experiences that improve motor skills, recovery, and participation in measurable therapeutic interaction tasks.

III. PROJECT OVERVIEW

SpaceRehab contains three rehabilitation-inspired VR activities designed to improve motor coordination, dexterity, and upper-extremity movement:

- Nine Peg Hole Test-inspired interaction
- Box and Block-inspired sorting task
- ARAT-inspired multi-exercise interactions

Each activity was redesigned into a space-themed gameplay experience while preserving therapeutic movement objectives.

IV. REPRESENTATIVE IMAGES

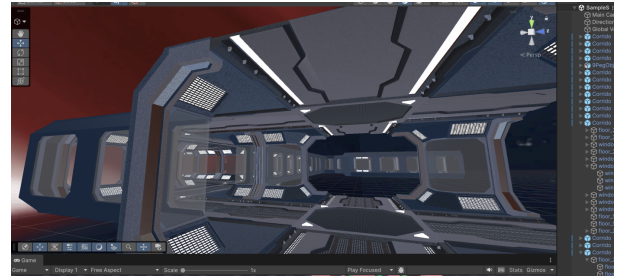


Fig. 1. SpaceRehab Gameplay Environment

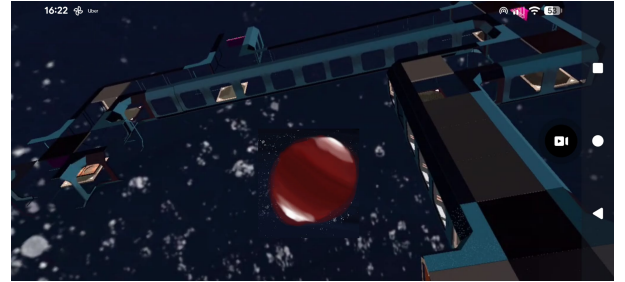


Fig. 2. Space Station (top-view)

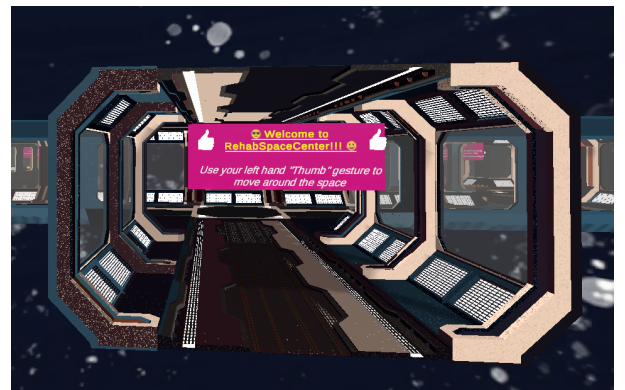


Fig. 3. Welcome! SpaceRehab (entrance)

V. MAIN UNITY SCENE

Unity Version: Unity 6000.3.6f1

Starting Scene:

`Assets/Scenes/ShowcaseDemo`

VI. GAMEPLAY AND INTERACTION DESIGN

The project utilizes Meta Quest hand tracking to create natural interaction systems. Players interact with objects directly using their hands and perform gestures for movement and gameplay actions.

Core interactions include:

- Hand tracking-based grabbing
- Object placement
- Gesture-based locomotion
- Floating object interaction
- Color matching tasks
- Peg placement exercises
- Space navigation mechanics

The low-gravity space environment was intentionally designed to reinforce immersion while introducing playful movement dynamics into rehabilitation exercises and also it's a space station.

VII. TECHNICAL COMPONENTS

A. Original Scripts and Systems

1) *XR Hands Gesture and Debug Samples*: Located under:

`Assets/Samples/XR Hands/1.4.3`

2) *XR Interaction Toolkit Starter Assets*: Located under:

`Assets/Samples/XR Interaction Toolkit/`

`2.6.5`

3) *XR Rig and Hand Setup*: The `XRhand.unity` setup contains:

- Left-hand tracking components
- Right-hand tracking components
- Hand gesture interaction scripts
- XR rig configuration

B. Packages Used

- `com.unity.xr.hands 1.4.3`
- XR Interaction Toolkit Sample Content 2.6.5
- Unity Input System
- XR Starter Assets/Input Actions

C. Scene and Template Components

1) *XR Origin (XR Rig)*: Used as the player root system for VR interaction and movement.

2) *Main Camera*: Serves as the movement and orientation reference.

3) *Hand Tracking Prefabs*: Implemented using XR Hands sample prefabs for real-time hand interaction.

VIII. CUSTOM SCRIPT FUNCTIONALITY

A. *HoleManager.cs* (in nine-peg hole test)

Controls the peg hole activation system. At initialization, all holes are disabled and one random unfilled hole becomes active. When a hole is completed, the system selects another available hole until all holes are filled.

B. *peg.cs* (in nine-peg hole test)

Handles peg placement behavior. The script stores placement status and freezes rigidbody physics after successful insertion into a hole.

C. *FloatObject.cs* (in box-block test)

Creates floating object behavior using simulated low-gravity movement. Objects drift and move vertically with buoyancy effects to simulate space-like interaction.

D. *ColorMatchZone.cs* (in box-block test)

Implements a color-matching rehabilitation task. Users place correctly colored objects into designated zones. The system updates colors dynamically and tracks task completion.

E. *GravityModeManager.cs* (in box-block test)

Controls switching between gravity and floating modes. Uses XR Hands gesture detection to identify a poke/point gesture. Holding the gesture toggles object behavior between normal gravity and low-gravity float states.

A keyboard fallback using the spacebar was included for debugging purposes.

F. *ThumbJetpackLocomotion.cs* (used for navigation movement)

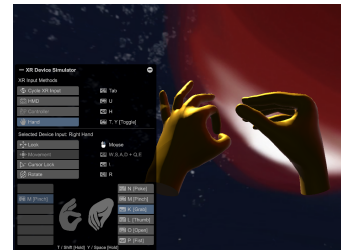
Implements gesture-based locomotion using thumb orientation and hand pose tracking. Users move through the environment using directional thumb gestures combined with open and closed hand states.

Movement directions include 6-DoF (degree-of-freedom):

- Forward
- Backward
- Upward
- Downward
- Left
- Right

G. *Gesture .cs* files

Each file has their gesture threshold conditions like pinch, grab, open, fist, poke, thumb for both hands.





This interaction system was designed to provide immersive navigation without traditional VR controllers.

IX. REHABILITATION GAME MODULES

SpaceRehab consists of three rehabilitation-inspired VR game modules designed to improve upper-extremity motor performance, hand-eye coordination, dexterity, and functional movement. Each game adapts clinically inspired physical therapy exercises into immersive virtual reality interactions within a space-themed environment. These activities were designed to increase user engagement while preserving therapeutic movement objectives commonly used in rehabilitation settings.

A. Nine Peg Hole Test Module

The Nine Peg Hole Test module is inspired by the clinical Nine-Hole Peg Test frequently used by physical therapists to evaluate finger dexterity, fine motor coordination, and hand function. In traditional therapy environments, patients are instructed to place and remove pegs from a pegboard as quickly and accurately as possible.

In the VR adaptation, users interact with floating pegs inside a space station environment using natural hand tracking interactions. Players grasp and place pegs into highlighted target holes while operating in a low-gravity simulation. The task encourages repetitive grasping, release control, wrist stabilization, and precise finger movement.

Physical therapists commonly use this exercise for:

- Stroke rehabilitation
- Hand injury recovery
- Neurological motor assessment
- Fine motor skill improvement
- Dexterity evaluation

The VR implementation introduces immersive visual feedback and interaction-based motivation while maintaining clinically relevant hand movements.



Fig. 4. VR-based Nine Peg Hole Test interaction in SpaceRehab



Fig. 5. Traditional clinical Nine-Hole Peg Test used in physical therapy

B. Box and Block Test Module

The Box and Block module is inspired by the Box and Block Test commonly used in occupational and physical therapy to evaluate gross manual dexterity and arm-hand coordination. Traditionally, patients move small blocks from one compartment to another within a fixed amount of time.

In SpaceRehab, the activity is transformed into a color-matching task where users manipulate floating blocks in a low-gravity space environment. Players grab cubes and place them into matching color zones while maintaining hand stability and coordinated arm movement. The floating mechanics increase interaction complexity and encourage controlled movement patterns.

Physical therapists use this type of exercise to improve:

- Gross motor coordination
- Reach-and-grasp ability
- Bilateral coordination
- Hand control and endurance
- Functional upper-extremity movement

The VR adaptation introduces interactive feedback, environmental immersion, and increased patient engagement while preserving therapeutic objectives.



Fig. 6. VR Box and Block inspired interaction in SpaceRehab



Fig. 8. ARAT-inspired rehabilitation interaction in SpaceRehab



Fig. 7. Traditional Box and Block Test used in rehabilitation therapy

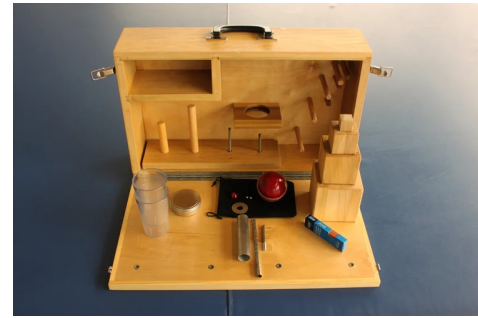


Fig. 9. Traditional Action Research Arm Test (ARAT) rehabilitation assessment

C. ARAT-Inspired Rehabilitation Module

The ARAT-inspired module is based on movements and interaction tasks commonly found in the Action Research Arm Test (ARAT), which is widely used to evaluate upper-limb functionality after neurological or musculoskeletal impairments. The ARAT includes activities involving grasping, gripping, pinching, and gross movement tasks.

In the VR environment, users complete multiple interaction challenges involving object manipulation, reaching tasks, and coordinated hand movement exercises integrated into a space mission scenario. These interactions encourage functional movement repetition while providing immersive gameplay elements.

Physical therapists use ARAT-related activities to assess and improve:

- Upper-extremity functional recovery
- Grip strength and control
- Object manipulation ability
- Shoulder and elbow movement coordination
- Daily living task performance

The VR implementation allows therapeutic exercises to be performed in a motivating and interactive environment while supporting repeated functional movement practice.

X. ARTISTIC COMPONENTS AND ENVIRONMENT DESIGN

A. Original Assets Crafted

- Modified Interior Environment

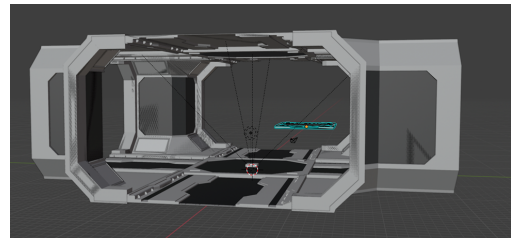


Fig. 10. Modified Interior Environment

- Rounded Coin 3D Design

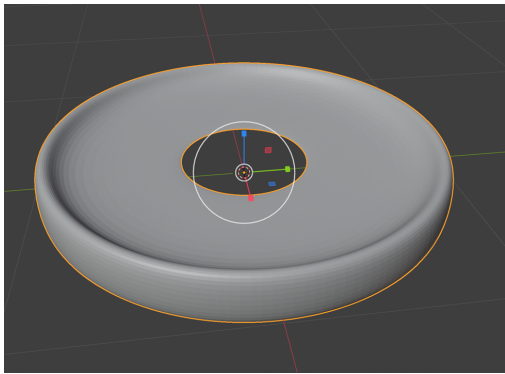


Fig. 11. Rounded Coin 3D Design

- Mug Design

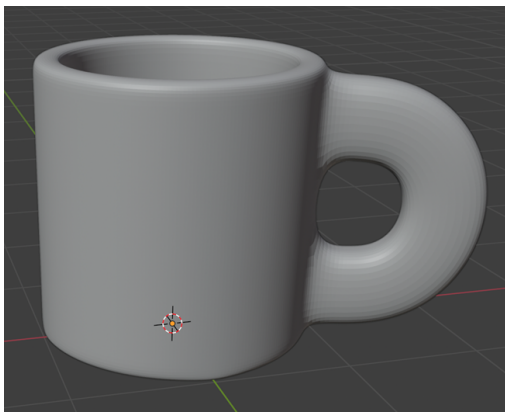


Fig. 12. Mug Design

- ARAT Multi-exercise Design

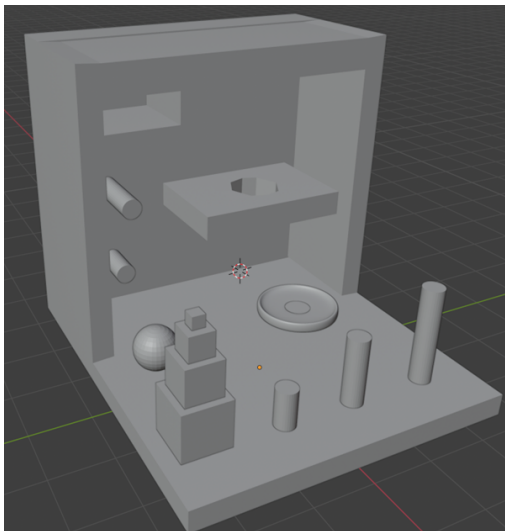


Fig. 13. ARAT Multi-exercise Design

- Nine Peg Hole Test Design

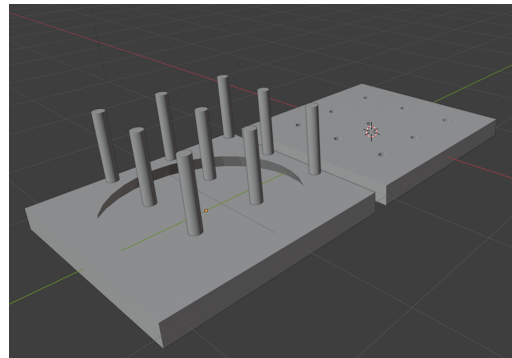


Fig. 14. Nine Peg Hole Test Design

- Space Background Environment

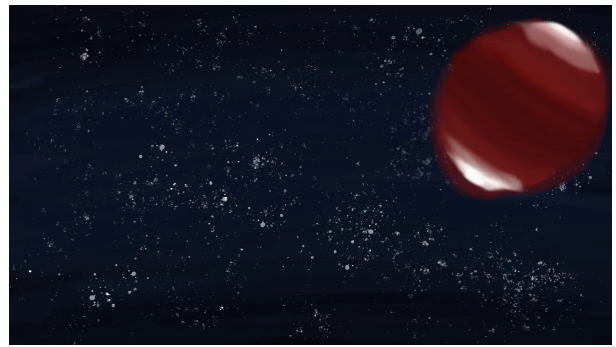


Fig. 15. Space Background

XI. PROCESS AND CONCEPT DEVELOPMENT

A. Process and Concept Arts (sketches, prototypes)

- Interior Space Station Concepts Art (Jacob Levin)

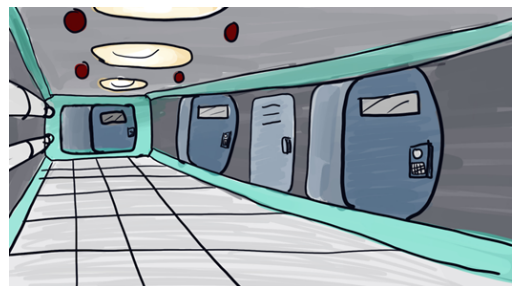


Fig. 16. Interior Space Station Concepts Art

- Rough Concept of space station Exterior



Fig. 17. Rough Concept of space station Exterior

- Character Concept Art (If Character was visible)

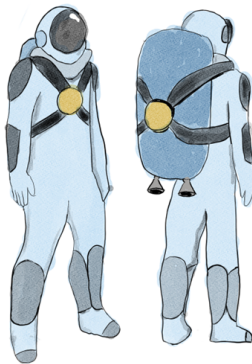


Fig. 18. Character Concept Art

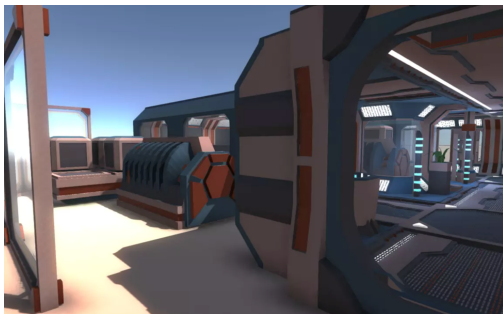
XII. EXTERNAL ASSETS AND CREDITS

A. Sci-Fi Styled Modular Pack

Created by Michal Karbowski

Website: <https://karboosx.net>

Unity Asset: Link



The project utilized modular sci-fi environment assets which were modified and integrated into the final VR rehabilitation experience.

XIII. FUTURE ASSETS AND PLANNED EXPANSION

Several additional assets and systems were prototyped for future development:

- Map Redesign (Starting with Floor)

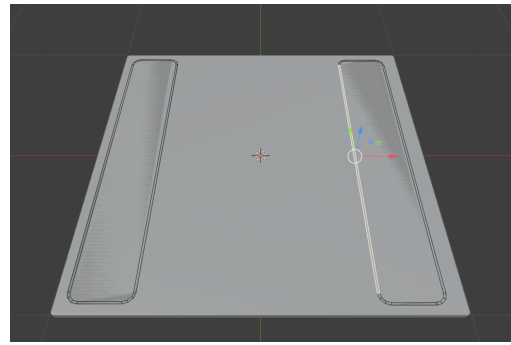


Fig. 19. Map Redesign

- Navigation Screens

Navigation Screen Video Link: [navigation_screen_link](#)

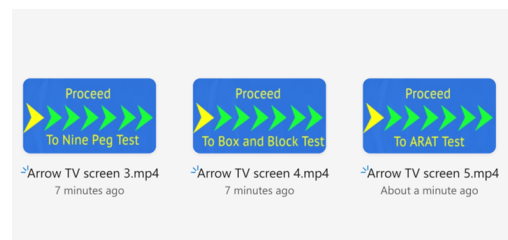


Fig. 20. Navigation Screens

- Interior Texture Redesign

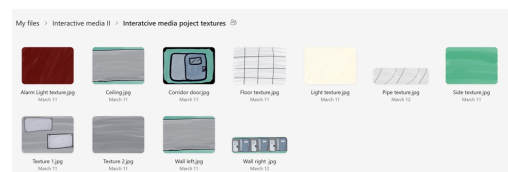


Fig. 21. Interior Texture Redesign

- Door Keypad Systems

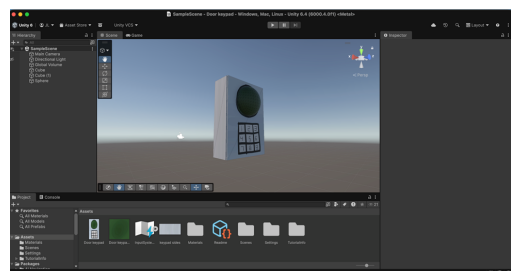


Fig. 22. Door Keypad

- Animated Window Displays

Link to video: [cloud_animation_link](#)

- Angle2_DIP_PIP_MCP_Index
- Angle3_PIP_MCP_CMC_Index
- Distance_Tip_Dip_Middle
- Distance_Dip_Pip_Middle
- Distance_Pip_MCP_Middle
- Distance_MCP_CMC_Middle
- Angle1_TIP_DIP_PIP_Middle
- Angle2_DIP_PIP_MCP_Middle
- Angle3_PIP_MCP_CMC_Middle
- Distance_Tip_Dip_Ring
- Distance_Dip_Pip_Ring
- Distance_Pip_MCP_Ring
- Distance_MCP_CMC_Ring
- Angle1_TIP_DIP_PIP_Ring
- Angle2_DIP_PIP_MCP_Ring
- Angle3_PIP_MCP_CMC_Ring
- Distance_Tip_Dip_Pinky
- Distance_Dip_Pip_Pinky
- Distance_Pip_MCP_Pinky
- Distance_MCP_CMC_Pinky
- Angle1_TIP_DIP_PIP_Pinky
- Angle2_DIP_PIP_MCP_Pinky
- Angle3_PIP_MCP_CMC_Pinky
- timestamp_ms
- timestamp_diff

XV. SCOPE EVOLUTION



Fig. 26. Project Timeline

A. Initial Vision

The original project scope aimed to create a large-scale VR rehabilitation platform featuring:

- Multiple fully developed game environments
- Advanced locomotion systems
- Narrative Space integration
- Expanded rehabilitation activities
- Animation and sound effects
- Fully interactive station exploration
- Real-time data-analysis

B. MVP Development

The minimum viable product focused on:

- Functional hand tracking
- Basic rehabilitation interactions
- Two playable rehabilitation activity
 - 9-hole peg test
 - box-block test
- Core locomotion system
- Space-themed environment

This phase prioritized system functionality, hand tracking and technical stability.

C. Final Outcome

The final project successfully delivered:

- Three rehabilitation-inspired VR experiences
- Gesture-based locomotion
- Hand tracking interaction systems
- Space-themed immersive environments
- Functional therapeutic gameplay mechanics
- Measurable interaction tasks
- Jetpack Navigation inside Space (with thumb gesture)
- Storing Hand Data (csv format) for analysis (Hand Data is used for individual Hand gestures “Customization”)

Although several planned systems were reduced in scope, the final version achieved a strong balance between gameplay, accessibility, and rehabilitation-focused interaction.

XVI. LESSONS LEARNED

A. Liam

Coming into this project, I was wildly ambitious. I had experience in 3D game design before I thought virtual reality would be similar. My team was incredible to work along the way even if my ideas and goals were way too big for a single class project.

With running on a virtual reality headset and even just functioning in Unity, one of the most critical things I found is that I had to be careful about adding too much into the details of any design. With Blender, we can make models with lots of different polygons to produce very smooth edges. Bringing assets into Unity, it was important for it to function first at a low poly and make sure the game works before jumping into design changes.

Working in Unity VR was pretty difficult. The first hiccup we ran into was that we were working in different versions of Unity. This issue would have been easily remedied by working in the same area. As a student, it was a strange adjustment moving group work outside of the classroom. Our team members in Computer Science had their equipment in the lab. They came up with the idea of us meeting them in their lab on North Campus, and our development accelerated. Especially because we were all on the same Unity version together.

A personal development lesson for me came from building the map for the game. When I was attempting to put it together, I was working in the VR Unity project and I had almost

completely hit a wall. The structures wouldn't go where I needed them to go; I was having such a difficult time modeling everything. I started doing some YouTube research to see how others had built VR projects. What I found was that a large number of game designers build the map in a 3D project and then import it as a Scene Asset in the VR project. This worked perfectly for me; the lesson was to explore options that work for others when you run into problems.

To summarize my takeaway from the lessons I learned, I learned how to adjust my scope, adjust to unfamiliar settings, and learn from others. I believe with a job it would have been easier to adjust to moving to a more optimal setting. With classes at this level, we see the clear transition of educational work bleeding into career work. I think these lessons are incredibly important at this level because they teach us as students to be more self-sufficient and remind us to continue to ask for help and work together while we become more independent.

B. Jacob

When I first started working on this project, I felt both excited and a little nervous at the same time. Excited because I got to work with fun and creative ideas and grow some of my digital art skills. Drawing the concept art, assets, and creating new ideas (like the navigation signs) allowed me to experiment / play around with different tools nervous because I'm not super familiar with 3D software and I have bad luck when trying to make assets in Unity. Though thankfully when working with this group, my luck changed from bad to good. Because we were able to set tasks for each member according to their skill set. Plus, my luck with unity turned. Both because the asset I was assigned to make was within my skillset, and because I got a stronger computer, ha ha ha :)

What impressed me the most this semester was seeing how much goes into making a VR asset come to life, like the hand-tracking mechanic. Though not just the assets, it was impressive seeing how much goes into making a VR project like this. Even though I was a little disappointed that not all my assets made it in the final product, I was still impressed with what we made in the end and proud of how well we worked together. Not to mention how efficiently we finished it on time. While I was worried about some of the hiccups in the final product, like how players can accidentally interact with parts of the space station, I'm glad that it made it more enjoyable for players.

C. Ravi

This project taught us how important it is to carefully connect user interaction, physics, and gesture recognition in XR development. We learned that even simple interaction ideas, like grabbing or placing objects, require precise collider, rigidbody, and layer settings to work reliably. The project also showed us that hand gesture controls must be tested repeatedly because small mistakes in detection thresholds can make interactions inconsistent. We gained experience in organizing

custom scripts so that each script handles one clear responsibility, such as movement, grabbing, floating, or task management. Another lesson was that debugging in Unity often involves checking both the scene hierarchy and the script logic together, since problems can come from either side. We also learned the value of reusing existing XR Hands and XR Interaction Toolkit samples as a starting point, then modifying them for our own needs. The project improved our understanding of how immersive interactions should feel natural and intuitive for the user, not just technically functional. Overall, this work helped us build stronger skills in Unity XR design, scripting, testing, and problem-solving. It also strengthened our communication with art students, helped us collaborate in gathering assets, and made the learning process more enjoyable and meaningful through teamwork and shared creativity.

D. Gayathri

Before taking this class, I was somewhat familiar with Unity but often hesitant about working in XR environments and developing AR/VR games. Through this class and the SpaceRehab project, I gained hands-on experience in immersive application development, which significantly improved my confidence in Unity, VR interaction design, hand tracking integration, and XR development workflows. Since I had previously worked with hand tracking and rehabilitation-related research, this project allowed me to extend my engineering knowledge into an interactive and immersive VR application. I also learned how engineering and healthcare concepts can be combined through rehabilitation-focused experiences while strengthening my skills in Unity scripting, interaction design, and collaborative development. One of the most valuable experiences was collaborating with teammates from artistic backgrounds, which helped me understand how designers and artists view environments, aesthetics, and user experiences in creative ways. This collaboration encouraged me to transform technical engineering concepts into a more visually engaging and artistic approach within the project. In addition, I explored Blender for 3D modeling and asset creation, which introduced me to a creative workflow that I genuinely enjoyed. Overall, the project helped me grow both technically and creatively, and the supportive collaboration within the team made the experience especially meaningful and rewarding.

XVII. TRANSFERABLE SKILLS AND TECHNICAL OUTCOMES

A. Technical Skills

- Unity XR Development
- VR interaction design
- Hand tracking integration
- Gesture recognition systems
- Physics-based interaction systems
- User-centered gameplay mechanics
- XR locomotion systems
- Debugging and optimization

B. Interdisciplinary Skills

- Collaboration across engineering and art disciplines
- Scope management
- Iterative prototyping
- Rehabilitation-focused design thinking
- Human-computer interaction design
- Communication between technical and creative teams

XVIII. CONCLUSION

SpaceRehab demonstrates how virtual reality and immersive technologies can transform traditional rehabilitation exercises into engaging and interactive experiences. By combining therapeutic movement tasks with VR gameplay mechanics and space-themed immersion, the project highlights the potential of XR technologies for healthcare and rehabilitation applications.

The interdisciplinary collaboration between engineering, computer science, and artistic design contributed to a system that balances functionality, immersion, and therapeutic engagement. Future expansion could include additional rehabilitation exercises, adaptive difficulty systems, patient performance analytics, and broader clinical integration.

SUPPLEMENTARY MATERIALS

Build: Windows

Video Walkthrough:

MVP Video: [_link_](#)

Final Video: [_link_](#)

Source Code Repository: [_link_](#)