Inclusive Immersive E-Learning: Participatory Design of Accessible Virtual Reality. Supporting Diverse Learners Through Inclusive Medical Simulation Design

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Abstract: Simulation-based education is a well-established approach for introducing medical students to real-world clinical scenarios within controlled learning environments; however, ensuring accessibility and inclusion for diverse learners remains an ongoing challenge in immersive e-learning contexts (Lukava et al., 2022). This article explores the unique challenges faced by neurodivergent medical students and emphasises the critical role of participatory design and lived experience in shaping VR environments that are inclusive and responsive to diverse needs. The paper advocates for a paradigm shift in medical education and VR design, one that not only supports neurodivergent medical students but also fosters inclusivity across the broader neurodivergent health professions, educational and workforce landscape. Furthermore, it highlights the intersection between Universal Design Principals (UDL), empirical evidence, and lived experience as essential for creating accessible and immersive VR learning environments.

Keywords: Lived Experience, Participatory Design, Virtual Reality, Neurodiversity, Universal Design for Learning

1. Introduction

Worldwide, mass-casualty incidents (MCI) are occurring with increasing frequency and complexity, driven by factors such as political conflict and natural disasters (Merson et al., 2025, Mundo et al., 2025). Medical responders are therefore required to make rapid, high- stakes decisions in unpredictable environments, often while exposed to significant psychosocial risks, including witnessing traumatic events and violence (Reale et al., 2023). Such exposures place medical responders at increased risk of psychological distress and physical harm (Utara, 2025, Mundo et al., 2025).

In response, simulation-based training for MCI management in senior medical education has progressively evolved through the adoption of advanced technologies, including virtual reality (VR) (Dzhumatovich and Salimrouhi, 2025). The increasing use of immersive platforms has enhanced experiential learning and clinical skills training; however, accommodations for neurodiverse learners and those with sensory accessibility needs remain under-represented in VR design and pedagogical research (Dahlstrom-Hakki et al., 2024, Lukava et al., 2022, Schmidt and Glaser, 2026, Schmidt et al., 2023, Wehrmann and Zender, 2024).

While VR offers a safe space for senior medical students to practise complex clinical competencies, its intensive cognitive and sensory demands, such as visual complexity, auditory load, and time-pressured interaction may create barriers to engagement for neurodivergent students (Giroux and Pélissier-Simard, 2021, Lukava et al., 2022, Creed et al., 2024). Effective instructional design therefore requires careful consideration of multisensory inputs, including visual, auditory, proprioceptive, and haptic feedback (Boyd et al., 2018). Many existing VR learning platforms insufficiently address cognitive diversity and accessibility, reinforcing the need for inclusive, learner-centred design approaches (Wehrmann and Zender, 2024, Lukava et al., 2022).

1.1 Project Background

1.1.1 Project Collaboration

This collaborative research project aims to address the need for inclusive VR Team Based Learning experiences for undergraduate medical students at the University of New South Wales (UNSW). Structured as a co-production initiative, the project brings together students, academic, and technology specialists to collaboratively refine instructional design and enhance learning outcomes (Strnadová et al., 2020). Using a

participatory design methodology, the research explores how immersive VR environments can support inclusive team-based medical education.

A key strength of the project is its interdisciplinary collaboration, integrating expertise from medical students, design students, academics, and immersive technology specialists. Supported by in-kind contributions from the School of Arts & Design, School of Clinical Medicine and Pro-Vice Chancellor Education (PVCE) Media & Immersive team, this collaborative partnership enhances both innovation and scalability. Delivered as a Work Integrated Learning (WIL) initiative, the project engages Master of Simulation and Immersive Technology (MSIT) students through successive capstone cohorts, each building on prior research and prototype development to support an iterative and cumulative design process. Undergraduate medical students contribute as clinical consultants, providing domain expertise and insights into the cognitive, sensory, and communication demands of clinical practice. As intended end users, their input ensures that VR scenarios are clinically relevant, pedagogically meaningful, and technically feasible.

Individuals with lived experience of neurodiversity and sensory accessibility needs are actively involved as co-designers across all stages of the project, including, ideation, prototyping, testing, and evaluation. The inclusion of team members with lived experience supports the identification of key challenges related to sensory processing and attentional challenges, and communication, including sources of overload, distraction, and breakdown. These insights are critical in designing for neurodivergent users and position lived experience act as a bridge between technical development and clinical application.

While the project was initially conceived as the development of a multiplayer VR platform grounded in Universal Design for Learning (UDL) principles, its scope has evolved through iterative design to incorporate lived experience, enabling a nuanced exploration of neurodivergent needs within immersive learning environments (CAST, 2024).

1.2 Multiplayer VR Trauma Simulation

1.2.1 Mass Casualty Incident: Trauma and Hypothermia onboard the Antarctic II Research Vessel

In this study, a mass casualty scenario is used in which students are deployed (via helicopter) to a remote maritime disaster site (onboard the AVR11) and tasked with triaging and stabilising patients. The simulation is designed to support the development of clinical management skills, as well as communication and teamwork in a high-pressure, resource- constrained setting.

1.2.2 Project Objective

To design and develop a virtual reality learning experience through a co-production framework that engages students, academics and technology specialists from ideation to prototype testing, ensuring meaningful inclusive design and collaborative innovation.

1.2.3 Infrastructure

The project employs simulation-based education delivered through a multiplayer VR platform developed in Unity game engine and implemented using the Meta Quest 3 head-mounted display and hand controllers. The system enables users to navigate avatars within a clearly defined operational environment, including a rescue helicopter and a ships deck, designed to replicate key spatial and workflow features of a real-world maritime emergency.

A core- decision support system, currently under development by MSIT and medical students, underpins the educational experience. The simulation is structured around a custom designed mass-casualty scenario developed by UNSW academics, representing a high-risk disaster onboard a research vessel. Consistent with simulation-based pedagogy, the environment prioritises psychological fidelity over sensory threat realism; no overt visible or auditory threat stimuli are included (Pedram et al., 2023). This approach allows users to focus on objectives such as team communication, triage decision-making, role coordination and patient management.

The scenario includes five simulated casualties with varying injuries and clinical presentations, enabling deliberate practice across multiple levels of clinical complexity. Users are orientated through an in-scenario pre-briefing tutorial., consistent with best practice simulation design. User actions including movement patterns, triage tagging decisions and patient management are captured to support structured debriefing and reflective

learning. An optional academic facilitator, represented by an in-simulation avatar, can be included to support facilitation, and reinforce educational objectives.

2. Study Design

Our project integrates a participatory co-design framework with UDL, foregrounding lived experience to inform flexible, accessible VR simulation design. UDL provides the pedagogical lens, while participatory co-design operationalises inclusion through learner-informed decision-making.

2.1 Universal Design for Learning

Universal Design for Learning offers a framework that informs the design of learning environments that promote inclusivity, accessibility, and meaningful cognitive challenge for every learner (CAST, 2024). This project is theoretically grounded in UDL, which frames the design and implementation of the VR simulation as an inclusive learning environment responsive to learner variability. UDL provides a lens through which learning is conceptualised not as a fixed outcome, but as emerging from the interplay between users, the environment and tasks (CAST, 2024).

Guided by UDL principals of multiple means of engagement (the 'why' of learning), representation (the 'what of learning), and action and expression (the 'how' of learning), the VR platform is intentionally designed to reduce barriers to participation and support neurodiverse learners, psychological safety and authentic performance (CAST, 2024). The prototype design has been conceptualised to incorporate multiple means for learners to engage with tasks, access information, and demonstrate understanding, enabling flexibility in how learning is experienced and enacted within the simulation. The principal of engagement focuses on fostering, affirming and sustaining learners' interests and identities. Representation highlights the importance of multiple ways of knowing and making meaning, while ensuring the inclusion of diverse identities, perspectives and narratives. Action and expression centres on the need to challenge exclusionary practices and to promote more accessible, inclusive, and user-centred learning environments (CAST, 2024).

2.1.1 UDL Methods in VR in the Study

Accessibility was central to the design of this multiplayer VR simulation. Accordingly, we operationalised key UDL principles within the VR environment to enhance flexibility in how students engage with content and demonstrate learning in immersive contexts. We explored design strategies to support diverse learners, including those with colour vision deficiency, auditory sensitivity, hearing impairment, and autism, with the aim of enhancing usability, comfort, engagement, and learning effectiveness.

Targeted interventions include high-contrast colour palettes and pattern overlays; adjustable Hz levels to accommodate sensory sensitivity; and multimodal feedback such as haptic cues, visual indicators, and in-environment virtual assistants. Additional design considerations include shape-based communication, multilingual support, and alternative interaction methods. These include simplified point and click modes to reduce cognitive load, verbal communication for team interaction, and gaze-based controls to minimise fine motor demands.

Importantly, these features were not implemented as a fixed or perfect solution but evolved through iterative co- design and ongoing refinement. Continuous feedback from individuals with lived experience and incremental improvements are central to the project.

3. Student Co-Design Projects

The following student co-design projects illustrate how UDL principals were operationalised through participatory design.

3.1 Auditory Sensitivity: Hz Level Controls to End Users

While there are VR systems that explicitly manipulate audio frequencies, most current systems address neurodivergence through broad sensory controls rather than precise frequency tuning. To address auditory sensitivity, this project explored selective, band-based frequency modulation rather than relying on broad sensory controls. Users can adjust specific audio frequency bands through selectable audio sources, presets, and real-time frequency visualisation. The approach enables personalise sensory regulation, supporting

neurodivergent users through greater control over audio input, and aligning with inclusive and user- centred design principals.

3.2 Colour Vision Deficiency

Colour blindness was explored by simulating visual impairments using Unity's channel mixer. Three environments were compared: non-optimised colours, colour friendly palettes, and palettes enhance with pattern overlays. In a pilot useability test (n=3), participants completed object selection tasks with randomised order; results showed increased reaction times with optimised colours, and further improvement when patterns were added, suggesting combined cues may enhance accessibility.

3.3 Hearing Impairment

This project explored how audio cues in VR can be supplemented or replaced with visual or haptic feedback. Two simulations were compared, one with multimodal feedback (visual, haptic, and audio) and another with limited cues. The prototype explores how different feedback designs influence attention and task performance, with future work needed to evaluate effectiveness and consistency.

3.4 Neurodivergence (Autism): Cognitive Overload

User interface design was examined to reduce sensory and cognitive overload for autistic users. Key features included simplified fonts, rounded buttons, low-stimulation colour palettes, multimodal feedback (including optional voice guidance), and adjustable audio-visual settings. A comparison with a poorly designed interface highlighted these improvements. The design acknowledges variability in user needs, and the limitations of the prototype in capturing real-world complexity.

Collectively, these student co-design projects highlighted the need for further usability testing with neurodivergent participants through first-person lived experience of the VR environments.

4. Neurodivergence and Lived Experience

While UDL is a significant framework bringing flexibility into the VR design and presentation of a learning environment it still is still subject to a degree of standardisation in its delivery through a technological framework. There remains a risk of mismatch between the bespoke processing needs of the individual user based on their specific neurodivergent needs and the technology platform used to deliver the learning. To understand this gap in more detail, we conducted an additional useability study based on lived experience feedback. We collaborated with neurodivergent participants, including neurodivergent members of the project team, to undertake a first-person reflective exploration of two distinct technology VR platforms utilising the phenomenological research methodologies of lived experience.

4.1 First Person Reflective Exploration: Method

Participant responses were tracked via a guided qualitative phenomenological first-person analysis paying close, minute by minute attention, to emotional reactions, sensory impressions, and cognitive processes within the virtual environment to capture the lived experience in real time. Responses we captured via a subjective think aloud narration and followed by an additional subjective reflection.

The experiment comprised two parts a) lived experience of the first-person subjective narrative b) personal reflective analysis. The exercise was repeated on two classes of VR headsets commercially available in 2025: the Apple Vision Pro and Meta Quest 3.

4.2 Preliminary Findings

In addition to findings related to UDL, this study includes a sample of subjective reflections derived from a lived experience exploration, presented as qualitative evidence. These reflections illustrate the types of unexpected insights that can emerge through detailed, first-person experiential inquiry. All reflections are reported anonymously to protect participant identity.

The following extract highlights how limited embodiment, poor spatial grounding, and interface complexity can lead to cognitive overload, disorientation, and delayed engagement in VR contents:

> The AVP presented only my hands, offering no view of the ground or my legs, which hindered my ability to ground myself in this new digital space. Instead, a vast digital sky and an array of menus filled my view, creating an immediate sense of being "a little overwhelming to understand where I start and where I finish". It took a significant amount of time to even process the options presented to me.

The participant described a tension between immersion and safety. The extract highlights a sense of being pulled between engagement in the virtual environment and the need for real world grounding. This loss of physical grounding contributed to a diminished awareness of their surroundings, resulting in feelings of disorientation and discomfort:

> Throughout my experience, the tension between immersion and a pervasive need for real-world awareness was palpable. While the initial creation of a virtual environment felt "beautiful," like a "movie", the sudden disappearance of my real surroundings "threw me off". The inability to see my legs or feet felt "off" and unsettling, triggering a desire for haptic feedback when interacting with virtual objects like a table, to better ground my physical presence.

The following extract highlights how gesture-based interactions in VR, when lacking tactile feedback and requiring sustained visual fixation, can feel unnatural, disrupt interaction flow and reduce user trust and confidence:

> My primary mode of interaction with the AVP involved looking at a dot and pinching my fingers to select. This interaction felt not like a normative experience [...] A pinch gesture feels intuitive in theory, but in practice it demands rigid fixation that breaks flow. A finger ray resembles pointing, but without muscular resistance it fails to build trust.

The participant describes how the design works against how they see and process information: *“my "dyslexic scanning tendencies," where the eyes tend to dart ahead to anticipate the next point, directly conflicted with the system's narrow tolerances”*

This extract describes how non-intuitive special set-up processes and inflexible interaction design can conflict with neurodivergent perceptual styles, increasing cognitive load and reducing usability:

> The process of spatial orientation and room setup was remarkably challenging and non-instinctual. While the system could auto-load a saved room preset, which beneficial for repeat users, I keenly felt the absence of an immediate option to declare a new environment for calibration. My "dyslexic nature," characterized by eyes shifting past targets to track the next movement, directly conflicted with the system's "rigid grammar of action”

The central theme of misalignment between VR design and neurodivergent cognitive, sensory, and perceptual needs emerged within the findings. The lived experienced highlighted reduced embodiment and spatial grounding, leading to disorientation and discomfort. Interaction methods, particularly those requiring sustained visual fixation and precise gestures, were perceived as cognitively demanding. Additionally, ridged interaction structures and limited flexibility conflicted with scanning behaviours, further increasing cognitive load. These findings highlight how current VR design can mistakably exclude neurodivergent users, underscoring the need for more flexible, and inclusive approaches informed by lived experience and UDL principals.

5. Insights and Recommendations

Normally, user interface design (UX) evaluates the extent to which a device conforms to user’s needs and enables intuitive interaction. However, in VR systems, interaction protocols often shift with each new product iteration. While UDL principals may be mandated, the interface shifts and technological developments across VR systems do not necessarily foster more fluid, inclusive learning or VR engagement experiences for neurodivergent users.

Some of the insights and recommendations to emerge from lived experience include:

- the need for more structured and prescriptive onboarding, ensuring that the user feel safe, grounded and in control when entering immersive environments;
- the importance of sensory channels and anchors to support orientation, predictability, and presence;
- the need to move beyond overly rigid or ‘forced narrowness’ in system design allowing, for diverse perceptual and sensory processing needs;
- the simplification of controls and action triggers that invertedly hinder neurodivergent users by increasing cognitive load or ambiguity in interaction.

- the need review all of the above with each new product iteration

Formative qualitative data generated through participatory design activities and lived experience recounts enables iterative design refinement throughout the development process, ensuring that accessibility considerations are embedded from the outset rather than applied retrospectively.

6. Limitations and Future Work

While our preliminary findings suggest that a multipronged approach combining UDL principals, empirical evidence, and lived experience insights through participatory co design may enhance accessibility in VR, several important limitations must be acknowledged.

First, heterogeneity within neurodivergent populations presents a significant challenge. Neurodivergence among medical students is not a uniformed experience, and sensory profiles vary widely both between individuals and within the same individual overtime. This variability limits the effectiveness of predefined solutions and reinforces the need for highly flexible and tailored systems.

Second, the proposed combined UDL and lived experience approach, including self-adjustment of audio parameters, may introduce usability barriers. Although user-adjustable EQ precision allows for precise control (e.g., reducing 4,000 Hz by -8 dB), it may also increase cognitive load or require technical understanding that the user may not have.

Third, the current work is based on preliminary, small scale, and potentially non-representative samples. Although, lived experience insights and participatory co-design provide valuable depth, findings cannot yet be generalised across broader neurodivergent populations or cultural contexts.

Finally, there are technical and implementation constraints. Shared VR environments present challenges related to processing performance and maintaining consistency of shared experiences. For example, disparities in audio filtering between users may affect team-based communication, shared attention, and collaborative task performance.

Future work will prioritise larger, more diverse, and longitudinal studies to better capture variability and changes in neurodivergent sensory experiences over time. More work is needed to explore collaborative implications of tailored audio in multiplayer VR environments, including how differing audio filters influence communication, presence and group dynamics. An important implication of this work is the need to further develop participatory co-design methodologies, enabling neurodivergent users to shape not only featured requirements but also VR interface design and system behaviour.

7. Conclusion

Mass-casualty incidents are increasing in frequency and complexity, placing greater demands on medical responders under intense cognitive and psychologically challenging conditions. As immersive VR platforms are increasingly utilised in medical education to prepare students for future clinical practice, the need for equitable and accessible design becomes critical. The literature underscores that despite their pedagogical potential, many VR learning environments fail to adequately account for neurodiversity and sensory accessibility, thereby risking exclusion of some learners from training opportunities (Shaw et al., 2023, Dahlstrom-Hakki et al., 2024, Giroux and Pélissier-Simard, 2021, Schmidt et al., 2023, Creed et al., 2024).

These limitations in VR learning environments may perpetuate a culture of non-disclosure, as unaddressed sensory or cognitive barriers can discourage learners from engaging or accessing appropriate supports (Green et al., 2025). Addressing these issues within VR-based training is particularly important given the sensory intensity and time-pressured nature of such simulations. Increasing awareness of neurodivergence, alongside the development of inclusive VR design, has the potential to create more accessible, supportive, and immersive learning environments.

Formative qualitative data generated through participatory design activities and lived experience informed iterative design refinement throughout the development process, ensuring that accessibility considerations are embedded from the outset rather than applied retrospectively. However, neurodivergent users have highly individual and context-dependent sensory needs, making universal design inherently complex. Approaches such as user-adjustable parametric EQ and neurodivergent-informed audio profiles could represent future directions for creating VR learning environments that are not only accessible but adapted to individual sensory preferences.

This study supports a paradigm shift in both medical education and VR design, moving beyond standardised approaches toward more inclusive, flexible, and neurodivergent-affirming practices. By integrating a multipronged approach that combines UDL principles with empirical evidence and lived-experience insights through participatory co-design, this work contributes to a more nuanced and responsive understanding of accessibility.

Ethics Declaration

This study is covered by the ethics approval obtained from the UNSW Human Research Ethics Committees (HC230349 - The Use of Media and Immersive Technologies in Higher Education).

AI Declaration

This manuscript was copyedited and proofread using AI-assisted (Microsoft Co-pilot) tools in accordance with IPEd guidelines. All intellectual content and argumentation are the authors own.

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