MONASH UNIVERSITY

FACULTY OF INFORMATION TECHNOLOGY

MASTER OF ARTIFICIAL INTELLIGENCE

FIT5128 ASSIGNMENT 3: THESIS

Investigating Situated Visualisations of EHR Data in Immersive Spaces for ICU Nurse Handover

---

Author:
Jun Yong Khor

Supervisors:
Dr. Jiazhuo 'Joe' Liu
Dr. Agnes Haryanto

Student ID:
32429975

Semester 1, 2026 (Word Count : 7771)

Contents

Part 1

General Literature Review

Monash University

Faculty of Information Technology

Master of YOUR DEGREE

Literature Review

HandovAR: A Framework of Collaborative ICU Nurse Handover System via Mixed Reality

Author:
Jun Yong Khor

Student ID:
32429975

Supervisors:
Jiazhou 'Joe' Liu
Agnes Haryanto

Semester 2, 2025

MONASH University

Contents

1 Introduction

Nurse handover is a vital process in healthcare. It is the formal transfer of patient information, responsibility, and accountability between nurses during shift changes. Effective handovers ensure continuity of care, improve patient safety, and reduce the risk of medical errors. On the other hand, ineffective handovers can harm patient outcomes. According to the Joint Commission (2017), failed handovers are a significant factor contributing to adverse events and potential patient harm, often due to communication issues between the sender and receiver. More recently, the Joint Commission (2024) reported that approximately 67% of communication errors are associated with handovers and the transfer of patient care responsibility. This highlights the urgent need to enhance handover practices.

In intensive care units (ICUs), the stakes are even higher. The medical complexity of ICU patients requires more intensive and specialised care, making the handover process much more complicated than in standard healthcare settings (Kowitlawakul et al., 2015). Traditionally, handovers occur through verbal communication or written notes (Pothier et al., 2005). While verbal handovers are common in emergency and critical care due to their efficiency, they are also vulnerable to errors. Particularly, cognitive overload, especially when dealing with large amounts of critical data, often leads to information loss and omissions (Festila & Müller, 2021). Additionally, the time-pressured environment of ICUs requires the handovers to be completed quickly, as the nurses may need to attend to clinical events urgently (Hoskote et al., 2016). These challenges reveal a persistent issue: how can nurses effectively exchange the handover information while maintaining a low cognitive load without compromising critical details?

Emerging technologies may provide a solution. Mixed reality (MR) overlays digital information onto the physical environment, showing promise in transforming healthcare practices (Gansohr et al., 2022; Albrecht-Gansohr et al., 2024; Ricci et al., 2025). By enabling interactive and situated visualisation and providing a unified space for information transfer, MR could potentially improve the completeness, cognitive load, and efficiency of ICU handovers. This highlights the potential of mixed reality as a promising solution to provide an innovative approach to the longstanding problems of traditional nurse handover practices. However, there is still limited guidance on how nurses should utilise this technology for collaborative handovers. Questions persist about how MR can best support communication among nurses, facilitate the transfer of critical data, and integrate seamlessly into the fast-paced work of the ICU. To address this issue, this research will explore design opportunities for a collaborative ICU nurse handover system using mixed reality. The goal is to create guidelines to ensure both usability and clinical effectiveness.

This literature review aims to investigate how mixed reality and related design principles can be leveraged to enhance communication and information transfer in ICU nurse handovers. In the substantive literature review section, the first subsection will introduce the concepts of MR technology and examine current applications within the context of medical environments. The second subsection will analyze common practices in nurse handover and factors affecting information-sharing effectiveness. The third subsection will explore information design principles for immersive technology in healthcare, particularly how AR and MR can reduce cognitive load through integrated information presentation. The next part of this literature review is the research project plan which outlines the expected timeline to implement the MR technology and evaluation of the prototype with ICU nurses based on the feedback collected. Following the research plan are the ethical considerations for the application of MR in ICU settings. This part will focus on ensuring the research process is in compliance with Monash ethics standards such as de-identifying the data collected to protect the privacy of the nurses and minimizing the harm to all stakeholders involved. At the end of this literature review, comprehensive insights and findings will be presented, focusing on how the MR prototype can be designed to help revolutionize the current ICU handover process, ensuring information sharing efficiency and minimizing the cognitive loads on ICU nurses. Ultimately, this literature review will contribute to the continuous development of the MR implementation for ICU nurse handover.

2 Substantive Literature Review

This section provides a comprehensive exploration of literature relevant to the research questions. The first subsection explores the application of mixed reality in medical environments, establishing foundational concepts and current implementations. The second subsection will analyse common nursing handover practices and factors affecting information transfer effectiveness. The third subsection examines some potential design principles for immersive technologies to improve information sharing effectiveness with low cognitive loads.

2.1 Application of Mixed Reality in Medical Environment

2.1.1 Background of Immersive Technology

According to the explanation provided by Lo et al. (2025), virtual reality(VR), augmented reality(AR) and mixed reality(MR) fall under the umbrella term extended reality (XR), with their main difference being the level of immersion. From an immersive spectrum perspective, AR sits at the leftmost end as the least immersive, since it only overlays digital elements onto the real world. VR sits at the other end, providing full immersion into a completely virtual environment. MR occupies the middle ground, as it blends both real and virtual environments such that digital objects can be interacted with and augmented by Ricci et al. (2025) have identified some usage of immersive technology in medical education. For example, VR has been effectively applied to train technical skills, such as laparoscopic procedures, while AR has supported haemorrhage management training by enhancing situational awareness and decision-making. In this section, relevant AR, VR literatures will be included and discussed as these technologies share fundamental principles that still provide informative insights towards the MR development.

2.1.2 Immersive Technologies for Patient Care and Clinical Training

Albrecht-Gansohr et al. (2024) demonstrates the potential of applying AR technology in wound management through a user-centered design approach grounded in Self-Determination Theory (SDT), aim to bring positive effects on the user's well-being through satisfaction of three key psychological needs: autonomy, competence, and connectedness. In their qualitative study, they obtained positive results on the general experiences of using AR glasses and it enhanced both autonomy (through ability to position windows and customize their digital workspace freely as illustrated in Figure 1(b)) and competence (such as reference images that support accurate wound assessment and observed changes in wound from past observation) in nurses. A key insight

Figure 1: AR prototype on supporting nurses in wound management (Albrecht-Gansohr et al., 2024). (a) Patient's status overview (b) Windows is movable according to nurse preference. (c) Documentation interfaces for pain score (d) Additional window to record wound stage

from Albrecht-Gansohr et al. (2024) is that immersive technologies must be designed to satisfy users' psychological needs—particularly autonomy and competence. In other words, the nurses should perceive themselves as capable and in control of using the technology, willingly to pick up the technology because they truly believe it will improve their performance, rather than obligated to adopt them due to external factors.

Gansohr et al. (2022) provide another evidence for reducing cognitive load and emotional exhaustion among nurses by applying AR to support medication dispensation (as shown in Figure 2). One key advantage of AR is being hands-free with continuous visual access, allowing nurses to perform tasks simultaneously while using the AR glasses. Their study found that experienced nurses prefer to have an overview of all medications for efficiency, while novice nurses prefer to have step-by-step guidance to prevent errors. Apart from that, they also found that nurses appreciated AR's space efficiency which makes it more convenient than PC, in cases where space is limited and documentation is distributed in multiple places. Additionally, Tharun et al. (2025) have applied similar strategies using audio cue, visual guides and instructions for teaching proper tourniquet application, a critical skill for controlling severe bleeding that can increase survival rates in trauma situations (as shown in Figure 3). Through their usability study, all 20 participants without medical experience successfully complete the training while reporting low cognitive workload and minimal simulation sickness.

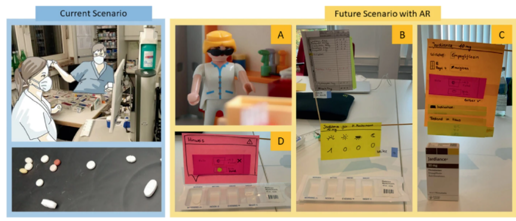

Figure 2: Low-fidelity AR application on medical dispensaries (Gansohr et al., 2022). (A) Context of using AR in medical dispensaries, (B) Dispense medication according to prescription, (C) Displays important information about medicine usage (D) Display checklists for error recognition

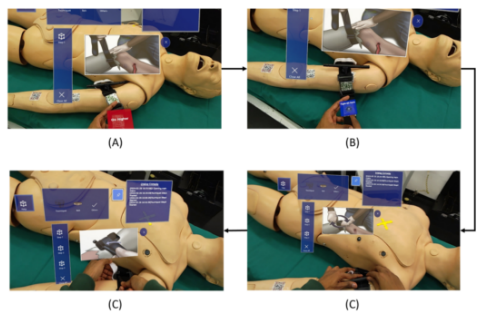

Figure 3: Snapshot of the AR application guiding participants step by step in learning to use tourniquet properly (Krishant Tharun et al., 2025)

These findings are highly relevant to the design of MR in ICU handover, where similar visual cues and step-by-step guidance could reduce cognitive overload and help novice nurses feel more confident while reducing errors in patient care tasks.

2.2 Common Practices in Nurse Handover and Factors Affecting Information Sharing Effectiveness

Multiple nurse handover methods exist, ranging from purely verbal exchanges and verbal communication with note-taking, to pre-prepared sheets supplemented by verbal clarification (Pothier et al., 2005). Additionally, many hospitals have also adopted checklists and structured communication techniques, such as SBAR (Situation, Background, Assessment, and Recommendation), a communication framework designed to facilitate effective information sharing by creating a common information structure (Kowitlawakul et al., 2015). According to South Western Sydney Local Health District (2016), the correct nurse handover follows a structured process where outgoing staff transfer essential patient information to incoming staff, including patient identification, relevant medical history, current medications, recent observations, complications, last checks and medications, and agreed care plan. In ICU settings, handovers become particularly complex due to the volume and criticality of patient data. Laboratory results, medication charts and radiological investigations are but a few critical pieces of information stored in electronic health records (EHRs) and nurses often rely on their memory and paper records during the handover process (Kowitlawakul et al., 2015). This section will analyze current nurse handover practices by examining how duration impacts effectiveness, exploring the communication patterns that facilitate or hinder information transfer, and identifying nurses' preferences for information display and organization.

2.2.1 Relationship between Duration of Handover and Handover Effectiveness

Based on Carroll et al. (2012), they observed that the general nurse handover is conducted verbally with an average time of 5.4 minutes per patient, while (Hoskote et al., 2016) observed that average time for nurse handover in ICU settings is about 2.5 minutes per patient. This shorter duration in ICUs appears counter-intuitive as the complexity of data is higher, yet reflects the time pressures within the ICU environments. ICU Nurses in Hoskote et al.'s study revealed that if the handover is too long, they would most likely risk leaving the handover incomplete as they may be called to attend acute clinical events without notice. Although the nurse handover duration observation cannot be generalized to other hospitals, the relationship between nurse handover duration and effectiveness still reveals some important patterns. Carroll et al. (2012) found that shorter nurse handover time is directly related to the high effectiveness ratings from outgoing nurses. This correlation is further explained by Kowitlawakul et al. (2015), who found out that longer handovers do not correlate with better effectiveness. Rather, they notice that longer handovers can relate to higher distractions, reducing nurses' ability to focus on critical information and ultimately decreasing the nurse handover efficiency.

Drawing attention to improving handover efficiency, these findings suggest that MR technology development should help nurses focus on critical details during handover by minimizing distractions. Structured approaches like checklists and SBAR have proven successful in minimizing disruptions, allowing nurses to focus on handovers and prevent task-switching behaviors that compromise handover quality, which benefits the cognitive loads of the nurses (Cornell et al., 2013). While these methods may not shorten the overall nurse handover duration, they enable nurses to focus more on important information. The findings provide important insights for user interface (UI) design in MR development. The success of structured framework in maintaining focus suggests that MR interfaces should incorporate a similar approach to ensure comprehensive coverage of critical information during nurse handovers.

2.2.2 Communication Dynamics During Handovers

As mentioned earlier, the main challenges in handover stem from communication breakdowns. Carroll et al. (2012) identified a fundamental tension arising from contradictory communication styles between incoming and outgoing nurses. Incoming nurses prefer to follow principles of effective communication such as maintaining eye contact, nodding, and smiling, while outgoing nurses prefer the opposite. Outgoing nurses prefer less eye contact, fewer questions, and shorter handover durations. If an incoming nurse asks more questions, the outgoing nurse often feels that there are some problems with their handover. Apart from that, outgoing nurses often omit information when they assume that incoming nurses already know the patient. As a consequence, these reports become inadequately brief and raise more questions from incoming nurses, creating a negative communication spiral between the two parties.

This pattern is supported by Manias and Street (2000), who observed that nurses dislike being questioned as they interpret these questions as examinations of competence and critiques of their clinical practices. From the study, some nurses even express fear and anxiety towards the question because they are afraid about exposing what they may not know. Similarly, nurse coordinator (outgoing nurse) will not provide detailed information when a patient has been an inpatient for several days and often split attention among patients which results in some patients receiving only brief summaries. A nurse who had not worked in recent shifts mentioned that this is particularly a disadvantage to them as they cannot understand the patient's current status due to inadequate handover information. Concerningly, the researchers found that these brief handovers are sometimes used by nurse coordinators to judge incoming nurses' nursing competency.

2.2.3 Nurses Preference View of Information via Immersive Technology

Nurses prefer receiving patient information through a centralized, easily accessible format rather than having to gather fragmented data from multiple sources. As noted by Albrecht-Gansohr et al. (2024), nurses favour positioning information displays where they can maintain simultaneous visual access to both patients and their data, minimizing the disruption and effort required. Where the nurse does not have to turn away to look at patient data, and turn back to the patients when they need to speak (as shown in Figure 4). This preference for consolidated information is observed from the inefficiencies created by current fragmented systems, where medical providers often create individual notes and to-do lists, which leads to duplication of effort across team members (Hoskote et al., 2016). Furthermore, nurses value aggregated data that has been contextualized from multiple sources compared with raw and unprocessed information. For instance, Festila and Müller (2021) found that even though the electronic medical records(EMR) contain all detailed care instructions, the nurses still request for additional oral information from other healthcare providers. This additional information allows the nurse to contextualize the patient information using their own judgement and expertise which ultimately increases the handover's value in terms of credibility.

2.3 Design Principles for Information Sharing with Immersive Technology in Healthcare

2.3.1 Overview on AR in Relation with Cognitive Loads and Performance

Research by Buchner et al. (2022), who systematically reviewed 58 studies on AR's cognitive impact, demonstrates that 56.2% of studies reported reduced cognitive load with higher performance when using AR, particularly for procedural tasks. According to their findings, AR's effectiveness

Figure 4: Nurse prefer to have both patient and patient's information in the same view (Albrecht-Gansohr et al., 2024)

stems from its ability to enable integrated information presentation, which prevents split-attention effects that occur when users must divide their attention between multiple information sources. Although the study emphasizes that these results should be interpreted carefully and does not guarantee consistent outcomes across all applications, AR may still prove useful for procedural tasks in medical settings such as patient handover where nurses have standardised protocols in patient care. Several design implementations from the research are worth noting, including the importance of visual cues and proper instructional design in optimizing AR effectiveness.

2.3.2 Notable Design Interface that Enhance Information Sharing Effectiveness with Low Cognitive Loads

Supporting research from Thomas et al. (2017), who developed a large display interactive visualization system for ICU handovers, addresses similar information integration challenges. Their study revealed that current ICU care transition teams face significant difficulties in gathering and integrating multivariate data from multiple sources and sharing aggregated information meaningfully with others. To address these challenges, they developed a large display visualization to support collaboration among healthcare teams. The large display promotes shared cognition by allowing all team members to view the same information simultaneously, facilitating data-oriented conversations and eliminating the context switching that frequently occurs with smaller screens. Due to typically low visual literacy among healthcare teams, the researchers deliberately display statistics with simpler visual encodings to make these representations easier to interpret with less confusion and en-

Figure 5: Large Display with Interactive Visualization of Data (Thomas et al., 2017)

able fast comparison. Pothier et al. (2005) found that medical history and demographics are less likely to experience data loss because they are easier to visualize and may be used more to create a mental picture of patients than other data types. This suggests that effective visualisation of critical data could potentially support information retention during the handover process. Another notable finding from Thomoas et al. (2017) is that the healthcare teams appreciated the annotation features that allowed them to record their observations directly onto the display. This preference for interactive, contextual information input suggests that immersive technologies like MR could potentially deliver similar collaborative benefits in nursing handover scenarios by overlaying information directly in the nurse's field of view.

3 Summary of the State of the Art

Nurse handover remains a critical challenge in ICU care, where communication breakdowns, inadequate information, and cognitive overloads of nurses can compromise patient safety. While there exist structured frameworks such as SBAR to improve the quality of the nurse handover, persistent challenges remain, rising from the tension between outgoing nurses who prefer brief, uninterrupted conversation and incoming nurses who seek more detailed questioning (Carroll et al., 2012). The dynamics often create frustration and compromise the quality of information transfer. At the same time, immersive technologies have demonstrated their potential in related healthcare tasks such as wound management and medication dispensation.

In the wound management tasks, Albrecht-Gansohr et al. (2024) has shown benefits of immersive technology such as hands-free operations which allow nurses to multitask, and most importantly, increase nurse competency in their task. Systematical reviews from Buchner et al., (2021) further confirms that over half of AR-based interventions improved performance without evidence of cognitive overload, improved information processing though AR's capability to integrate data into a single view, and prevented the user from splitting attention to look for additional information in different locations. Apart from that, Thomas et al., (2017) has provided promising results from using a large display that integrates data with interactive visualization to foster shared cognition about healthcare team and promote meaningful data oriented conversation. Although these remain confined to large display systems the concepts and design ideas behind the implementation can can be transferable to immersive technologies

A significant gap exists in the integration of advances from mixed reality technology for nurse handover. Current MR applications in healthcare are very limited and mainly focus primarily on single tasks while nurse handover remains to suffer from fragmented information spread across multiple locations and lack of contextualized data (Hoskote et al., 2016; Festila & Müller, 2021). This gap presents an exciting opportunity to apply MR technology specifically designed for ICU nurse handovers. By enabling nurses to directly interact with the integrated patient information, they can make faster comparisons, foster shared cognition on the data and facilitate meaningful data-oriented conversations during the handover. Most importantly, it ensures that critical patient information is transferred accurately and efficiently to support the high quality of patient care. The nurse could also potentially benefit from reduced cognitive overload and shorten handover duration as the incoming nurse is less likely to raise questions when all information is presented to them accurately.

4 Research Project Plan

This research aims to enhance collaboration between ICU nurses during handover through the development of a MR application. The proposed MR application will build upon the findings from recent studies identified in the literature review, specifically focusing on supporting effective information sharing and managing cognitive load during ICU nurse handovers. This section will detail the comprehensive project plan, including the project timeline, research questions and aims, research design and methodology, data collection procedures, experimental design, and ethical considerations regarding data privacy.

4.1 Project Timeline

Semester 2, 2025

Task 1: Literature review (Week 1 to Week 8) This task involves systematically reviewing existing MR applications in healthcare, analysing current ICU nurse handover processes and communication challenges, and identifying opportunities where MR technology can improve information sharing and reduce cognitive load during handovers.

Task 2: Initial Prototype Development (Week 9 to Week 12) Focuses on developing an initial MR prototype using Unity visionOS for Apple Vision Pro, based on literature review findings. Key activities include acquiring necessary MR development skills, setting implementation milestones for each core functionalities. Week 12 will be focusing on submitting interim video presentations to Moodle.

Semester 1,2026

Task 3: Continue Development of Prototype and Design Interview Questions. (Week 1 to Week 6) Continuing with the Unity visionOS prototype development and conducting demonstrations with supervisors to ensure correct features implementations. Upon completion of the prototype, design and finalise questionnaire focusing on usability, cognitive loads assessment, and information sharing effectiveness for user evaluation.

Task 4: Prototype Evaluation (Week 7 to Week 9) This phase involves conducting user evaluation with ICU nurses to test the prototype's effectiveness using the finalized questionnaires from Task 3. Ethical approval from Monash University Human Research Ethics Committee (MUHREC) and written informed consent of participants will be obtained prior to conducting any interviews or user testing sessions.

Task 5: Feedback Evaluation and Report (Week 10 to Week 12) Analyse the results obtained from ICU nurses to evaluate whether the MR prototype successfully improved handover quality and achieved the research objectives. The final thesis report will be written, detailing each key findings throughout the research process, drawing conclusions, and identifying limitations and recommendations for future research. The report will then be prepared for submission, concluding the research.

4.2 Research Question and Aims

ICU nurse handovers are often chaotic and error-prone. When nurses change shifts, they struggle to share important patient information effectively due to several factors identified in the literature review, including time pressure to minimize handover duration, communication breakdowns, and extensive critical data that causes cognitive overload and results in missed information. To address these challenges, this research centres on the key question: How can we design effective user interface and interaction techniques in Mixed Reality environments that support ICU nurses in sharing information and managing cognitive load during handovers? To address the key question comprehensively, three sub-questions will be explored:

1. How can Mixed Reality be designed to affect the information exchange and cognitive load during ICU handovers?

2. In what ways can Mixed Reality be applied to improve the communication between outgoing and incoming ICU nurses?

3. What usability and design factors most influence ICU nurses' acceptance and adoption of Mixed Reality for handovers?

4.3 Research Methodology and Design

4.3.1 Research Methodology

This research adopts Design Science Research Methodology, which Delport et al. (2024) described as "knowing through building". This paradigm focused on creation of knowledge through research output that addresses real-world problems. This approach is particularly suited for this study because it supports concurrent artifact development while ensuring the insights generated through design, reflections, or analysis can further contribute to the theoretical knowledge. The methodology proceeds with six iterative phases: problem identification and motivation, defining objectives of a solution, design and development, demonstration, evaluation, and communication. Its iterative nature provides maximum flexibility and enables continuous refinement in future study, which is well aligned with the application of immersive technology to enhance information sharing and reduce cognitive loads during nurse handovers.

4.3.2 Research Design

Inspired by Albrecht-Gansohr et al. (2024), this research seeks to form insights with respect to how technology can be designed to support basic psychological needs and ultimately adhere to the "ACS Code of Ethics" to strive to enhance the quality of life for those who will be affected by the MR prototype (ACS, 2023). The MR application design will be grounded in the Motivation, Engagement and Thriving in Use Experience (METUX) model proposed by Peters et al. (2018), ensuring the final product enhances handover efficiency while reducing cognitive load on ICU nurses. The METUX model is based on Self-Determination Theory, providing a framework for designing technology that addresses autonomy, competence, and relatedness across different spheres of user experience (as shown in Figure 6). This includes adoption, interface, task, behavior, and overall life impact. This multi-sphere approach comes along with some evaluation measures to ensure that technology was designed in a way that not just succeeds at the interface level but actually improves the intended behavior and contributes to user wellbeing, addressing the common problem where the prototype may be engaging to use but fail to support their underlying purpose. Using an example from Peters et al. (2018), a user might find a fitness app engaging but this does not result in willingness to exercise. Following prototype development, user evaluation will be conducted through structured interviews and testing sessions with ICU nurses. The evaluation protocol will follow the standardized handover procedure outlined in the training video published by South Western Sydney Local Health District (2016). The testing sessions will involve one outgoing nurse and two incoming nurses, following the established handover sequence: patient identification, relevant medical history, current medications, recent observations, complications, last checks and medications, and agreed care plan. Throughout the handover progress, the MR prototype will be integrated to assess the effectiveness of the MR application in information sharing and cognitive loads of the ICU nurses.

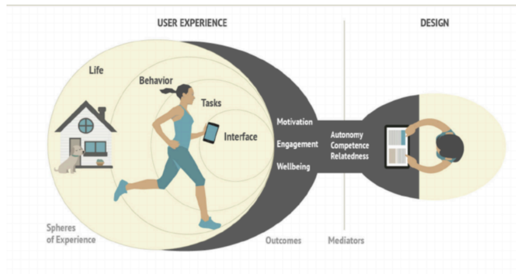

Figure 6: Mutex model on designing technology that satisfies the three basic psychological needs to positive user experience outcomes across different spheres of experience (Peters et al., 2018)

4.4 Data Collection

Several types of data will be collected in the research. This includes questionnaire data like using NASA-TLX cognitive loads assessments, user's acceptance and trust for psychological measurement of autonomy and competency. Next, behavioural data like "agreement" between incoming and outgoing nurses will be used to assess the accuracy of information shared between the nurses, where both outgoing and incoming nurses must independently identify the same piece of key information being passed over (Hoskote et al.,2016).

4.5 Ethics and Data Privacy

This research will ensure adherence to Monash University's ethics standards and guidelines for human research. Approval from the Monash Human Research Ethics Committee (HREC) will be obtained before any data collection, ensuring that nurses' rights, privacy, and data security are prioritized. Data analysis and evaluation will commence only after ethical approval is granted. Informed written consent will be obtained from all participants, who retain the right to withdraw without explanation at any time. Participant safety and comfort will be prioritized, with protocols in place to minimize disruption to clinical workflows and address any technical issues with the MR system. Data will be stored securely and retained for 15 years after completion of research according to Monash University's data retention policy.

5 Conclusion

This literature review has established the foundational concepts of mixed reality (MR) and examined its current applications in healthcare, particularly in supporting patient care tasks by reducing cognitive load and enhancing performance. The review demonstrates that while MR technology shows promise for reducing cognitive load in healthcare tasks, there remains a significant gap in research specifically addressing MR applications for communication breakdowns, information sharing inefficiencies, and cognitive load issues in nursing handovers. The review also highlighted the complexities of ICU nurse handover, where communication effectiveness depends heavily on well-structured information exchange but is often undermined by conflicting communication styles and inadequate information transfer. From these insights, several design principles have been identified, emphasizing that MR should centralize critical information to minimize split-attention effects and support nurses' decision-making processes.

References

ACS. (2023, March 14). Code of Professional Ethics. Retrieved from www.acs.org.au website: https://www.acs.org.au/memberships/professional-ethics-conduct-and-complaints.html

Albrecht-Gansohr, C., Timm, L., Eimler, S. C., & Geisler, S. (2024). An Augmented Reality Application for Wound Management: Enhancing Nurses' Autonomy, Competence and Connectedness. *Virtual Worlds*, *3*(2), 208–229. https://doi.org/10.3390/virtualworlds3020011

Buchner, J., Buntins, K., & Kerres, M. (2021). The impact of augmented reality on cognitive load and performance: A systematic review. *Journal of Computer Assisted Learning*, *38*(1), 285–303. https://doi.org/10.1111/jcal.12617

Carroll, J. S., Williams, M., & Gallivan, T. M. (2012). The ins and outs of change of shift handoffs between nurses: a communication challenge. *BMJ Quality & Safety*, *21*(7), 586–593. https://doi.org/10.1136/bmjqs-2011-000614

Cornell, P., Gervis, M. T., Yates, L., & Vardaman, J. M. (2013). Improving Shift Report Focus and Consistency With the Situation, Background, Assessment, Recommendation Protocol. *JONA: The Journal of Nursing Administration*, *43*(7/8), 422–428. https://doi.org/10.1097/nna.0b013e31829d6303

Delport, P. M. J., Solms, R. V., & Gerber, M. (2024). Methodological Guidelines for Design Science Research. *Procedia Computer Science*, *237*, 195–203. https://doi.org/10.1016/j.procs.2024.05.096

Festila, M. S., & Müller, S. D. (2021). Information handoffs in critical care and their implications for information quality: A socio-technical network approach. *Journal of Biomedical Informatics*, *122*, 103914. https://doi.org/10.1016/j.jbi.2021.103914

Gansohr, C., Thelen, M. B., Geisler, S., & Eimler, S. C. (2022). Supporting Hospital Nurses During Medication Dispensation with Augmented Reality – A Participatory Approach. *Communications in Computer and Information Science*, 35–42. https://doi.org/10.1007/978-3-031-06394-7_6

Hoskote, S. S., Racedo Africano, C. J., Braun, A. B., O'Horo, J. C., Sevilla Berrios, R. A., Loftsgard, T. O., … Smischney, N. J. (2016). Improving the Quality of

Handoffs in Patient Care Between Critical Care Providers in the Intensive Care Unit. *American Journal of Medical Quality*, *32*(4), 376–383. https://doi.org/10.1177/1062860616654758

Joint Commission. (2024). Reducing handoff communication failures and inequities in healthcare. Retrieved from Jointcommission.org website: https://www.jointcommission.org/en-us/knowledge-library/news/2024-08-reducing-handoff-communication-failures-and-inequities-in-healthcare

Kowitlawakul, Y., Leong, B. S. H., Lua, A., Aroos, R., Wong, J. J., Koh, N., … Mukhopadhyay, A. (2015). Observation of handover process in an intensive care unit (ICU): barriers and quality improvement strategy. *International Journal for Quality in Health Care*, *27*(2). https://doi.org/10.1093/intqhc/mzv002

Lo, M., Wünsche, B. C., Manfredini, M., & Hooper, S. (2025). (Semi-)immersive digital placemaking: A systematic literature review on augmented reality, virtual reality, and mixed reality applications in placemaking. *Convergence the International Journal of Research into New Media Technologies*, *0*(0), 1–21. https://doi.org/10.1177/13548565251372796

Manias, E., & Street, A. (2000). The handover: uncovering the hidden practices of nurses. *Intensive and Critical Care Nursing*, *16*(6), 373–383. https://doi.org/10.1054/iccn.2000.1523

Peters, D., Calvo, R. A., & Ryan, R. M. (2018). Designing for Motivation, Engagement and Wellbeing in Digital Experience. *Frontiers in Psychology*, *9*(797). https://doi.org/10.3389/fpsyg.2018.00797

Pothier, D., Monteiro, P., Mooktiar, M., & Shaw, A. (2005). Pilot study to show the loss of important data in nursing handover. *British Journal of Nursing (Mark Allen Publishing)*, *14*(20), 1090–1093. https://doi.org/10.12968/bjon.2005.14.20.20053

Ricci, S., Penza, V., & Neri, F. (2025). Editorial: VR, AR, MR in healthcare: the role of immersive technologies in medical training. *PubMed*, *7*, 1669899–1669899. https://doi.org/10.3389/fdgth.2025.1669899

Sentinel Event Alert 58: Inadequate hand-off communication. (2017). Jointcommission.org. Retrieved September 15, 2025, from https://www.jointcommission.org/en-us/knowledge-library/newsletters/sentinel-event-alert/issue-58

South Western Sydney Local Health District. (2016). Correct Clinical Handover. Retrieved from https://www.youtube.com/watch?v=Rn6r_hFWP0Q

Tharun, K., Drogo, A., Recchiuto, C. T., & Ricci, S. (2025). Augmented Reality for extremity hemorrhage training: a usability study. *Frontiers in Digital Health*, *6*. https://doi.org/10.3389/fdgth.2024.1479544

Thomas, M. M., Kannampallil, T., Abraham, J., & G. Elisabeta Marai. (2017). Echo: A large display interactive visualization of ICU data for effective care handoffs. *Europe PMC (PubMed Central)*, 47–54. https://doi.org/10.1109/vahc.2017.8387500

Part 2

Research Paper

Investigating Situated Visualisations of EHR Data in Immersive Spaces for ICU Nurse Handover

Student: Jun Yong Khor
Student ID: 32429975
Monash University
Melbourne, VIC, Australia
jkho0038@student.monash.edu

Supervisor: Dr. Joe Liu
Department of Human Centred Computing
Monash University
Melbourne, VIC, Australia
joe.liu@monash.edu

Co-Supervisor: Dr. Agnes Haryanto
Department of Human Centred Computing
Monash University
Melbourne, VIC, Australia
Agnes.Haryanto@monash.edu

Abstract

Intensive Care Unit (ICU) nurse handovers involve the exchange of highly complex, multivariate patient information in a fast-paced environment prone to unpredictable emergency events [9]. Although the Electronic Health Record(EHR) contains comprehensive patient details, it is highly time-consuming to navigate. ICU nurses spends approximately 22% of their time with EHR and a survey found that many of them use EHR mainly to verify patient information [14] [12]. Within the EHR, critical data is frequently fragmented across separate tabs and flow sheets, creating data silos rather than a single integrated interface that effectively supports data comparison and cognitive decision-making [12]. Therefore, this paper aims to evaluate the potential of Mixed Reality (MR) devices to serve as a single, border-less source of integrated information to assist the handover process givens its potentials and promising results in medical training [17] [13] [4]. Two prototypes were developed for this study: a unified dashboard and a spatially anchored immersive space, designed to test their efficacy in supporting the handover process. To evaluate the effectiveness of these prototypes, the study employs a user-centred methodology, incorporating expert feedback and practical testing by PhD nursing students with active handover experience.

Keywords

Mixed reality, ICU nurse handover, electronic health records, situated visualisation

1 Introduction

Nurse handover is a critical process in healthcare that involves the formal transfer of patient information, clinical responsibility, and accountability between nurses during shift changes. In intensive care units (ICUs), this process is particularly important because patients are often medically complex, unstable, and dependent on continuous monitoring and timely decision-making. Effective handover supports continuity of care by enabling incoming nurses to understand the patient's current condition, recent changes, risks, and ongoing priorities. However, ineffective handover can compromise patient safety when essential information is omitted, misunderstood, or not communicated in a timely manner. In Australia, approximately seven million clinical handovers occur in hospitals each year [2], and Ye et al. found that 15.4% of emergency department handovers lacked required information, which contributes to adverse events later [22]. Communication breakdown has also been identified as a major contributor to failed handovers [20]. These risks are amplified in ICU environments, where nurses must communicate complex and rapidly changing patient information while remaining prepared to respond to acute clinical events [9].

ICU handover is not only a transfer of clinical facts, but also a collaborative sense-making process in which outgoing and incoming nurses develop a shared understanding of the patient. During handover, nurses must communicate and interpret multiple categories of information, including vital sign trends, medication changes, laboratory results, ventilation status, infusions, care plans, risks, and pending tasks. This requires incoming nurses to rapidly construct a mental model of the patient's current situation and anticipate potential risk and care priorities. However, this process can be affected by time pressure, interruptions, differences in communication style, and cognitive workload. Previous work has shown that verbal handover can suffer from information degradation and omission, especially when large amounts of patient information must be digested under pressure [8]. At the same time, verbal and face-to-face handover remains valuable because it allows questions and clarification tailored to the local clinical context [16]. Therefore, technologies designed for handover should support, rather than replace, the collaborative communication that occurs between nurses.

Electronic health records (EHRs) play an important role in supporting handover because they serve as the central repository for all of patient data, tracking the patient's entire medical history in detail. However, current EHR use does not fully resolve the challenges of ICU handover. A systematic review found that inpatient nurses spend approximately 22% of their workday interacting with the EHR, indicating that EHR use forms a substantial part of nursing workflow [14]. However, the presence of patient data in the EHR does not necessarily mean that the information is easy to synthesise during handover. Lindroth et al. found that ICU nurses commonly use the EHR during handover to verify verbal information, while majority of surveyed ICU nurses reported that current EHR visualisation was insufficient [12]. A key limitation to this is because patient data are often distributed across separate tabs, flow sheets, and systems rather than integrated into a single coherent view [12]. As a result, nurses may need to navigate multiple sources to reconstruct the patient's condition, which increase their cognitive workload. This demonstrates the necessity for nurse-centred interfaces designed to alleviate cognitive load and eliminate interface fragmentation, providing a more streamlined way to synthesise critical clinical data.

Mixed reality (MR) offers a promising direction for addressing these challenges because it can present digital patient information within the physical clinical environment. Unlike conventional EHR interfaces that require users to navigate through multiple tabs and screens, an MR handover system could provide a shared visual space where outgoing and incoming nurses review critical information together, clarify uncertainties, and develop a common understanding of the patient's condition. MR may support handover by enabling situated visualisation, spatial organisation of information, and collaborative interaction. However, MR should not be assumed to automatically reduce cognitive workload. Prior research on augmented and mixed reality suggests that immersive interfaces can reduce cognitive load when information is well integrated, but they can also introduce additional perceptual and interaction demands if poorly designed [4]. Therefore, the potential value of MR for ICU nurse handover depends not only on the technology itself, but also on how clinical information is spatially organised and presented.

This study investigates the potential of MR as an assistive tool for ICU nurse handover, with a focus on how spatial interface design may affect information sharing, retention, and cognitive load for incoming nurses. Specifically, this research compares two MR design conditions. The first is a unified dashboard that consolidates key clinical data into a single spatial view to reduce context switching and fragmented navigation. The second is a spatially anchored immersive layout that embeds information within the surrounding environment to support situated understanding and spatial memory. These two conditions represent different design strategies for supporting the same handover task: one priorities information consolidation, while the other priorities contextual and spatial organisation. The aim of this study is not to replace traditional verbal handover, but to examine the potential of MR spatial interfaces to assist incoming nurses in integrating complex patient information more effectively while maintaining manageable cognitive load.

By evaluating these two MR design conditions, this study addresses the gap between existing handover support tools and the need for collaborative, nurse-centred interfaces that help incoming ICU nurses form a clear and memorable understanding of the patient. The study is guided by the following research questions:

- **RQ1 (Information Retention):** How do different MR spatial interface configurations (Unified Dashboard vs. Spatially Anchored Space) affect an incoming nurse's retention and recall of critical ICU handover data?
- **RQ2 (Cognitive Load):** How do these MR spatial interface configurations affect incoming nurses' perceived cognitive load during ICU handover?
- **RQ3 (Design Considerations):** What user experience and spatial design considerations emerge from practitioner feedback to guide the design of future collaborative MR handover systems?

Through this investigation, the thesis contributes to human-computer interaction and healthcare interface design by exploring how MR can be designed to support collaborative sense-making in ICU handover. The findings may inform future development of spatial clinical interfaces that improve information visibility, support shared understanding, and reduce unnecessary cognitive burden during high-risk transitions of care.

2 Related Work

2.1 Design Requirements for Nurse Handover Support

Prior studies suggest that clinical handover tools should satisfy several design requirements to support nurses in highly acute environments. First, they should support the construction of a rapid patient overview. ICU handovers involve multiple forms of time-sensitive and interdependent patient data, including vital sign trends, laboratory results, infusions, ventilator settings, medications, and pending care tasks [9]. From a nursing perspective, Lindroth et al. identify several "big picture'" data elements that direct care ICU nurses consider important at the start of a shift, including haemodynamic, continuous IV medications, laboratory results, mechanical circulatory support, code status, and ventilation status [12]. This suggests that handover tools should not simply reproduce isolated EHR values, but should help incoming nurses form an integrated understanding of the patient's current condition and care priorities.

Second, handover tools should preserve collaborative communication. Handover is not merely a transfer of raw data, but a social and interpretive process through which outgoing and incoming nurses develop shared understanding. Carroll et al. found that incoming and outgoing nurses may have different expectations of a good handover: incoming nurses often value conversation, questions, and eye contact, while outgoing nurses may prefer to deliver their report with fewer interruptions [5]. Similarly, Randell et al. argue that technology should support rather than replace verbal handover, because face-to-face communication allows clarification, contextual explanation, and flexible access to additional information when needed [16]. Therefore, a technological intervention for ICU handover should function as a shared reference point for discussion, rather than as a substitute for nurse-to-nurse communication.

Third, handover tools should reduce fragmentation across information sources. EHRs are already central to nursing work, with inpatient nurses spending a substantial proportion of their workday interacting with EHR systems [14]. However, Lindroth et al. found that ICU nurses often use the EHR during handover mainly to verify verbal information, while many reported that current EHR visualisation was insufficient [12]. Relevant clinical information may be distributed across tabs, flow sheets, notes, and bedside monitoring systems, requiring nurses to search across multiple locations and mentally integrate the information. Similar issues have been reported in dashboard research outside the ICU context, where Swartz et al. argue that EHR systems can fragment clinically related information across separate modules, increasing the cognitive effort required to form a holistic understanding of the patient [19]. Festila and Müller further show that information quality in critical care is shaped by interactions between human actors and information and communication technologies(ICTs), suggesting that patient information may lose accuracy, completeness, or clarity as it moves through both verbal communication and digital systems [8]. This indicates a need for handover tools that integrate clinically related information into a more coherent visual structure.

Finally, handover tools should manage cognitive load. ICU handover already involves high intrinsic cognitive load because nurses must interpret complex and interdependent clinical data. Poor interface design may add extraneous cognitive load when nurses are required to switch between screens, remember disconnected values, and manually reconstruct relationships between data. Cognitive Load Theory suggests that presenting related information in spatially and temporally integrated formats can reduce unnecessary processing demands [4]. However, immersive technologies can also introduce new perceptual and interaction demands if poorly designed [4]. For this reason, the design of MR-supported handover should not only aim to increase information visibility, but also examine how different spatial configurations affect information retention, cognitive load, and collaborative communication.

2.2 Visual and Mixed Reality Interfaces for Clinical Sense-Making

Prior work on clinical visualisation provides one possible direction for support information integration. Koch et al. suggest that integrated displays may improve ICU nurses' situation awareness by reducing the need to gather information from multiple monitoring devices [10]. Their observations highlights that ICU nurses perform an average of 23.4 tasks per hour, yet the data required for these tasks is frequently inaccessible, difficult to view at a distance, or distributed across separate systems. This supports the idea that handover interfaces should not merely make raw data available, but also organise information in ways that actively reduce cognitive effort to help nurses perceive, understand, and anticipate changes in the patient's current condition [10].

Large and shared visual displays have also been explored as tools for supporting ICU care transitions. To address the need for data consolidation, researchers have designed large-display interactive visualisations that help clinicians find, filter, organise, and annotate patient information during handoffs [21]. The display was designed in a way that support both overview and detail views, enabling anomaly detection and data comparison across a shared screen. This is relevant to handover because it treats visualisation not only as a way to display data, but also as a shared workspace for collaborative decision-making. However, because the large displays remain limited by their physical location, clinicians conducting bedside handovers may still need to visually move between the distant display, the patient, and other colleagues. This limitation motivates the interest in "situated visualisation", exploring how immersive technologies might bridge the gaps between digital data and the physical world. Situated visualisation addresses some limitations of the fixed displays by anchoring digital information directly to relevant real-world locations or physical referents [3]. MR may therefore provide a design space for placing clinical information in ways that are more closely aligned with the collaborative context of an ICU handover. Recent healthcare research suggest that immersive interfaces is capable of support nursing tasks when they designed around the clinical user needs. For example, Albrecht-Gansohr et al. [1] developed an application using HoloLens 2 to support wound care management. Their findings suggest that immersive technology can support nurses' autonomy when users are able to adapt the digital workspace to their preferences, such as freely repositioning digital information within the physical environment. The study also indicates that immediate access to relevant patient information can support nurses' perceived competence during care tasks. However, the same study also highlights an important design risk. Immersive device may affect interpersonal connectedness because the device may obstruct eye contact and make gesture-based interaction appear socially awkward to other observers [1]. This is particularly relevant to ICU handover, where communication, eye contact, and shared attention between outgoing and incoming nurses remain important to overcome the standard handover challenges [5]. Therefore, MR interfaces must have a careful design to ensure interface supports these collaborative purposes, rather than disrupting collaborative communication. The potential benefits of MR must also be considered alongside its inherent cognitive demands. Buchner et al. found mixed evidence regarding immersive technologies and cognitive load; while some studies suggest that it can reduce cognitive load by integrating information with the physical environment, others show that it may be distracting and even cognitively demanding when it presents too much information or requires unfamiliar interaction [4]. This points to the importance of spatial interface design when applying MR to ICU handover. A unified dashboard may reduce fragmentation by consolidating information into one view, while a spatially anchored layout may support situated understanding by distributing information in relation to the clinical environment. However, either approach could also introduce new demands, interaction complexity, or divided attention if poorly designed. Therefore, this study evaluates MR as an assistive tool for ICU nurse handover, examining whether MR-supported handover can reduce the cognitive load, improve information retention, and support perceived usefulness, by comparing whether a unified dashboard or a spatially anchored layout better supports these outcomes.

3 Methodology and System Design

This chapter describes the methodology, prototype design, study procedure, measures, and ethical considerations used to evaluate the proposed MR system for ICU nurse handover. Specifically, the study compared two MR interface configurations

(1) **Unified Dashboard:** Integrates all critical handover information into a single virtual dashboard.
(2) **Spatially Anchored Situated Visualisations:** Distributes the same information dynamically around a simulated ICU bed according to contextual relevance (e.g., medication details near the IV pole, patient diagnosis above the patient).

3.1 Research Methodology

This research adopts a Design Science Research (DSR) methodology. DSR is commonly used in information systems research to address real-world problems through the design and evaluation of technological artefacts [6]. This methodology was selected because the study aims not only to understand challenges in ICU nurse handover, but also to develop and evaluate an MR artefact that may support collaborative communication, information retention, and cognitive load management. The research process was structured into three stages. First, literature on ICU handover, EHR visualisation limitations, situated visualisation, and immersive healthcare technologies was reviewed to identify design requirements. Second, a functional MR prototype was developed for the Apple Vision Pro. To align the artefact with clinical handover practice, patient information in the prototype was structured using the ISBAR framework: Identify, Situation, Background, Assessment, and Recommendation [11] [2]. Third, the prototype was evaluated through a controlled user study in which the participants, who were practising nurses or PhD nursing students, completed simulated ICU handover tasks using both the Unified Dashboard and Spatially Anchored Situated Visualisations. The evaluation primarily focused on qualitative feedback regarding user experience, perceived usefulness, and spatial design considerations. Information retention and perceived cognitive load were also collected as descriptive indicators to contextualise participant responses.

3.2 Design Rationale

The prototype's information was structured around the ISBAR framework: Identify, Situation, Background, Assessment, and Recommendation. ISBAR was selected because it is commonly used in Australian clinical handover practice and provides a standardised structure for communicating complex patient information [2]. In this project, ISBAR was used both as the communication framework for the handover script and as the information architecture for organising patient data within the MR interfaces.

The design was informed by local health district training materials, including a South Western Sydney Local Health District ISBAR training video [18] and a Western Health EMR-related handover video [7], alongside empirical studies of ICU handover information needs. These materials helped the student researcher, who did not have a clinical background, understand the expected structure, content, and sequencing of clinical handover. Kowitlawakul et al.'s observational study of ICU handovers was particularly relevant, as it identified patient background, current condition, completed tasks or interventions, abnormal findings, and actions related to abnormal findings as among the most frequently included information during ICU handover [11]. Similarly, Lindroth et al. found that direct care ICU nurses prioritise hemodynamics, continuous intravenous medications, laboratory results, code status, and ventilation status at the start of a shift [12]. These findings guided the selection of information categories included in the prototype. Consequently, the prototype included patient identification, diagnosis, acuity, allergies, code status, relevant background, vital signs, active infusions, lines and access, abnormal laboratory results, treatment plan, escalation concerns, and systems assessment. These categories were intended to provide an overview of the patient's current status while also supporting rapid access to clinically significant details.

The interface was designed to prioritise clinically significant information and support rapid sense-making. Rather than presenting raw patient data alone, the prototype emphasised abnormal values, recent trends, and care priorities. Prior work on clinical dashboards and ICU handoff visualisation suggests that integrated displays can help clinicians organise fragmented information, identify anomalies, and compare relevant data during care transitions [19, 21]. Therefore, abnormal values in the prototype were colour-coded and paired with trend indicators where appropriate, allowing users to identify critical changes on whether the patient was improving or deteriorating.

Finally, to ensure the clinical plausibility of the research artefact, the simulated handover scenarios were generated with the assistance of artificial intelligence and subsequently reviewed by a healthcare expert before the user study. This expert review accessed whether the scenarios covered the main types of information commonly transferred during ICU nurse handover, thereby improving the clinical relevance and clarity of the scenarios before participant testing.

3.3 Prototype and Interface Design

The MR prototype was developed for the Apple Vision Pro to support simulated ICU nurse handover using two interface configurations: a Unified Dashboard and Spatially Anchored Situated Visualisations. Both conditions presented the same categories of ISBAR-based handover information, including patient identification, current diagnosis, acuity, allergies, code status, relevant background, vital signs, active infusions, lines and access, abnormal laboratory results, treatment plan, escalation concerns, and systems assessment. The two conditions differed primarily in how this information was spatially organised and accessed within the MR environment.

The purpose of designing two interface configurations was to explore how different spatial arrangements may influence handover experience. The Unified Dashboard represented a centralised approach, where information was consolidated into a single large virtual display. In contrast, the Spatially Anchored Situated Visualisations represented a distributed approach, where information panels were placed around a simulated ICU bed according to contextual relevance. This allowed the study to compare a compact overview layout with environmentally situated layout.

3.3.1 Unified Dashboard. The Unified Dashboard condition presented the handover information within a single large virtual dashboard positioned in front of the participant, as shown in Figure 1. The dashboard used a modular card-based layout, where each panel represented a different category of patient information. For example, the patient header provided the patient's name, diagnosis, bed location, medical record number, ICU day, acuity status, allergy status, code status, and overall clinical trend. Other panels displayed vital signs, relevant background, active infusions, lines and access, abnormal laboratory results, treatment plan, escalation concerns, and systems assessment from head to toe.

This condition was designed to support rapid overview and comparison across information categories. By presenting the major handover components in one visual field, the dashboard aimed to reduce the need for spatial searching and allow participants to quickly connect related information. For example, abnormal laboratory results could be viewed alongside active infusions and treatment priorities, supporting interpretation of how the patient's current condition related to ongoing treatment plan.

Visual hierarchy was used to help participants identify clinically important information. Abnormal values were colour-coded, and trend indicators were included where appropriate to show whether values were improving, worsening, or remaining stable. Vital signs

Figure 1: Unified Dashboard condition showing consolidated ICU handover information in a single virtual display.

were displayed with simple trend graphs covering the previous 12 hours, allowing participants to interpret recent changes from last shifts rather than relying only on raw numerical values. The dashboard therefore functioned as a centralised handover summary, intended to provide a "big picture" overview of the patient at the start of a shift.

3.3.2 Spatially Anchored Situated Visualisations. The Spatially Anchored Situated Visualisations condition presented the same handover information as separate virtual panels distributed around a simulated ICU bed, as shown in Figure 2. Instead of placing all critical information in a single dashboard, this condition explored a distributed approach by positioning panels near relevant physical locations in the ICU environment. For example, active infusion information was placed near the IV pole, while patient background and systems assessment information were arranged around the patient space. By anchoring virtual information near these contextual references, the interface aimed to make the handover environment more spatially meaningful.

This design was informed by the idea that spatially located information may support memory by allowing users to associate information with locations in the surrounding environment. Ponce et al. found that MR can be effective for short-term spatial memory assessment, with users transferring object-location information into a mental map of the environment [15]. In the context of ICU handover, this suggests that placing information near relevant bedside objects may help users form spatial associations between clinical data and the care environment. Consequently, this condition was designed to explore whether spatially situated information could support an incoming nurse's contextual understanding of the patient's overall status.

However, distributing information across the environment may also introduce cognitive trade-offs. While spatial placement may support contextual memory and immersion, participants may need to look around the environment to locate different information categories, increasing visual search effort and divided attention. Prior research on AR and cognitive load has shown that immersive interfaces can reduce cognitive load in some contexts, but may also become distracting or cognitively demanding when too much information is presented at once [4]. This condition therefore allowed

Figure 2: Spatially Anchored Situated Visualisations condition showing handover panels distributed around the simulated ICU bed.

the study to examine not only the potential benefits of situated visualisation, but also whether distributing information across the environment could increase navigation demands during handover.

3.3.3 Interaction and Collaboration Features. Both interface conditions supported basic MR interactions, including moving, repositioning, expanding, and collapsing information panels. These interactions allowed participants to adjust the interface according to viewing comfort and personal preference. Previous literature suggests that allowing nurses to flexibly configure their digital workspace can increase their sense of autonomy and competence [1]. In the Unified Dashboard condition, participants could reposition the order of each panel to match their preferred communication style. For example, if a participant preferred to begin the handover by discussing abnormal laboratory results, they could move the corresponding section to an earlier position in the dashboard. Similarly, in the Spatially Anchored Situated Visualisations condition, participants could interact with individual panels distributed around the ICU environment.

Expandable and collapsible panels were included to support progressive disclosure of information. This allowed the interface to show high-level categories while still allowing participants to access more detailed information when needed. For example, a collapsed panel could show only the section title, while an expanded panel displayed the full handover content. This interaction design aimed to reduce unnecessary visual clutter while preserving access to clinically relevant details.

The prototype also included a SharePlay-based collaboration feature that allowed users to share their view with each other, supporting awareness of what the other user was viewing or doing during the handover. Users could also see each other's spatial persona during the handover, as shown in Figures 3 and 4. This feature was included because head-mounted MR devices may obstruct natural face-to-face cues, such as direct eye contact and facial visibility, which have been identified as potential barriers to interpersonal connectedness and trust in nursing contexts [1]. Since handover is a relational activity where nonverbal behaviours and eye contact can contribute to shared understanding [5], the spatial persona was intended to mitigate the visual obstruction caused by the headset and support a sense of co-presence and shared attention between the incoming and outgoing nurse.

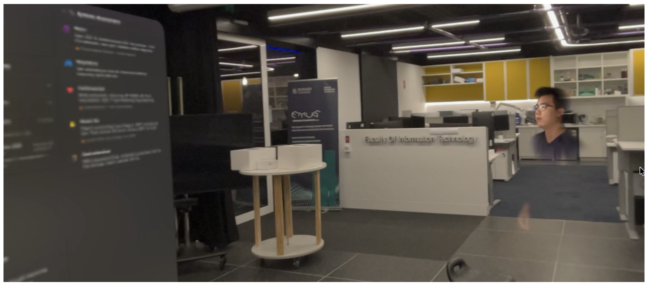

Figure 3: SharePlay collaboration in the dashboard condition, showing the spatial persona of another user in the shared MR environment.

Figure 4: SharePlay collaboration in the spatially anchored ICU condition, showing co-presence between users during the simulated handover.

The collaboration feature was particularly relevant to the handover context because handovers are not merely individual information retrieval tasks, but also collaborative communication activities. Rather than replacing verbal communication, the prototype was designed to function as a shared reference point to support conversation around patient data. The combination of shared visual information, movable panels, and spatial persona was therefore intended to explore how MR could support both information presentation and the collaborative, relational interactions necessary for effective handover.

3.4 Participants

Two participants took part in the study. Participants were eligible if they were practising registered nurses or PhD nursing students with prior exposure to patient handover practices through clinical work, coursework, simulation training, lectures, or clinical placement. Participants with no prior exposure to patient handover were excluded, as the study required participants to interpret clinical information within a simulated ICU handover context.

Participants were recruited from Monash Clayton Campus through direct contact methods. Due to the small sample size, the study was designed to examine initial interactions and present the data in an exploratory way, rather than serving as a statistical test of hypotheses. The aim was to gather preliminary feedback on how clinically informed users experienced the two MR interface configurations, with particular attention to information presentation, perceived cognitive load, and design considerations for future MR handover systems.

Basic demographic and background information was collected, including age range, gender, participant role, familiarity with the ISBAR framework, prior clinical handover experience, and prior experience with immersive technologies. These data were used to contextualise participants' feedback in later section.

Before participation, participants were informed of safety considerations related to using the Apple Vision Pro headset. Individuals with a history of seizures, severe motion sickness, migraine, serious heart conditions, or pregnancy were advised not to participate or to consult a general practitioner before taking part.

3.5 Study Procedure

The study was conducted face-to-face at the Embodied Visualisation Group, Monash University Clayton Campus. Each session took approximately 90 minutes and was completed using the Apple Vision Pro headset. Before beginning the study tasks, participants were provided with the explanatory statement, asked to provide informed consent, and asked to complete a short demographic questionnaire.

After consent was obtained, participants completed a 10 to 15 minute for device calibration and familiarisation trial with the Apple Vision Pro. This allowed them to practise basic interaction techniques, including viewing, selecting, moving, and interacting with virtual interface elements. This familiarisation step was to reduce the influence of headset unfamiliarity to the handover experience later.

Participants then completed simulated ICU handover tasks under two interface conditions: the Unified Dashboard and the Spatially Anchored Situated Visualisations. The study involved two rounds. In the first round, participants acted as the Incoming Nurse and received handover information using both interface conditions. After each condition, they completed an information retention questionnaire. A 10-minute break was then provided to reduce fatigue.

In the second round, participants acted as the Outgoing Nurse and delivered handover information using both interface conditions. After completing the handover tasks, participants completed the NASA-TLX workload assessment and a post-task questionnaire about their experience of the two interfaces. The session concluded with a short debrief, where participants were invited to provide additional comments on their experience and overall preference between the two MR configurations.

3.6 Measures and Data Collection

The study collected information retention responses, workload ratings, interface usefulness ratings, and open-ended feedback. Given the small sample size, these measures were used descriptively to support qualitative interpretation rather than to test for statistical significance.

Information retention was assessed using five open-ended recall questions completed after each interface condition during the incoming nurse round. The questions asked participants to recall the patient's primary reason for admission, main treatment or intervention, known allergies, the vital sign showing the most significant change over the previous 12 hours, and the main pending task or action required for the next shift. As two participants each completed two interface conditions, four information retention responses were collected. These responses were reviewed interpretively by comparing participants' answers with the intended scenario information and noting whether responses were accurate, partially accurate, or incomplete.

Perceived workload was collected using NASA-TLX questions on a seven-point scale. Participants rated mental demand, physical demand, time pressure, perceived success, effort, and frustration or stress for each interface condition. These ratings were not analysed statistically, but were used to describe each participant's perceived workload across the Unified Dashboard and Spatially Anchored Situated Visualisations.

The post-task questionnaire collected five-point Likert ratings on whether each interface helped participants deliver and receive handover information. Participants were also asked to indicate their overall preferred interface and provide open-ended comments on the two interfaces and the experiment experience. These written comments, together with debrief observations, were used to identify design considerations relating to information organisation, spatial layout, usability, collaboration, and perceived suitability for ICU handover.

3.7 Ethical Considerations

The study was approved by the Monash University Human Research Ethics Committee (Project ID: 51851; see Appendix A). Before participation, participants were provided with an explanatory statement and gave written consent. Participation was voluntary, and participants could stop the study at any time. All collected data were de-identified using participant codes and stored securely in accordance with Monash University data management requirements.

4 Findings

This section presents the findings from the exploratory pilot evaluation. As the study involved two participants, the results are reported descriptively rather than statistically. The findings focus on participant background, information retention, perceived workload, interface usefulness ratings, and qualitative feedback on the two MR interface configurations.

4.1 Participant Overview

Both participants were PhD nursing students who were also practising nurses. Both participants reported being extremely familiar with the ISBAR framework. However, their handover experience differed. P1 routinely performed clinical handovers and had actively given and received handovers in practice. P2 had performed handovers under supervision a few times. Neither participant had prior experience using immersive technologies. The background shows that both participants had substantial clinical and handover knowledge, but were unfamiliar with immersive technologies.

4.2 Information Retention

Information retention was assessed after each interface condition during the incoming nurse round. Case 1 and Case 3 were completed using the unified dashboard, while Case 2 and Case 4 were completed using the spatially anchored situated visualisations. Because each task used a different simulated patient case, the retention outcomes should not be interpreted as a direct measure of comparative interface effectiveness. Instead, the responses are merely used to descriptively to examine the types of information participants retained, approximated, or omitted after each condition. The full simulated handover scenarios are provided in Appendix B.

Overall, both participants retained the broad clinical picture and several major care priorities after using the MR interfaces. P1 demonstrated strong recall across both cases, correctly identifying the primary clinical context, key treatments, and several pending actions. However, some details were incomplete. For example, in Case 1, P1 incorrectly described all five vital signs as trending upward, although one vital sign was trending downward, and missed to report another pending task which was to follow up sputum culture and sensitivity results.

P2 also retained the general clinical direction of both cases, but showed more difficulty recalling exact diagnostic labels, medication names, target ranges, and complete task lists. In Case 3, P2 described the admission reason as "acute renal failure" rather than "severe diabetic ketoacidosis with acute kidney injury Stage 3". In Case 4, P2 described the admission reason as "post-operative hepatic" rather than "orthotopic liver transplant" and recalled the Tacrolimus target range as 8–10 rather than 8–12.

Taken together, these findings suggest that the MR handover interfaces may supported recall of the broad patient situation and major care priorities, while exact terminology, numerical values, and secondary pending tasks remained more vulnerable to omission or approximation. This should be interpreted cautiously, as the evaluation relied on unaided recall, whereas one participant noted that she would normally use write some persona notes during handover.

4.3 Cognitive Load and Interface Usefulness Ratings

The NASA-TLX ratings showed mixed patterns across the two participants. P1 rated the dashboard as less demanding across the workload dimensions, including mental demand, physical demand, time pressure, effort, and frustration. By contrast, P1 rated the spatially anchored situated visualisations as more demanding, particularly in relation to mental demand, physical demand, time pressure, and effort. This suggests that, for P1, the spatially distributed interface required more navigation and active management during handover. Interestingly, P1 still selected the spatially anchored situated visualisations as the preferred interface overall. This indicates that preference did not map directly onto lower workload. Instead, P1 appeared to value the spatial interface despite its higher effort and reported that it is easier to manage based on the flow of handover.

P2 showed the opposite workload pattern. P2 reported the same level of mental demand across both interfaces, but rated the spatially anchored situated visualisations as less physically demanding, less rushed, less effortful, and less frustrating than the dashboard. P2 also rated the spatially anchored situated visualisations higher for both delivering and receiving handover.

Overall, the workload ratings do not indicate a consistent reduction in cognitive load for either interface across both participants. However, both participants selected the spatially anchored situated visualisations as their preferred interface, suggesting that perceived value may have been influenced by factors beyond workload alone, including handover flow and situated visualisation.

4.4 Qualitative Feedback on the Interfaces design

Qualitative feedback suggested that the two interface configurations offered different strengths. The unified dashboard was valued for its readability. P1 described it as "easier to read" with "no disruption", suggesting that the centralised layout supported quick overview and reduced the need to look around and hunt for information across the environment. However, P2 described the dashboard as "okay but a little bit difficult to navigate", indicating that the dashboard's effectiveness depends on whether users can easily locate and follow the information presented in the sequence required for handover.

In contrast, both participants preferred the spatially anchored situated visualisations overall. P1 reported that this condition was easier to manage according to the flow of handover and suggested that it could help students to mentally prepare for real ICU handovers. P2 similarly stated that the spatial interface made it easier to access previous information, compare abnormal values with the treatment plan, and organise information according to personal preference. P2 also reported that spatial placement helped memorisation because she could remember where she placed digital information.

These comments suggest that spatial organisation may support handover flow and recall by allowing participants to associate information with locations in the immersive environment. However, this should be interpreted as a design insight rather than evidence that spatial visualisation improved retention, due to the small sample size of the study.

4.5 Summary of Findings

The findings suggest that both participants could retain the broad clinical picture and identify major care priorities after using the MR handover interfaces, although exact clinical details and secondary pending tasks were sometimes incomplete or approximated. The workload ratings showed mixed patterns: P1 experienced the spatially anchored condition as more demanding, while P2 experienced it as less demanding than the dashboard. Despite this difference, both participants preferred the spatially anchored situated visualisations overall. Qualitative feedback suggests that the dashboard supported readability and reduced disruption, while the spatially anchored condition better supported handover flow and recall through spatial memory. At the same time, interaction difficulty, headset comfort, and the need for deeper case-specific clinical information remain important design considerations for future MR handover systems.

5 Discussion and Limitations

This study explored how two mixed reality (MR) interface configurations, a unified dashboard and spatially anchored situated visualisations, could support simulated ICU nurse handover. The evaluation was conducted as an exploratory pilot with two participants from clinical background. Therefore, the findings should not be generalise as evidence for interface effectiveness. Instead, they provide early design insights into how MR spatial organisation may affect information retention, perceived workload, and user experience during handover.

5.1 Interpretation of Findings

The retention findings suggest that both participants were able to recall the broad clinical situation and several major care priorities after using the MR handover interfaces. Across the simulated cases, participants generally retained the main patient context, important treatments, and some pending tasks for the next shift. This indicates that both MR configurations were able to present enough information for participants to form a general understanding of the patient situation.

However, the findings also show that exact clinical terminology, numerical values, target ranges, and secondary pending tasks were more vulnerable to omission or approximation. For example, P2 recalled the general liver-related context of Case 4 but did not identify the exact diagnosis as orthotopic liver transplant, and recalled the Tacrolimus target range as 8–10 rather than 8–12. Similarly, some pending tasks were omitted across cases. This suggests that MR visualisation alone may not be sufficient to ensure accurate unaided recall of detailed clinical information. In real handover practice, nurses may use written notes, existing electronic records, or verbal clarification to support [5, 11]. Therefore, the retention results should be understood as evidence of what participants could recall under the study conditions, rather than as a direct measure for real-world handover.

The findings also suggest that information retention during handover should not be understood only as remembering facts. In ICU handover, the incoming nurse needs to understand the patient's overall condition, recognise abnormal or changing values, and identify priorities for ongoing care. The participants' responses suggest that the MR interfaces may support this broader situational understanding, even though precise details may still require additional support such as having additional individual interface for note taking for incoming nurse. Future MR systems may therefore need to combine visual overview with mechanisms for quickly checking exact values, pending tasks, and treatment plans.

5.2 Spatial Organisation and Handover Flow

The evaluation suggests a design tension between spatial organisation and interaction effort. Although the spatially anchored visualisations were preferred overall, this preference did not consistently correspond with lower workload ratings. This indicates that the value of spatial anchoring may not be simply workload reduction, but rather its ability to support how users structure, revisit, and make sense of handover information.

For future MR handover design, spatial placement should be used selectively rather than as a default presentation strategy. If too much information is distributed across the environment, the interface may increase navigation demands and divide attention. However, when spatial placement aligns with clinical meaning or handover flow, it may provide useful memory cues and support situated understanding, allowing critical information to remain visible while context-specific information can be accessed spatially when needed.

5.3 Implications for MR Handover Training and Design

Participant feedback suggests that MR handover systems may have value not only as handover support tools, but also as training environments. P1 suggested that a more realistic ICU case could help students mentally prepare for real handover practice, especially if the simulation included realistic environmental factors such as equipment sounds and interruptions.

The use of MR may allow students or less experienced nurses to practise receiving and delivering handover in a immersive way. A spatially organised MR environment could help learners associate clinical information with locations, equipment, and patient care activities. However, this would require more realistic scenarios and stronger clinical validation. The current prototype used simulated cases and simplified interface structures, so it should be viewed as an early exploratory artefact rather than a complete training system.

Importantly, the role of MR should not be framed as replacing existing electronic medical record systems. Existing clinical systems remain the authoritative source of patient data. Because current EHRs often isolate data into fragmented modules, nurses must put significant cognitive effort to manually retrieve, hold in working memory, and integrate this information [10, 19]. MR may be used as a supplementary handover tool that extracts and reorganises selected, relevant information into a shared spatial environment. In this role, MR can actively support communication between nurses and synthesise complex data to form a more holistic understanding of the patient's condition.

5.4 Limitations

This study has several limitations. First, the evaluation involved only two participants. Recruitment was constrained by the inclusion criteria, which required participants to be either a practising nurses or PhD nursing students with prior handover exposure. As a result, the findings cannot be generalised to the wider population of ICU nurses. The results should instead be interpreted as exploratory design insights.

Second, both participants were clinically knowledgeable but had no prior experience with immersive technologies. This may have influenced their workload ratings and interaction experience. Some perceived effort may have resulted from unfamiliarity with the Apple Vision Pro and MR interaction techniques rather than from the interface.

Third, the study used simulated handover cases rather than real ICU patient data. This was necessary because realistic ICU data are sensitive, difficult to access, and not publicly available with sufficient detail. As a result, the scenarios may not fully capture the complexity and depth of real ICU handover. Publicly available examples of ICU handover workflows and EMR interface designs are also limited, which constrained how closely the prototype could reflect real clinical systems.

Fourth, each interface condition used a different simulated patient case. Therefore, retention outcomes cannot be interpreted as a direct comparison of the unified dashboard and spatially anchored situated visualisations. Differences in recall may have been influenced by case content and complexity.

Fifth, the retention task relied on unaided recall. In real clinical practice, nurses may use notes, verbal clarification, and the EMR to confirm information during and after handover. Therefore, some omissions or approximations in the study may reflect the nature of the evaluation task rather than a failure of the interface alone.

Sixth, the student researcher's background was primarily technical rather than clinical. This may have influenced the clinical depth, information and realism of the prototype. This limitation was only partially mitigated through literature review. However, future work would benefit from closer co-design with ICU nurses or researcher with clinical background throughout the design process.

Finally, the scope of the study was constrained by the timeline of a master's minor thesis. The project required completion of the literature review, MR application design and implementation, ethics application, participant recruitment, user evaluation, analysis, and thesis writing within a limited period. This affected the scale of recruitment, the number of design iterations, and the depth of ICU case validation that could be conducted.

5.5 Future Work

Future work should evaluate the MR handover system with a larger size and more diverse sample of nurses. A counterbalanced study design using equivalent patient cases would allow stronger comparison between the unified dashboard and spatially anchored situated visualisations. Further development should focus on increasing the clinical realism of the handover scenarios. This includes using more in-depth ICU cases and simulating realistic environmental interruptions such as alarms and equipment noise. Based on participant feedback, future work could also explore MR handover as a training tool for nursing students.

6 Conclusion

ICU nurse handover is a critical communication process that requires nurses to understand, prioritise, and transfer complex patient information under time pressure. Existing electronic health record systems contain large amounts of patient data, but the information required for handover may still be distributed across multiple views and require active synthesis by nurses. This thesis explored whether MR could be served as a supplementary handover tool.

The project designed and implemented two MR interface configurations for simulated ICU nurse handover: a unified dashboard and spatially anchored situated visualisations. Both interfaces were structured around the ISBAR communication framework and presented key patient information such as patient background, vital signs, active infusions, lines and access, abnormal laboratory values, treatment plans, escalation information, and system assessment. The unified dashboard presented this information in a centralised layout, while the spatially anchored condition distributed information around the virtual clinical environment.

An exploratory evaluation was conducted with two participants who were PhD nursing students and practising nurses. The findings suggest that both MR configurations supported recall of the broad clinical situation and several important care priorities. However, exact clinical terminology, numerical values, target ranges, and secondary pending tasks were more vulnerable to omission or approximation. This indicates that MR visualisation may support general situational understanding, but additional support and design is still needed for precise recall of detailed clinical information.

The results also showed that both participants preferred the spatially anchored situated visualisations overall, even though the workload ratings did not consistently favour this condition. This suggests that the perceived value of spatial anchoring may not simply results in reducing workload. Instead, spatially situated visualisation may support handover flow, information revisiting, and memory cues when information is placed meaningfully within the environment. However, at the same time, it may also introduce additional navigation and management demands. Therefore, future MR handover systems should use spatial placement selectively rather than distributing information purely because immersive space is available.

This thesis contributes an early exploratory prototype and evaluation of MR-supported ICU nurse handover. The study does not provide generalisable evidence of clinical effectiveness due to the small sample size of participants. However, it identifies some useful design considerations for future work. Future research should continue investigating MR as both a handover support tool and a training environment for nursing students. More clinically realistic scenarios could help determine whether MR can better prepare users for the cognitive and communicative demands of real ICU handover. Overall, this project suggests that MR has potential for supporting collaborative handover, but its value depends strongly on careful design and integration with existing nursing workflows.

References

[1] Carina Albrecht-Gansohr, Lara Timm, Sabrina C. Eimler, and Stefan Geisler. 2024. An Augmented Reality Application for Wound Management: Enhancing Nurses' Autonomy, Competence and Connectedness. *Virtual Worlds* 3, 2 (2024), 208–229. doi:10.3390/virtualworlds3020011

[2] Australian Commission on Safety and Quality in Health Care. 2010. The OSSIE Guide to Clinical Handover Improvement. https://www.safetyandquality.gov.au/resources/ossie-guide-clinical-handover-improvement Accessed: 2026-02-26.

[3] Nathalie Bressa, Henrik Korsgaard, Aurélien Tabard, Steven Houben, and Jo Vermeulen. 2022. What's the Situation with Situated Visualization? A Survey and Perspectives on Situatedness. *IEEE Transactions on Visualization and Computer Graphics* 28, 1 (2022), 107–117. doi:10.1109/TVCG.2021.3114835

[4] Josef Buchner, Katja Buntins, and Michael Kerres. 2021. The Impact of Augmented Reality on Cognitive Load and Performance: A Systematic Review. *Journal of Computer Assisted Learning* 38, 1 (2021), 285–303. doi:10.1111/jcal.12617

[5] John S. Carroll, Michele Williams, and Theresa M. Gallivan. 2012. The ins and outs of change of shift handoffs between nurses: a communication challenge. *BMJ Quality & Safety* 21, 7 (2012), 586–593. doi:10.1136/bmjqs-2011-000614

[6] Petrus Delport, Rossouw Solms, and Mariana Gerber. 2024. Methodological Guidelines for Design Science Research. *Procedia Computer Science* 237 (2024), 195–203. doi:10.1016/j.procs.2024.05.096

[7] Digital Health Training Team. 2025. Nursing Handover using the EMR. Vimeo video. https://vimeo.com/1114750317 Accessed: March 25, 2026.

[8] Maria Stefania Festila and Sune Dueholm Müller. 2021. Information Handoffs in Critical Care and Their Implications for Information Quality: A Socio-technical Network Approach. *Journal of Biomedical Informatics* 122 (2021), 103914. doi:10.1016/j.jbi.2021.103914

[9] Sumedh S. Hoskote, Carlos J. Racedo Africano, Andrea B. Braun, John C. O'Horo, Ronaldo A. Sevilla Berrios, Theodore O. Loftsgard, Kimberly M. Bryant, Vivek N. Iyer, and Nathan J. Smischney. 2017. Improving the Quality of Handoffs in Patient Care Between Critical Care Providers in the Intensive Care Unit. *American Journal of Medical Quality* 32 (2017), 376–383. doi:10.1177/1062860616654758

[10] Sven H. Koch, Charlene Weir, Maral Haar, Nancy Staggers, Jim Agutter, Matthias Görges, and Dwayne Westenskow. 2012. Intensive care unit nurses' information needs and recommendations for integrated displays to improve nurses' situation awareness. *Journal of the American Medical Informatics Association* 19, 4 (2012), 583–590. doi:10.1136/amiajnl-2011-000678 PMID: 22437074; PMCID: PMC3384123.

[11] Yanika Kowitlawakul, Benjamin S. H. Leong, Adela Lua, Rana Aroos, Jie Jun Wong, Nicola Koh, Nicholette Goh, Kay Choong See, Jason Phua, and Amartya Mukhopadhyay. 2015. Observation of handover process in an intensive care unit (ICU): barriers and quality improvement strategy. *International Journal for Quality in Health Care* 27, 2 (2015), 99–104. doi:10.1093/intqhc/mzv002 PMID: 25644706.

[12] Heidi L. Lindroth, Yuliya Pinevich, Amelia K. Barwise, Sawsan Fathma, Daniel Diedrich, Brian W. Pickering, and Vitaly Herasevich. 2022. Information and Data Visualization Needs among Direct Care Nurses in the Intensive Care Unit. *Applied Clinical Informatics* 13, 05 (2022), 1207–1213. doi:10.1055/s-0042-1758735

[13] Marvin Mergen, Norbert Graf, and Marcel Meyerheim. 2024. Reviewing the Current State of Virtual Reality Integration in Medical Education: A Scoping Review. *BMC Medical Education* 24, 1 (2024), 788. doi:10.1186/s12909-024-05777-5

[14] Yuliya Pinevich, Kathryn J. Clark, Andrew M. Harrison, Brian W. Pickering, and Vitaly Herasevich. 2021. Interaction Time with Electronic Health Records: A Systematic Review. *Applied Clinical Informatics* 12, 04 (2021), 788–799. doi:10.1055/s-0041-1733909

[15] David Ponce, Magdalena Mendez-Lopez, Javier Lluch, and M.-Carmen Juan. 2024. Extended Reality to Assess Short-Term Spatial Memory—A Comparative Study of Mixed Reality, Augmented Reality, and Virtual Reality. *Sensors* 24, 24 (2024), 7938. doi:10.3390/s24247938

[16] Rebecca Randell, Stephanie Wilson, and Peter Woodward. 2011. The Importance of the Verbal Shift Handover Report: A Multi-site Case Study. *International Journal of Medical Informatics* 80, 11 (2011), 803–812. doi:10.1016/j.ijmedinf.2011.08.006

[17] Serena Ricci, Veronica Penza, and Francesco Neri. 2025. Editorial: VR, AR, MR in healthcare: the role of immersive technologies in medical training. *Frontiers in Digital Health* 7 (August 2025), 1669899. doi:10.3389/fdgth.2025.1669899 eCollection 2025.

[18] South Western Sydney Local Health District. 2016. Correct Clinical Handover. YouTube video. https://www.youtube.com/watch?v=Rn6r_hFWP0Q Accessed: March 16, 2026.

[19] Jordan L. Swartz, James J. Cimino, Matthew R. Fred, Robert A. Green, and David K. Vawdrey. 2014. Designing a Clinical Dashboard to Fill Information Gaps in the Emergency Department. *AMIA Annual Symposium Proceedings* 2014 (2014), 1098–1104. PMID: 25954420; PMCID: PMC4420000.

[20] The Joint Commission. 2017. Sentinel Event Alert 58: Inadequate Hand-off Communication. https://www.jointcommission.org/en-us/knowledge-library/newsletters/sentinel-event-alert/issue-58 Accessed: 2026-05-26.

[21] Manu Mathew Thomas, Thomas Kannampallil, Joanna Abraham, and G. Elisabeta Marai. 2017. Echo: A large display interactive visualization of ICU data for effective care handoffs. In *2017 IEEE Workshop on Visual Analytics in Healthcare (VAHC)*. 47–54. doi:10.1109/VAHC.2017.8387500

[22] Ken Ye, David M. Taylor, Jonathan C. Knott, Andrew Dent, and Catherine E. MacBean. 2007. Handover in the Emergency Department: Deficiencies and Adverse Effects. *Emergency Medicine Australasia* 19 (2007), 433–441. doi:10.1111/j.1742-6723.2007.00984.x

A Ethics Approval

Below is the ethics approval for the user study.

Monash University Human Research Ethics Committee

Approval Certificate

This is to certify that the project below was considered by the Monash University Human Research Ethics Committee. The Committee was satisfied that the proposal meets the requirements of the *National Statement on Ethical Conduct in Human Research* and has granted approval.

Project ID:	51851
Application Type:	Non HREC Review
Project Title:	Investigating Situated Visualisations of EHR Data in Immersive Spaces for ICU Nurse Handover
Chief Investigator:	Dr Joe Liu
Approval Date:	12/05/2026
Expiry Date:	12/05/2031

Terms of approval - failure to comply with the terms below is in breach of your approval and the *Australian Code for the Responsible Conduct of Research*.

Approval is only valid whilst the Chief Investigator (CI) holds a position at Monash University. It is the responsibility of the CI to:

- Ensure that this project is conducted as per the approved proposal; submit and obtain approval for any amendments before implementation.
- Submit annual reports and a final report upon completion of the research.
- Notify MUHREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
- Ensure that all investigators comply with the Monash Research Data Management Policy and have a secure data management/sharing plan.
- Understand that study files, documents, and data may be inspected by MUHREC, governance officers, sponsor or auditors.

Kind Regards,

Professor William Sievert

Chair, MUHREC

CC: Dr Agnes Haryanto, Mr Jun Khor, Mr Trung Nguyen

List of approved documents:

Document Type	File Name	Date	Version
Supporting Documentation	NASA-TLX-Cognitive Load.pdf	25/04/2026	1
Supporting Documentation	User Study Invitation_Situated Visualisations for ICU Nurse Handover.pdf	25/04/2026	1
Supporting Documentation	Information Retention Questionnaires.pdf	25/04/2026	1
Supporting Documentation	Demographic Questionnaire: Investigating Situated Visualisations of EHR Data in Immersive Spaces for ICU Nurse Handover.pdf	27/04/2026	1
Supporting Documentation	Post task Questionnaire: Investigating Situated Visualisations of EHR Data in Immersive Spaces for ICU Nurse Handover.pdf	25/04/2026	1
Supporting Documentation	User Study Invitation_Situated Visualisations for ICU Nurse Handover.pdf	04/05/2026	2
Supporting Documentation	User Study Invitation_Situated Visualisations for ICU Nurse Handover.pdf	04/05/2026	3
Supporting Documentation	User Study Invitation_Situated Visualisations for ICU Nurse Handover.pdf	10/05/2026	4

Document Type	File Name	Date	Version
Supporting Documentation	Handover Registration Approved Email.pdf	11/05/2026	1
Explanatory Statement	MUHREC-explanatory-statement.pdf	25/04/2026	1
Explanatory Statement	MUHREC-explanatory-statement.pdf	04/05/2026	2
Explanatory Statement	MUHREC-explanatory-statement.pdf	04/05/2026	3
Explanatory Statement	MUHREC-explanatory-statement.pdf	10/05/2026	4
Consent Form	MUHREC-consent-form.pdf	25/04/2026	1
Consent Form	MUHREC-consent-form.pdf	04/05/2026	2
Consent Form	MUHREC-consent-form.pdf	04/05/2026	3
Consent Form	MUHREC-consent-form.pdf	05/05/2026	4

B Simulated ICU Handover Scenarios

B.1 Case 1: Dashboard Condition

Below is the visual interface presented to the nurse during the Case 1 unified dashboard handover execution.

Figure 5: Case 1: Unified dashboard display layout for patient data handover.

B.2 Case 2: Spatially Anchored Situated Visualisations Condition

This scenario demonstrates data visualisations physically projected and anchored next to relevant medical equipment.

Figure 6: Case 2: Spatially anchored virtual dashboards mapped directly into the clinical environment.

B.3 Case 3: Dashboard Condition

Below is the visual interface presented to the nurse during the Case 3 unified dashboard handover execution.

Figure 7: Case 3: Unified dashboard display layout for patient data handover.

B.4 Case 4: Spatially Anchored Situated Visualisations Condition

This scenario demonstrates data visualisations physically projected and anchored next to relevant medical equipment.

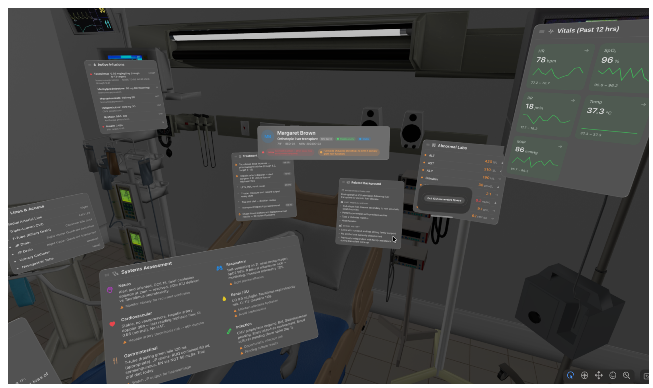

Figure 8: Case 4: Spatially anchored virtual dashboards mapped directly into the clinical environment.