Faculty of Information Technology

Master of Business Information Systems

# Toward a User-Informed AR System for ICU Nurse Handover: A Qualitative Exploratory Study

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# Part 1

# General Literature Review

Faculty of Information Technology

Master of Business Information Systems

# Literature Review

## AR-Facilitated Clinical Handover Process in Intensive Care Unit (ICU) Department

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# 1. Introduction

The handover process in Intensive Care Units (ICUs) is critical for patient safety and continuity of care, which involves the transfer of complex medical data between shifts. Traditional methods like verbal reports and written notes are prone to errors and inefficiencies, especially in high-pressure ICU settings (Cheah et al., 2005; Kowitlawakul et al., 2015). Despite advances with electronic systems, issues like fragmented data and poor integration with Electronic Health Records (EHRs) persist (Ebright et al., 2004; Spooner et al., 2018).

The electronic systems have enhanced data organisation and accuracy; however, usability and integration have remained challenging (Strople & Ottani, 2006; Spooner et al., 2018). Recent research underlines that traditional tools and reduced screen size are most often associated with cognitive overload and communication errors (Thomas et al., 2017). AR technology can project digital information onto the real world and, therefore, helps address such issues by offering intuitive, detailed visualisations. These enhance data interpretation and team communication, as explained in Hilary (2021). Integrating AR would likely make ICU handovers more efficient and effective with a view to improving patient care and staff coordination.

This literature review critically examines the current state of ICU nurse handover software and assesses how advanced data visualisation technologies, particularly AR, might address existing problems. The review will primarily focus on the interaction of ICU nurses with data during handovers, the adoption of electronic systems, and AR's potential to enhance communication, lower cognitive load, and reduce errors.

The first section investigates the nurse handover process in ICU settings, identifying key issues with traditional handovers and the interaction between nurses and data. This section will explore how nurses engage with vast amounts of information, often under time constraints, and the limitations posed by current documentation tools. A critical review of how traditional handovers impact workflow efficiency and patient safety will provide a foundation for assessing the need for improved data visualisation solutions.

The second section examines existing data visualisation applications within ICU handover processes, focusing on the implementation of electronic systems. This section will analyse current technologies used for nurse handovers, particularly the usability and efficiency of electronic interfaces, and assess their integration with EHRs. Subsections will review specific electronic tools, highlighting their advantages and limitations and how these systems manage to support or hinder ICU workflows.

The third section focuses on AR technologies and their potential application in medical data visualisation. This part of the review will outline the current state of AR technology in healthcare, exploring how AR enhances real-time access to critical patient data. Special attention will be given to the benefits of AR in providing hands-free, immersive visualisations that reduce cognitive load during high-stakes handovers. The review will also address advanced visualisation techniques, such as embedded or situated visualisation, and the role of collaborative immersive analytics in supporting teamwork in ICU settings.

Following this literature review, the research project plan will outline a structured approach to testing and implementing AR technologies for the ICU nurse handover process. The first phase of the plan involves defining objectives that align with the key challenges identified in the literature. These include improving the accuracy and efficiency of handovers, minimising cognitive overload, and enhancing user interaction with patient data. The methodology will involve developing a prototype AR system tailored to the ICU context. The prototype will aim to provide intuitive visualisations of patient data, improve situational awareness, and streamline the transfer of information during nurse handovers.

The ethical considerations of implementing AR in healthcare will focus on ensuring responsible research practices, particularly when using de-identified patient data. While this mitigates privacy concerns, it remains essential to maintain strict protocols around data handling and usage. The research plan will also address the ethical implications of introducing new technologies in a clinical environment, ensuring that the study adheres to ethical guidelines on informed consent, minimising harm, and ensuring that the technology benefits both staff and patients.

By examining the current literature and outlining a comprehensive research plan, this review aims to provide a detailed assessment of how AR could revolutionise the ICU handover process. It addresses both the theoretical and practical aspects of implementing AR technologies, offering insights into how data visualisation advancements can improve patient care and support healthcare professionals in critical care environments. Ultimately, the findings of this review will contribute to the development of more integrated and intuitive solutions for ICU nurse handovers, guiding future research and technology implementation.

# 2. Substantive Literature Review

## 2.1 ICU Nurse Handover Process and Data Interaction

### 2.1.1 Nurse Handover Process in ICU Unit

Intensive Care Units (ICUs) provide specialised care for critically ill or injured patients, characterised by a high staff-to-patient ratio and advanced medical resources. A critical challenge in ICUs is the "ICU patient handoff" or "care transition," involving the transfer of patient care responsibilities from one team to another (Manias & Street, 2000). This process is essential for maintaining continuity and quality of care (Thurgood, 1995) and promoting positive team dynamics, morale, and cohesion among healthcare staff (Parker et al., 1992).

The handover process varies in execution, with communication quality differing widely. Common methods include verbal handovers, written notes, tape recordings, and pre-prepared patient details (Pothier et al., 2005). In ICUs, the process often involves integrating data from multiple sources such as vital signs, health records, and notes before presenting it to the incoming team (Ebright et al., 2004). This complexity makes transitions time-consuming and prone to communication errors, potentially extending patient stays and impacting care quality (Cheah et al., 2005). Existing methods like spreadsheets, paper notes, and electronic copies often fall short in coordinating care transitions effectively (Hoskote et al., 2017). Additionally, the use of smaller displays like tablets and smartphones can contribute to cognitive overload and hinder collaboration due to limited screen size (Thomas et al., 2017).

A study by Kowitlawakul et al. (2015) further highlights factors affecting the handover process, including distractions and interruptions, particularly during longer transitions. Electronic health records (EHRs) and checklists are often underutilised, leading to reliance on memory and paper records. Important information such as patient concerns and DNR status can be overlooked, indicating a need for improved communication practices (Kowitlawakul et al., 2015).

Lastly, inadequate communication between outgoing and incoming shift nurses has been linked to decreased safety, lower service quality, and increased patient dissatisfaction (Raeisi et al., 2019). Standardising the handover process could enhance nurse communication and care quality, as suggested by Carroll et al. (2012) and Raeisi et al. (2019).

### 2.1.2 Interaction of ICU nurses with data during the handover process

**Cognitive load and challenges**

In ICU settings, nurses allocate approximately 22% of their shift to interacting with Electronic Health Records (EHRs), involving the documentation and interpretation of both continuous data (e.g., vital signs) and static data (e.g., delirium detection) (Pinevich et al., 2021). This significant engagement presents a considerable cognitive burden, as nurses must absorb and synthesise large volumes of information during handovers. This complexity can lead to inefficient workflows, communication issues, and potential patient safety risks. Effective handovers require both outgoing and incoming nurses to rapidly process and integrate extensive information, intensifying cognitive challenges.

Galatzan & Carrington (2022) highlight that increased cognitive load during handovers, influenced by environmental factors and communication content, contributes to cognitive overload. This overload impairs nurses' ability to accurately recall and integrate critical patient information. Transforming individual data elements, such as blood pressure and respiratory rate, into actionable knowledge further adds to cognitive strain, impacting the accuracy and efficiency of the handover.

**Interaction with ICT Systems**

The interaction between humans and ICT systems significantly affects the quality of information transferred during handovers. Festila and Müller (2021) note that while human-human handovers offer essential contextual understanding, they often suffer from issues related to accuracy and completeness. Verbal exchanges, though immediate, can result in incomplete information due to limited clarification opportunities. Conversely, human-ICT handovers provide improved accessibility and consistency through standardised input mechanisms. However, the rigidity of ICT systems may lead to data that does not fully reflect clinical realities, causing potential inaccuracies. ICT-human handovers enhance accuracy through critical review but can be time-consuming and affected by information overload and access difficulties.

Understanding these interactions is crucial for improving continuity and quality of patient care in ICUs. Each handoff type has unique strengths and weaknesses that must be addressed to optimise information transfer and decision-making processes.

**Data Elements and EHR Interfaces**

Lindroth et al. (2022) identified key data elements vital for ICU nurses during patient handoffs, including hemodynamics, mechanical circulatory support status, laboratory results, continuous IV medications, code status, and ventilation status. These elements are crucial for understanding a patient's current condition and planning ongoing care (see Figure 1).

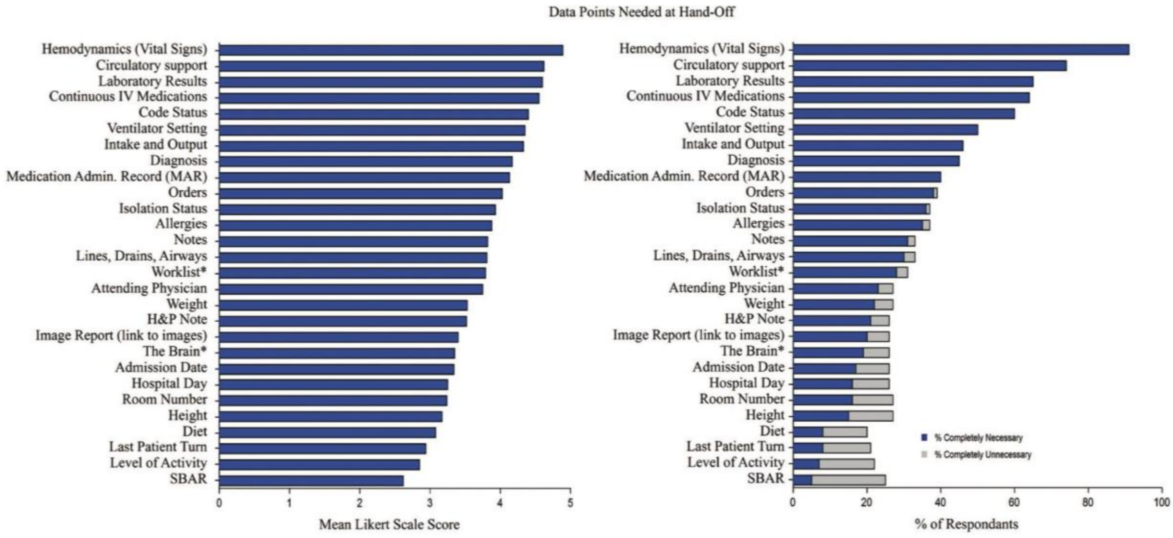


*Figure 1: Ranking of data elements needed for patient handoff for ICU according to the Likert's scale (left) and the necessity of each data element (right) for the handover process (blue as "Completely Necessary" and grey as "Completely Unnecessary") (Lindroth et al., 2022)*

Current EHR systems often present fragmented data, creating information silos that hinder comprehensive situational awareness and increase the risk of errors. Existing tools, typically relying on checklists or free-text entries, do not support effective integration and Visualisation of critical data. The study advocates for future EHR interfaces to incorporate integrated and visualised key data elements to enhance usability and reduce cognitive load. Adopting user experience frameworks and nurse-centered design approaches is recommended to develop interfaces that better support ICU workflows and decision-making.

## 2.2 Data visualisation applications for the ICU nurse handover process

### 2.2.1 Implementation of Electronic Systems for Nurse Handovers

The adoption of electronic systems for nurse handovers has become a significant trend as healthcare facilities aim to enhance the efficiency and accuracy of shift transitions. Research by Strople and Ottani (2006) and Randell, Wilson, and Woodward (2011) indicates that technologies such as electronic documentation, bedside documentation devices, and point-of-care tools can streamline and organise patient information, improving handover quality. Additionally, systems that enable junior doctors to input patient notes and task details while automatically generating patient lists with recent vital signs and laboratory values have been shown to be beneficial in enhancing the handover process (Van Eaton et al., 2005).

A notable research at Grady Memorial Hospital introduced a web-based handover application called WardManager that structured patient information, including demographic data, problem lists, medication lists, allergies, code status, historical illness data, team to-do lists, and handover tasks (see Figure 2). This approach led to a 50% reduction in perceived near-miss events, consistent inclusion of vital patient information, and increased resident confidence (Payne et al., 2012).

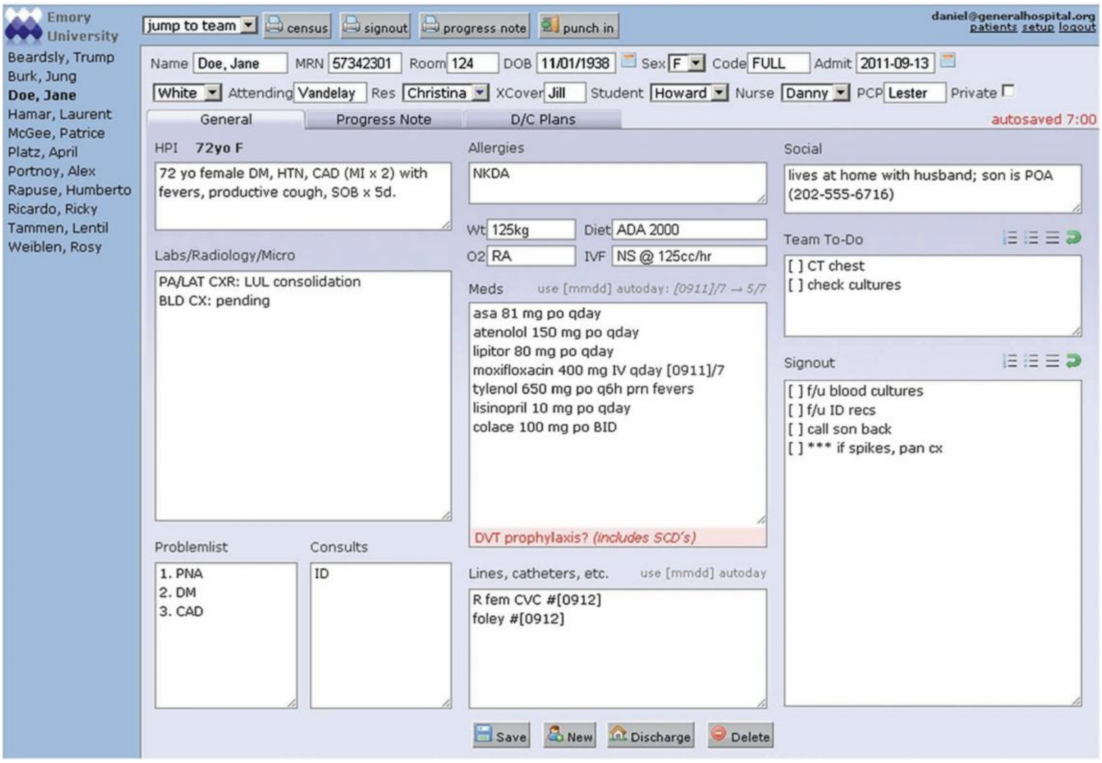


*Figure 2: Patient information entry dashboard on WardManager electronic handover system (Payne et al., 2012)*

Another study by Spooner, Aitken, and Chaboyer (2018) evaluated an electronic Medical Documentation System (eMDS) for ICU handovers using the Knowledge-to-Action (KTA) framework. Despite structured strategies like education, reminders, and feedback, the study found issues. After three months, eMDS was used by most team leaders, but key content was often missing, leading to additional documentation. Nurses receiving handovers had more positive views than those delivering them. Feedback indicated problems with the electronic interface, suggesting a need for usability improvements. The KTA framework was criticised for its lack of specific troubleshooting guidance. The study recommended integrating behavioral theories to address attitudes and improve knowledge translation. It also highlighted eMDS limitations, including integration issues and technical delays. Recommendations included making electronic tools flexible, user-friendly, and capable of integrating data from various sources, with adequate technical support for effective implementation.

## 2.2.2 Data visualisation interfaces used in the handover process

Research by Thomas, Kannampallil, Abraham, and Marai (2017) explored a web-based application designed for the ICU handoff process, addressing two main challenges: integrating multivariate data from various sources into a structured format and sharing aggregated information for meaningful discussion. The application used large display implementations with the assistance of personal displays to support collaboration through shared content, facilitating data-oriented conversations (see Figure 3).

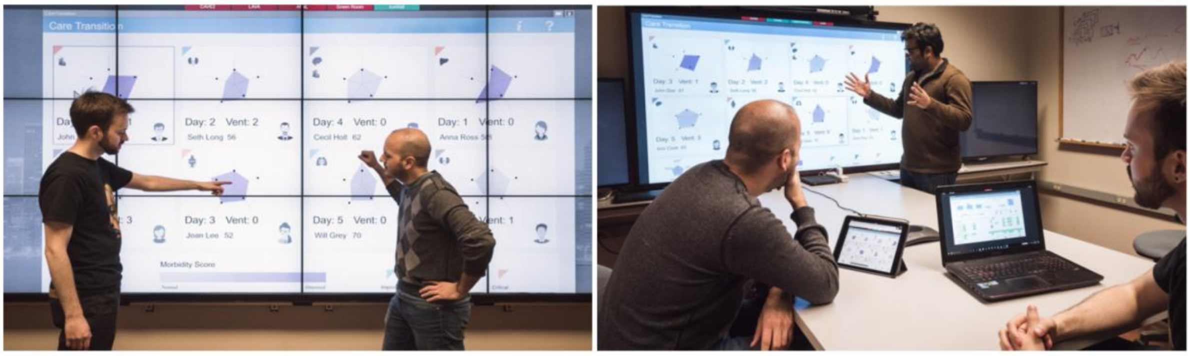

*Figure 3: (Left) Two testers collaborating on a common information space using Echo. (Right) A group of testers run Echo synchronously on a large display screen with additional personal displays (laptop and tablet for remote collaboration) (Thomas et al., 2017)*


*Figure 4: Card layout showing a summary overview of 8 patients in the ICU using Kiviat plot (Thomas et al., 2017)*

The first interface, Echo, provided data visualisations summarising key statistics, such as vital signs, morbidity scores, and medical conditions (see Figure 4). ICU nurses could quickly identify critical conditions through colour-coded indicators, and status glyphs highlighted whether patient health was improving or deteriorating (Thomas et al., 2017).

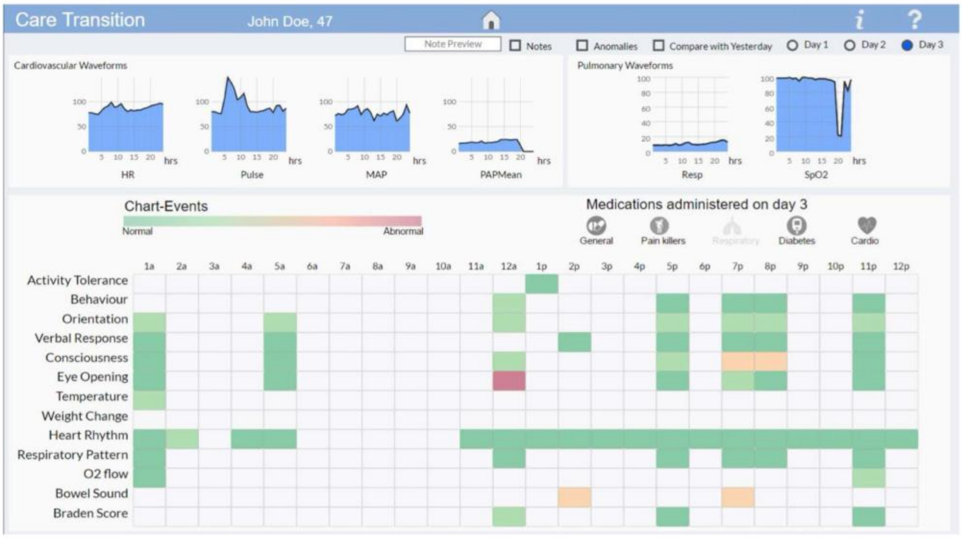


Figure 5: Detailed view of individual patient (Thomas et al., 2017)

The second interface offered a detailed patient view with waveform data for cardiovascular and pulmonary systems, a heatmap of frequently monitored events, and a summary of administered medications. It also included options to view notes, anomalies, comparisons, and historical data (see Figure 5) (Thomas et al., 2017).

The tool was tested with both naive users and experts, demonstrating its effectiveness in identifying trends, detecting anomalies, and improving communication during handovers. Experts praised its large display, patient card layout, and comparison features, noting its potential for both clinical use and training junior clinicians (Thomas et al., 2017).

Another study by Hilary (2021) found that using digital data visualisation dashboards (Figure 7,8,9) improved nurse shift handovers in terms of communication of essential information, efficiency, and overall satisfaction compared to traditional paper-based systems using the ISBAR communication tool (Figure 6). This indicates that electronic systems and data visualisation interfaces can significantly enhance the handover process, leading to better patient care and improved workflow efficiency in healthcare settings.

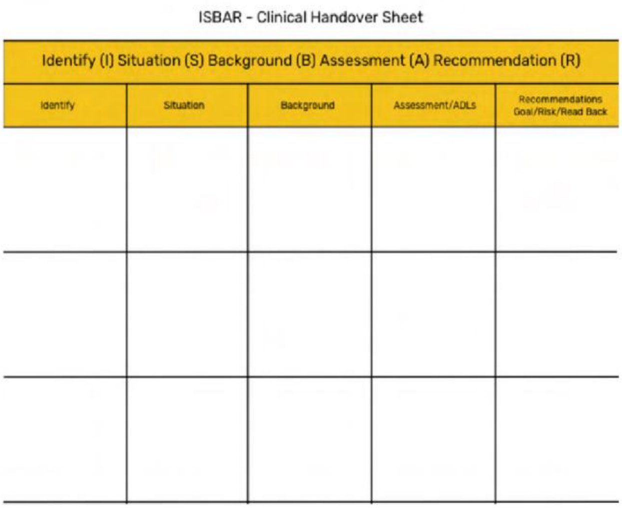


Figure 6: ISBAR paper prototype (Hilary, 2021)

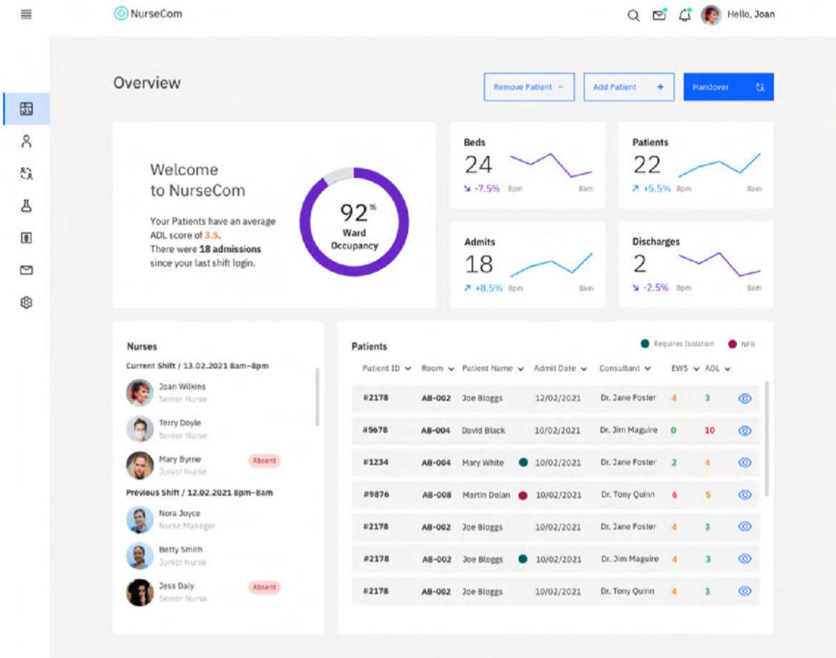


*Figure 7: Ward overview screen showing ward statistics, important tasks, nurses on duty, and patient profiles (Hilary, 2021)*

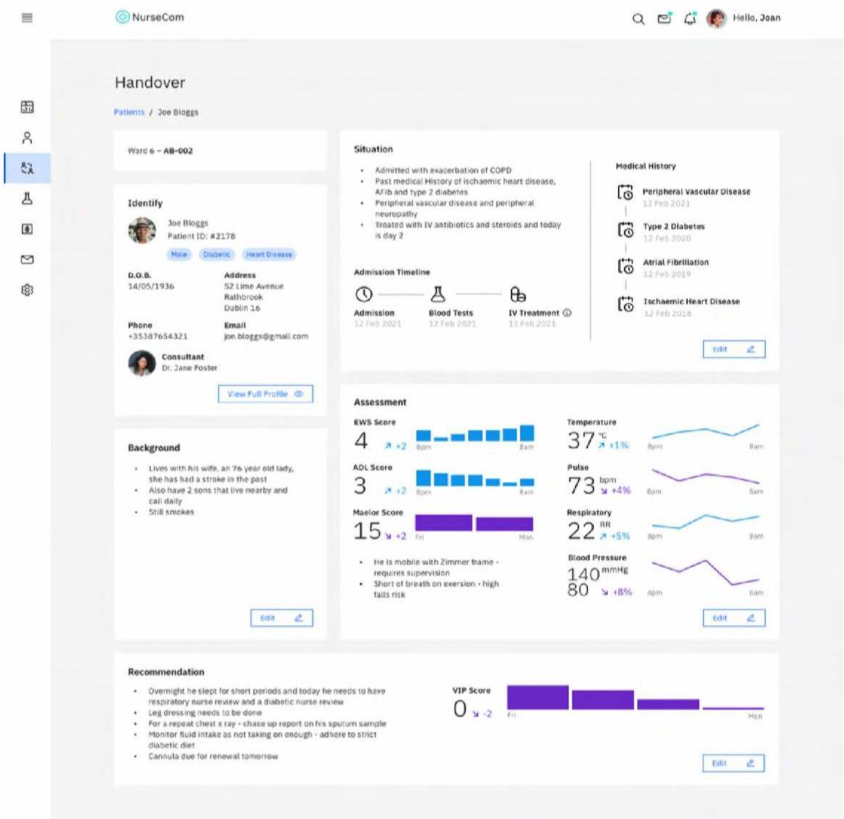


*Figure 8: Handover patient profile interface featuring the patient's medical history, admission timeline, personal information, records, and key statistics (Hilary, 2021)*

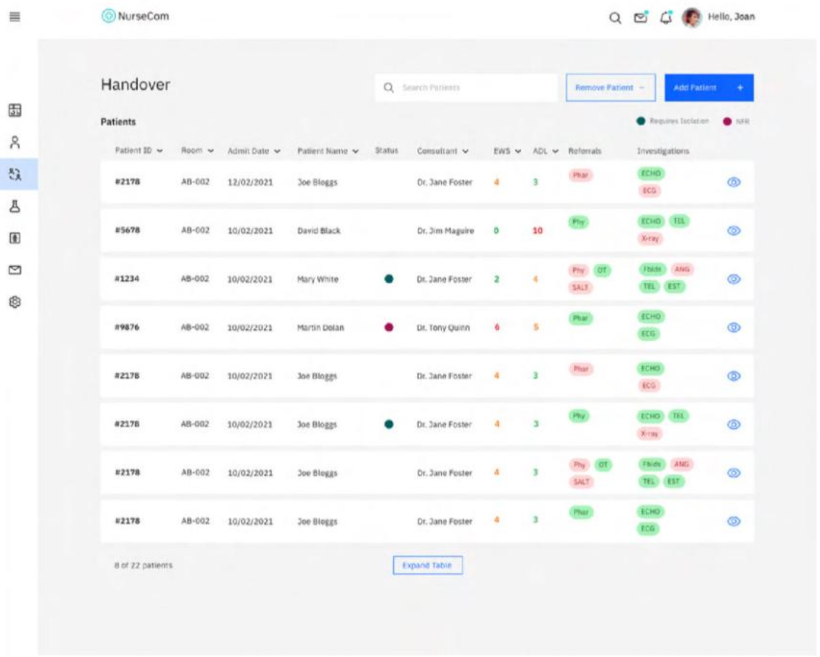


*Figure 9: Handover interface showcasing colour-coded scores, labels, patient status, and a search feature for quick access (Hilary, 2021)*

## 2.3 Augmented Reality applications for medical data

### 2.3.1 Current technologies in medical Augmented Reality

AR glasses offer transformative potential for nursing processes (Wüller et al., 2017). These devices enhance spatial usage and support hands-free tasks, timely execution, and sustained attention (Klinker et al., 2020). While AR's adoption in healthcare has focused on surgery and education, there is a growing body of research exploring its potential in other areas, such as nursing handovers.

Research into AR's role in data analysis highlights its benefits. Wang et al. (2020) demonstrated that AR, using Microsoft's HoloLens, can significantly improve data exploration and understanding in particle physics. This suggests similar enhancements could apply to nurse handovers by providing immersive, interactive patient data visualisations. Such integration could complement traditional documentation, boosting handover efficiency and accuracy.

However, challenges such as AR input methods and device usability are crucial. Wang et al. (2020) identified the need for intuitive interaction techniques and specialised devices, which are essential for creating a practical AR system for nursing. Solutions like touch controls or voice commands could address these concerns and enhance usability.


*Figure 10: Screenshots from the prototype (Gansohr et al., 2024). Image (a) displays the most recent recorded status. The top button allows users to access the specific steps in wound care and documentation as outlined by the nursing staff involved. In (b), the nurse adjusts the window to the preferred position for their task. Image (c) demonstrates how a new pain score is recorded, while (d) shows the activation of an additional window for documenting the wound stage.*

Recent studies on AR in wound management also provide relevant insights for handovers. Albrecht-Gansohr et al. (2024) explored AR glasses for wound care using a HoloLens 2 prototype (see Figure 10). Developed with nurse input, this system offers hands-free access to real-time data, improving work conditions and care quality. The AR glasses' hands-free nature enables nurses to focus on patient care while accessing critical information, thus streamlining the handover process and reducing the cognitive load (Albrecht-Gansohr et al., 2024).

The integration of AR glasses in nursing holds significant potential for improving handover efficiency and accuracy. By providing interactive Visualisations and real-time data access, AR can enhance workflow and reduce cognitive load. Insights from data analysis and wound care research highlight the importance of user-friendly AR systems tailored to nursing needs. As AR technology advances, its potential to revolutionise healthcare practices and improve patient care continues to grow, making it a promising area for future research and development.

### 2.3.2 Benefits of Augmented Reality Data Visualisation

**Minimising Cognitive and Information Overload**

Research highlights AR as a powerful tool for reducing cognitive and information overload, particularly through improved data visualisation. For example, Millais, Jones, and Kelly (2018) found that virtual reality (VR) outperformed 2D visualisations by reducing perceived performance workload and increasing user satisfaction. Users of VR, despite its requirement for more physical movement, reported fewer inaccuracies in their insights, likely due to enhanced engagement and detailed analysis (see Figure 11). This suggests that AR, akin to

VR, could similarly improve user experience and accuracy through immersive, interactive visualisations.

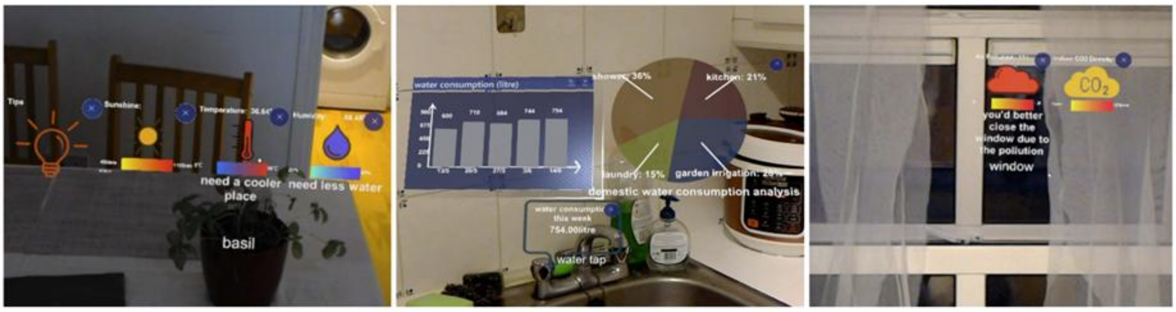


*Figure 11: Enhance physical objects by overlaying relevant data along with brief, actionable suggestions to provide instant, explainable decision support (Zheng et al., 2022)*

The STARE framework, which integrates AR technology into smart home decision support systems, underscores AR's potential to manage information overload effectively (Zheng et al., 2022). By focusing on pertinent data and minimising distractions, AR systems like STARE enhance decision-making efficiency. In the context of ICU nurse handovers, AR could facilitate access to real-time, contextual information, crucial for efficient transitions between shifts.

### Practical Considerations and User Satisfaction

The STARE study found that user satisfaction with AR did not significantly increase, underscoring the need to integrate AR into existing workflows without adding cognitive or physical burdens (Zheng et al., 2022). In ICU settings, AR systems must be user-friendly and seamlessly integrate with current practices to be effective and accepted by staff.

A review by Buchner, Buntins, and Kerres (2022) of 58 studies found that AR generally imposes less cognitive load compared to other technologies and can enhance performance. AR reduces the cognitive load during handovers by presenting information visually and contextually, allowing nurses to focus on critical details rather than recalling or manually accessing information.

Integrating AR into ICU nurse handovers offers significant potential to improve data presentation, reduce cognitive load, and minimise information overload. Future research should explore practical applications in clinical settings, focusing on hardware ergonomics, system integration, and the overall impact on nurse efficiency and patient care.

## 2.3.3 Embedded/Situated Visualisation

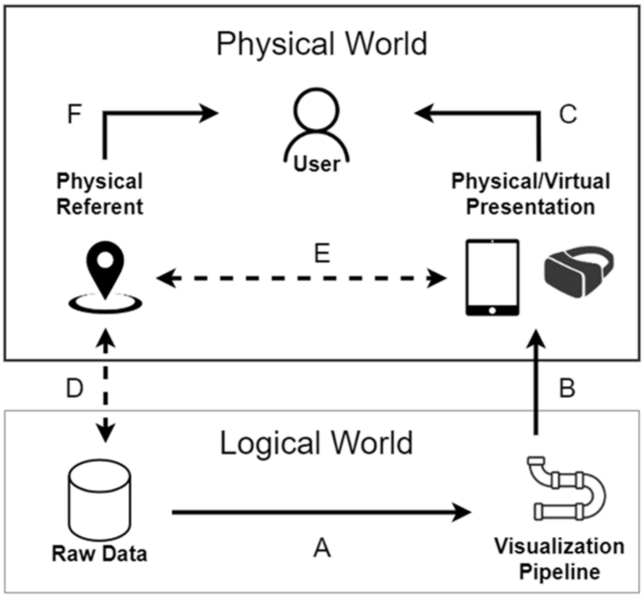


*Figure 12: The classical spatial SV model demonstrates the pathways through which information is processed and transmitted before being delivered to the user (Martins et al., 2023).*

Embedded or situated visualisation has gained recognition for its ability to enhance data representation in real-world settings, particularly within healthcare. Unlike traditional visualisation methods, which present data separately from physical contexts, embedded visualisation overlays data close to their physical referents, improving alignment and perception (Willett et al., 2016; Figure 12). This approach is particularly advantageous in clinical settings where real-time decision-making is crucial (Martins et al., 2023).


*Figure 14: Case studies (C1) Corsican Twin; (C2) Situated Glyphs; (C3) Cairn, (C4) Chemicals in the Creek; (C5) Activity Clock; (C6) Public Polling Displays (Bressa et al., 2021)*

A detailed study by Bressa et al. (2021) sheds light on the effectiveness of embedded and situated visualisations. Key insights include:

1. **Spatial Perspective**: The Corsican Twin (C1) project illustrates the importance of maintaining spatial integrity when transitioning from virtual to physical environments.

In healthcare, positioning data near relevant locations—such as patient bedsides and medical equipment—can significantly enhance decision-making speed and accuracy.

2. **Temporal Perspective**: The Activity Clock (C5) highlights the benefits of real-time data presentation. Minimising delays in data visualisation allows users to process and act on information promptly, which is critical in high-stakes environments. This immediacy helps in timely interventions and reduces errors from outdated information.

3. **Place Perspective**: The Public Polling Displays (C6) study demonstrates that tailoring vsualisations to specific locations increases their relevance and user engagement. Contextually appropriate and accessible information enhances usability in various healthcare settings.

4. **Activity Perspective**: The Situated Glyphs (C2) study shows that integrating context-aware displays into daily activities can reduce cognitive load and streamline workflows. Embedding visualisations into routine tasks supports more efficient and informed decision-making.

5. **Community Perspective**: The study emphasises the importance of customising technology to team needs. Involving healthcare professionals in the design process, as seen in projects like C4 and C6, can reduce cognitive load and improve efficiency. Similarly, integrating AR into ICU workflows can enhance handovers by tailoring tools to support healthcare professionals' activities.

These insights suggest that leveraging spatial, temporal, place, activity, and community perspectives can lead to more effective visualisations in healthcare, improving situational awareness and the accuracy of information transfer during critical processes like ICU handovers.

### 2.3.4 Collaborative immersive analytics

Recent research underscores the potential of augmented reality (AR) and virtual reality (VR) technologies to enhance ICU nurse handover processes, improving collaboration and efficiency. Studies by Cordeil et al. (2016) and Lee et al. (2020) demonstrate that shared VR environments can effectively foster communication and organise visual data on virtual walls, aiding both presentation and analysis.

Chen et al. (2021) further support the advantages of collaborative immersive environments. Their research shows that VR-based tools improve task performance and learning outcomes, particularly when used in pairs. This indicates that similar AR technologies could enhance decision-making in ICU settings by facilitating teamwork and increasing efficiency.

Engagement patterns in immersive settings highlight that shared interactive views improve communication and coordination. Participants in shared view environments exhibited higher engagement, effective task division, and proactive collaboration compared to those in non-shared setups. These findings suggest that AR visualisation could significantly boost nurse communication and coordination during handovers.

The arrangement of participants within immersive environments is also crucial. Research shows that side-by-side positioning (Figure 15a) is more effective for communication and task performance than back-to-back arrangements. Applying this principle to AR design for ICU handovers could enhance collaboration and satisfaction among nurses by ensuring clear visibility and intuitive interaction.

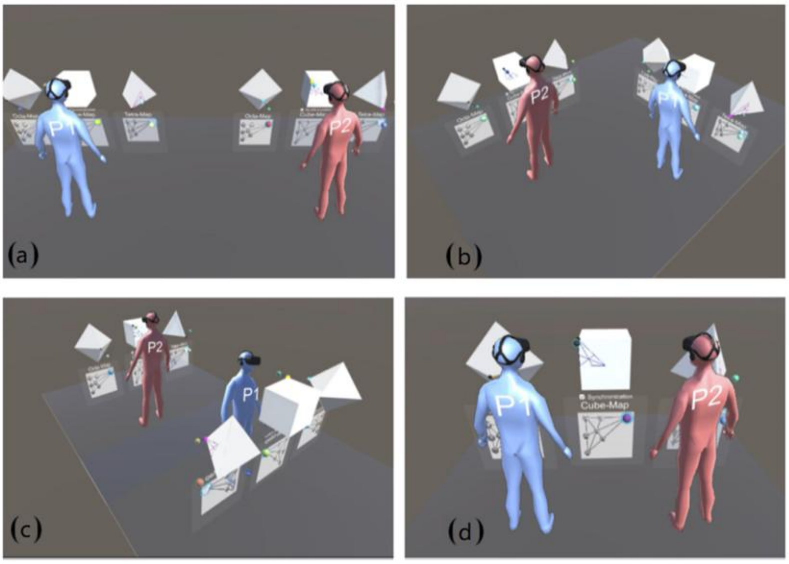


*Figure 15: The spatial configurations for immersive collaborative analytics include: (a) side-by-side, (b) corner-to-corner, (c) back-to-back, and (d) public workspace. Arrangements (a-c) can be utilised by both shared and non-shared users, whereas (d) is exclusively for shared groups (Chen et al., 2021)*

Recent insights from Tong et al. (2023) on asymmetric collaborative Visualisation reveal that combining VR with spatial sensemaking and PC with typing functions can balance the strengths of each device. Asymmetric setups, like PC-VR, maintain task performance and reduce mental load for PC users, as VR users manage comprehensive spatial views. This division of roles and integration of awareness cues can improve communication and efficiency, making asymmetric collaboration a promising approach for AR applications in healthcare.

In summary, integrating AR Visualisation into ICU nurse handovers can leverage features that support collaboration, enhance engagement, and optimise interaction arrangements. The positive impacts observed in immersive environments suggest that AR technologies could significantly improve the efficiency and effectiveness of critical healthcare processes.

# 3. Summary of the State of the Art

The integration of augmented reality (AR) technology in ICU nurse handovers represents a promising advancement for addressing the persistent challenges in this critical process. Traditional handover methods and electronic systems have shown limitations in usability and data integration, which contribute to inefficiencies and heightened cognitive burden for nurses (Pinevich et al., 2020; Cheah et al., 2005). This summary evaluates the current state of AR applications in healthcare, identifies gaps in traditional handover tools, and explores the potential of AR to enhance data integration, alleviate cognitive load, and improve the efficiency of ICU nurse handovers.

**Key Findings:**

Handovers by ICU nurses are complex, requiring the integration of extensive data such as patient history, vital signs, and treatment plans (Pinevich et al., 2020; Ebright et al., 2004). Traditional methods, including verbal reports and written notes, are prone to communication errors and inefficiencies, impacting patient safety and care quality (Cheah et al., 2005). Relying on outdated tools like spreadsheets and paper records contributes to cognitive overload, especially with fragmented data in Electronic Health Record (EHR) systems (Thomas et al., 2017; Hoskote et al., 2017).

Existing electronic systems for nurse handovers face usability and integration challenges. Studies by Kowitlawakul et al. (2015) and Pinevich et al. (2020) reveal that these systems often struggle with seamless EHR integration and lack user-friendly interfaces. Traditional electronic documentation can be cumbersome, leading to incomplete information and inefficient handovers. Spooner, Aitken, and Chaboyer (2018) found that the eMDS system, despite its structured format, suffers from missing content and interface difficulties, reducing its effectiveness. These issues underscore the need for more intuitive and integrated solutions to improve the handover process.

Recent research suggests that AR technology could significantly enhance healthcare, particularly in nursing. AR glasses enable hands-free operation, timely task execution, and improved focus (Wüller et al., 2017; Klinker et al., 2018). Although AR has shown effectiveness in surgical and educational contexts, its application in ICU handovers is still underexplored. Studies indicate that AR could enhance handovers by providing immersive visualisations of patient data, potentially improving accuracy, reducing cognitive load, and minimising information errors (Wang et al., 2020; Albrecht-Gansohr et al., 2024).

**Proposed Research Contributions:**

This research aims to bridge these gaps by developing and evaluating an AR application specifically designed for the ICU nurse handover process. Building on existing AR technologies and healthcare research, the project will:

1. **Design and Develop an AR Solution Prototype:** Create an AR system prototype to enhance the ICU handover process, incorporating real-time data visualisation, patient history access, and interactive features to support nurse communication and decision-making.

2. **Evaluate Effects on Cognitive Load, Usability and Integration:** Assess the AR system's usability and impacts on user's cognitive load within the ICU setting, focusing on data integration, workflow compatibility, and user feedback from ICU nurses.

By addressing these areas, the research seeks to establish a new standard for AR use in critical care environments, aiming to improve the quality of ICU handovers and patient care. The introduction of AR in this context promises to enhance information transfer, reduce errors, and streamline communication among healthcare professionals.

# 4. Research Project Plan

This research initiative aims to enhance ICU nurse handovers through the development of an AR application. Building on advancements in AR technology, particularly AR glasses, the project will create a prototype to improve data visualisation and hands-free access to information during handovers. By integrating insights from recent studies on AR's benefits for data analysis and healthcare applications, this project seeks to optimise the efficiency and accuracy of nurse handovers. The focus will be on addressing usability challenges and leveraging immersive visualisations to streamline communication and reduce cognitive load, ultimately enhancing patient care and workflow efficiency.

## 4.1 Objectives

The primary objectives of this research are:

**Design and Develop a Prototype of AR Application for ICU Handover**: Develop an AR system that integrates with existing electronic health records (EHR) to enhance and streamline the ICU handover process. The system will be tailored to support ICU nurses by presenting real-time, relevant patient information in an accessible and intuitive format.

**Evaluate Effectiveness, Usability and Integration**: Assess the usability of the AR system within the context of ICU settings and its potential integration with current workflows and EHR systems. This will involve testing the system's effectiveness in reducing cognitive load, improving handover efficiency, and aligning with established clinical practices.

**Identify Challenges and Recommendations**: Explore the challenges encountered during the implementation of the AR system and provide actionable recommendations for future improvements. This includes addressing issues related to usability, data integration, and the practical application of AR technology in clinical settings.

## 4.2 Methodology

The research will use a co-design methodology, as advised by Bressa et al. (2021), involving stakeholders and end-users to ensure the AR system aligns with ICU nurses' needs. This collaborative approach is essential for healthcare innovations (Istanboulian et al., 2023) as it integrates user feedback into the system's development. By engaging ICU nurses and stakeholders throughout, the system is more likely to fit seamlessly into workflows, enhancing usability and effectiveness (Slattery et al., 2020). Clear communication and detailed documentation ensure shared understanding, while addressing behavioral engagement challenges will further improve user interactions with the AR system (Slattery et al., 2020).

### 4.2.1 Development of AR System

The AR system will be designed to assist ICU nurses during the handover process by providing real-time, contextually relevant information. The development process will include the following steps:

**Requirement Analysis:** Detailed analysis of the ICU handover process will be conducted to identify key information needs and pain points. This will involve reviewing existing literature and interviewing ICU nurses to gain insights into their workflows and challenges.

**System Design:** Based on the requirements gathered, the AR application will be designed. This will involve creating wireframes and prototypes to visualise the interface and interactions. The design will focus on integrating critical data such as patient history, hemodynamics, mechanical circulatory support status, laboratory results, continuous IV medications, code status, and ventilation status (Lindroth et al., 2022) into an AR interface.

**Implementation:** The AR system will be developed using appropriate technologies and frameworks. Unity3D will be used for the development of the AR application, leveraging AR development tools such as AR Foundation. Key features will include real-time data overlay, interactive elements, and data integration.

### 4.2.2 Data Collection and Analysis

**Interviews with ICU Nurses:** Semi-structured interviews will be conducted with ICU nurses to gather qualitative data on their experiences with the current handover process and their expectations for an AR solution. The interviews will focus on understanding their needs, challenges, and how an AR system might improve their workflow.

**Usability Testing:** The AR system will be tested in a simulated environment to evaluate its usability and effectiveness. Participants will perform typical handover tasks using the AR system, and their interactions will be observed and recorded. Feedback will be collected through questionnaires, follow-up interviews, and two key assessment tools: the System Usability Scale (SUS) and the NASA Task Load Index (NASA-TLX). The SUS will be used to gauge overall user satisfaction and perceived usability of the AR system, while the NASA-TLX will assess participants' perceived cognitive workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration (Brooke, 1996; Hart, 2006). This data will provide insights into how the AR system impacts cognitive load and user satisfaction compared to traditional handover methods.

**Data Analysis:** Qualitative data from interviews will be analyzed using thematic analysis to identify common themes and insights. Usability testing data, including results from the NASA-TLX, will be examined to assess the system's impact on cognitive load, user satisfaction, ease of use, and handover efficiency. The NASA-TLX will provide quantitative insights into the cognitive demands of the AR system compared to traditional methods. The analysis will help determine the system’s effectiveness in improving the handover process and highlight areas for refinement.

### 4.2.3 Project Timeline

**Semester 1**

**Task 1: Literature Review (Weeks 1–8)**

Conduct a thorough review to identify gaps and challenges in the ICU nurse handover process. Focus on academic articles, case studies, and industry reports related to handovers and the role of AR. Assess existing AR applications in healthcare, identifying strengths and limitations to highlight areas where AR could improve ICU handovers.

**Task 2: Design interview questions and apply for ethics approval (Weeks 9-10)**

Create and finalise questionnaires and interview guides to gather insights from ICU nurses. Develop questions on communication, workflow, and challenges, ensuring clarity and relevance. Apply and obtain ethics approval from the Monash University Human Research Ethics Committee. Plan interview logistics, including participant selection, scheduling, and consent forms, to ensure consistent and ethical data collection.

**Task 3: Requirement Gathering and Analysis (Weeks 11-14)**

Conduct interviews with ICU nurses to identify requirements and challenges. Analyse the data to define precise AR system features that address identified issues and enhance the handover process. This analysis will guide the development of the AR prototype to align with real-world needs.

**Task 4: Learn Relevant Technical Skills (Weeks 9-14)**

Acquire technical skills for AR development, including Unity 3D and AR tools. Engage in tutorials, online courses, and practice exercises to build proficiency. Set learning goals and track progress to prepare for developing the AR system.

**Semester 2**

**Task 5: Design and Develop Prototypes (Weeks 1-6)**

Create wireframes and initial prototypes for the AR system. Develop these prototypes based on gathered requirements and seek feedback from supervisors and domain experts. Refine the designs to improve usability and ensure they meet the needs of ICU nurses.

**Task 6: Evaluation (Weeks 7-10)**

Test the AR prototype in a simulated ICU environment. Collect feedback from ICU nurses on usability and functionality through observations, questionnaires, SUS assessments, and NASA-TLX assessments to measure cognitive load. Analyze the data to evaluate user satisfaction, system performance, and the effectiveness of the AR system in supporting the handover process.

**Task 7: Data Analysis and Report (Weeks 11-14)**

Analyse interview and usability test data to draw conclusions. Prepare the thesis report, detailing the research process, findings, and recommendations for the AR system's implementation in ICU settings. Ensure the report is well-organised and clearly presents the research outcomes.

### 4.2.4 Ethics Considerations

In our research on developing an AR application for the ICU nurse handover process, ethical considerations are central to ensuring the integrity and impact of our work. Adherence to ethical standards is critical, particularly due to the sensitive nature of healthcare data and the involvement of participants in the study.

**ICU Medical Data Source:** Our research utilises the publicly available MIMIC-III dataset, which complies with HIPAA regulations. This dataset includes de-identified, multi-dimensional healthcare data from over 60,000 patients admitted to the critical care units of Beth Israel Deaconess Medical Center between 2001 and 2012 (Johnson et al., 2016). MIMIC-III provides rich temporal resolution with data such as lab results, electronic documentation, bedside monitor trends, and waveforms (Thomas et al., 2017). It also includes comprehensive information on demographics, vital sign measurements, and laboratory test results, procedures, medications, caregiver notes, imaging reports, and post-hospital discharge mortality. Importantly, all data in MIMIC-III is de-identified, ensuring that individual patient identities are confidential and protected.

**Informed Consent:** To ensure ethical conduct, all participants, including ICU nurses involved in interviews and usability testing, will be fully informed about the study's purpose, procedures, and potential risks. Consent will be obtained prior to participation, ensuring that participants are aware of their rights and can withdraw from the study at any time without penalty.

**Confidentiality:** The confidentiality of participants' personal information and responses is paramount. Data collected will be anonymised and stored securely to protect privacy. Only aggregated results will be reported to prevent any individual identification.

**Minimising Harm:** The study will be designed to minimise potential discomfort or disruption to participants' regular duties. Testing of the AR system will occur in a controlled environment to avoid interference with actual clinical workflows.

**Data Handling:** Data collected during interviews and testing will be managed in accordance with relevant data protection regulations. Secure storage and access protocols will be implemented to ensure the integrity and confidentiality of the data.

This methodology provides a comprehensive framework for developing and evaluating an AR system for ICU nurse handovers, ensuring that the system is effectively designed and tested while adhering to high ethical standards.

# 5. Conclusion

This research paper examined the application of Augmented Reality technology to enhance the ICU nurse handover process, identifying both its potential benefits and challenges. AR offers significant advantages, such as hands-free operation, real-time patient data visualisation, and the ability to streamline communication during handovers. Current AR implementations in fields like surgery and medical training demonstrate how the technology can improve workflow efficiency and accuracy, offering insights into how it could address key limitations in traditional nurse handover practices. Specifically, AR has the potential to reduce cognitive overload, enhance focus on patient care, and mitigate communication errors, which are critical during high-pressure ICU handovers.

The study emphasised the necessity of user-centered design principles to create an AR system that meets the specific needs of ICU nurses. Iterative testing in simulated environments and feedback from healthcare professionals play a crucial role in refining AR applications for this purpose. Challenges such as device usability, intuitive interaction techniques, and seamless data integration were also noted as areas requiring further attention to ensure the practical adoption of AR in ICU settings.

Future research should focus on continued refinement through usability testing, particularly in real-world ICU environments, and the integration of advanced interaction techniques, such as voice commands and intuitive gesture controls, to improve system usability. This project aims to contribute to the development of a more efficient, accurate, and reliable handover process using AR technology, ultimately enhancing patient safety and the overall quality of care in critical care settings.

# Reference list

Albrecht-Gansohr, C., Timm, L., Eimler, S. C., & Geisler, S. (2024, June). An Augmented Reality Application for Wound Management: Enhancing Nurses' Autonomy, Competence and Connectedness. In *Virtual Worlds* (Vol. 3, No. 2, pp. 208-229). MDPI.

Bressa, N., Korsgaard, H., Tabard, A., Houben, S., & Vermeulen, J. (2021). What's the situation with situated Visualisation? A survey and perspectives on situatedness. *IEEE Transactions on Visualisation and Computer Graphics*, *28*(1), 107-117.

Brooke, J. (1996). Usability evaluation in industry.

Buchner, J., Buntins, K., & Kerres, M. (2022). 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.

Cheah, L. P., Amott, D. H., Pollard, J., & Watters, D. A. (2005). Electronic medical handover: towards safer medical care. *Medical Journal of Australia*, *183*(7), 369-372.

Chen, L., Liang, H. N., Lu, F., Wang, J., Chen, W., & Yue, Y. (2021). Effect of collaboration mode and position arrangement on immersive analytics tasks in virtual reality: a pilot study. *Applied Sciences*, *11*(21), 10473.

Cordeil, M., Dwyer, T., Klein, K., Laha, B., Marriott, K., & Thomas, B. H. (2016). Immersive collaborative analysis of network connectivity: CAVE-style or head-mounted display?. *IEEE transactions on Visualisation and computer graphics*, *23*(1), 441-450.

Ebright, P. R., Urden, L., Patterson, E., & Chalko, B. (2004). Themes surrounding novice nurse near-miss and adverse-event situations. *JONA: The Journal of Nursing Administration*, *34*(11), 531-538.

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.

Galatzan, B. J., & Carrington, J. M. (2022). Communicating data, information, and knowledge in the nursing handoff. *CIN: Computers, Informatics, Nursing*, *40*(1), 21-27.

Hart, S. G. (2006, October). NASA-task load index (NASA-TLX); 20 years later. In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 50, No. 9, pp. 904-908). Sage CA: Los Angeles, CA: Sage publications.

Hilary, D. (2021). Evaluating how nurse communication during shift handovers can be improved using interactive data visualisation. *Ph.D. dissertation.*

Hoskote, S. S., Racedo Africano, C. J., Braun, A. B., O'Horo, J. C., Sevilla Berrios, R. A., Loftsgard, T. O., Bryant, K. M., Iyer, V. N., & Smischney, N. J. (2017). 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.

Istanboulian, L., Rose, L., Yunusova, Y., & Dale, C. (2023). Adapting co-design methodology to a virtual environment: co-designing a communication intervention for adult patients in critical care. *Research Involvement and Engagement*, 9(1), 103.

Johnson, A. E. W., Pollard, T. J., Shen, L., Lehman, L. H., Feng, M., Ghassemi, M., Moody, B., Szolovits, P., Anthony Celi, L., & Mark, R. G. (2016). MIMIC-III, a freely accessible critical care database. *Scientific Data*, 3(1), 160035. https://doi.org/10.1038/sdata.2016.35

Klinker, K., Wiesche, M., & Krcmar, H. (2020). Digital transformation in health care: Augmented reality for hands-free service innovation. *Information Systems Frontiers*, 22(6), 1419-1431.

Kowitlawakul, Y., Leong, B. S. H., Lua, A., Aroos, R., Wong, J. J., Koh, N., Goh, N., See, K. C., Phua, J., & 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), 99-104.

Lee, B., Hu, X., Cordeil, M., Prouzeau, A., Jenny, B., & Dwyer, T. (2020). Shared surfaces and spaces: Collaborative data visualisation in a co-located immersive environment. *IEEE Transactions on Visualisation and Computer Graphics*, *27*(2), 1171-1181.

Lindroth, H. L., Pinevich, Y., Barwise, A. K., Fathma, S., Diedrich, D., Pickering, B. W., & Herasevich, V. (2022). Information and data Visualisation needs among direct care nurses in the intensive care unit. *Applied clinical informatics*, *13*(05), 1207-1213.

Manias, E., & Street, A. (2000). The handover: uncovering the hidden practices of nurses. *Intensive and critical care nursing*, 16(6), 373-383.

Martins, N. C., Marques, B., Dias, P., & Sousa Santos, B. (2023). Expanding the horizons of situated Visualisation: The extended sv model. *Big Data and Cognitive Computing*, *7*(2), 112. https://doi.org/10.3390/bdcc7020112

Millais, P., Jones, S. L., & Kelly, R. (2018, April). Exploring data in virtual reality: Comparisons with 2d data Visualisations. In *Extended abstracts of the 2018 CHI conference on human factors in computing systems* (pp. 1-6).

Parker, J., Gardner, G., & Wiltshire, J. (1992). Handover: the collective narrative of nursing practice. *The Australian journal of advanced nursing: a quarterly publication of the Royal Australian Nursing Federation*, 9(3), 31-37.

Payne, C. E., Stein, J. M., Leong, T., & Dressler, D. D. (2012). Avoiding handover fumbles: a controlled trial of a structured handover tool versus traditional handover methods. *BMJ Quality & Safety,* 21(11), 925-932.

Pinevich, Y., Clark, K. J., Harrison, A. M., Pickering, B. W., & Herasevich, V. (2021). Interaction time with electronic health records: a systematic review. *Applied clinical informatics*, *12*(04), 788-799.

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*, 14(20), 1090-1093.

Raeisi, A., Rarani, M. A., & Soltani, F. (2019). Challenges of patient handover process in healthcare services: a systematic review. *Journal of education and health promotion*, 8(1), 173.

Randell, R., Wilson, S., & Woodward, P. (2011). The importance of the verbal shift handover report: A multi-site case study. *International Journal of Medical Informatics*, 80(11), 803–812.

Slattery, P., Saeri, A. K., & Bragge, P. (2020). Research co-design in health: a rapid overview of reviews. *Health research policy and systems*, 18, 1-13.

Spooner, A. J., Aitken, L. M., & Chaboyer, W. (2018). Implementation of an evidence-based practice nursing handover tool in intensive care using the knowledge-to-action framework. *Worldviews on Evidence-Based Nursing*, *15*(2), 88-96.

Strople, B., & Ottani, P. (2006). Can technology improve intershift report? What the research reveals. *Journal of Professional Nursing*, 22(3), 197–204.

Thomas, M. M., Kannampallil, T., Abraham, J., & Marai, G. E. (2017, October). Echo: A large display interactive Visualisation of icu data for effective care handoffs. In *2017 IEEE workshop on visual analytics in healthcare (VAHC)* (pp. 47-54). IEEE.

Thurgood, G. (1995). Verbal handover reports: what skills are needed?. *British Journal of Nursing,* 4(12), 720-722.

Tong, W., Xia, M., Wong, K. K., Bowman, D. A., Pong, T. C., Qu, H., & Yang, Y. (2023, March). Towards an understanding of distributed asymmetric collaborative Visualisation on problem-solving. In *2023 IEEE Conference Virtual Reality and 3D User Interfaces (VR)* (pp. 387-397). IEEE.

Van Eaton, E. G., Horvath, K. D., Lober, W. B., Rossini, A. J., & Pellegrini, C. A. (2005). A randomized, controlled trial evaluating the impact of a computerized rounding and sign-out system on continuity of care and resident work hours. *Journal of the American College of Surgeons*, 200(4), 538–545.

Wang, X., Besançon, L., Rousseau, D., Sereno, M., Ammi, M., & Isenberg, T. (2020, April). Towards an understanding of augmented reality extensions for existing 3D data analysis tools. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1-13).

Willett, W., Jansen, Y., & Dragicevic, P. (2016). Embedded data representations. *IEEE transactions on Visualisation and computer graphics*, *23*(1), 461-470.

Wüller, H., Garthaus, M., & Remmers, H. (2017). Augmented reality in nursing: designing a framework for a technology assessment. In *MEDINFO 2017: Precision Healthcare through Informatics* (pp. 823-827). IOS Press.

Zheng, M., Pan, X., Bermeo, N. V., Thomas, R. J., Coyle, D., O'hare, G. M., & Campbell, A. G. (2022). Stare: Augmented reality data Visualisation for explainable decision support in smart environments. *IEEE Access*, *10*, 29543-29557.

# Part 2

# Final Thesis

# Toward a User-Informed AR System for ICU Nurse Handover: A Qualitative Exploratory Study

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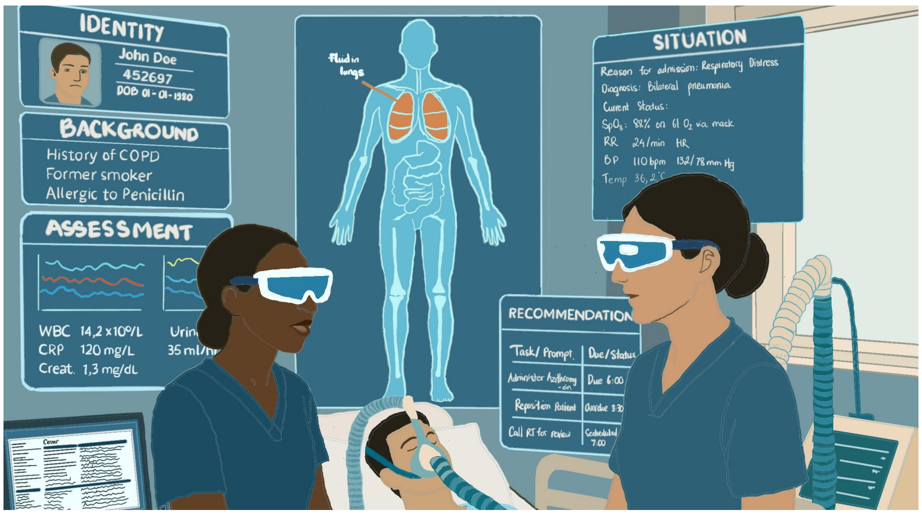


Fig. 1. Illustration of an AR-supported ICU handover using situated visualisation. ISBAR-aligned data panels are overlaid near relevant physical referents to support cognitive offloading and streamline clinical communication.

Effective communication during ICU handovers is vital yet challenged by fragmented electronic records, inconsistent ISBAR use, and cognitive overload. This qualitative exploratory study adopts a Design Science Research approach to investigate how augmented reality (AR) can support ICU nurse handovers. Semi-structured interviews with ICU nurses revealed key issues with current handover tools and practices. Thematic analysis identified six design priorities: unified AR dashboards, embedded ISBAR checklists, situated visualisations, semi-structured customization, hands-free interaction, and shared visibility for collaboration. While no prototype was built, the study produced a user-informed conceptual design artifact that addresses both cognitive and workflow challenges. These findings offer grounded design recommendations for developing AR systems that enhance information clarity, reduce mental effort, and foster collaborative, efficient handovers in high-acuity care settings.

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CCS Concepts: • **Human-centered computing → Mixed / augmented reality**.

Additional Key Words and Phrases: Augmented Reality (AR), Mixed Reality, ICU Nurse Handover, Workflow Support, Clinical Communication, Situated visualisation, Health Informatics

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## 1 Introduction

The handover process in Intensive Care Units (ICUs) plays a vital role in ensuring patient safety and maintaining continuity of care. During shift changes, nurses are required to transfer large amounts of complex patient information in a short period of time. However, traditional handover methods, such as verbal communication and handwritten notes, often lead to errors and inconsistencies, especially in high-pressure ICU settings [7, 22]. Communication failures have been associated with serious safety risks, with studies showing that they contribute to up to two-thirds of sentinel events in hospitals [36].

ICU Nurses face several challenges during handovers, including frequent interruptions, inconsistent communication practices, and a heavy cognitive load caused by the need to recall and prioritize large amounts of information under time pressure. Compared to doctors, nurse handovers are often longer and more frequently interrupted, increasing communication burden [22]. Although structured frameworks such as ISBAR have been introduced to improve the quality of handover, they are not always used consistently or effectively in practice [9]. This lack of standardization can result in missing or inaccurate information, increasing the chance of clinical errors, and compromising patient care. Furthermore, ICU nurses often have to manage urgent clinical tasks during handover, which further reduces their attention and increases the chance of mistakes [2].

Given these ongoing issues, there is a need for innovative solutions to support effective communication during handovers. One area of growing interest is the use of augmented reality (AR) technology in healthcare. AR allows digital information to be displayed over the physical environment, often through head-mounted displays, allowing users to access data in real time while keeping their hands free. In nursing and medical education, AR has shown the potential to improve learning engagement and task performance [38]. In clinical practice, AR has also been used to assist in procedures, diagnostics, and visual data analysis [21, 33, 44].

Prior studies have also explored the potential of AR to improve communication and decision-making process in complex environments. Zheng et al. [45] demonstrated that semantic AR overlays in smart environments can reduce cognitive load and enhance decision support, while Albrecht-Gansohr et al. [3] illustrated how AR can assist in nursing documentation and interaction work. Although these studies offer transferable insights, none have directly investigated the use of AR to support nurse-to-nurse handovers in intensive care settings. Our study seeks to address a critical literature gap by examining how augmented reality can support communication during handovers among ICU nurses. Specifically, we investigate nurses' experiences with existing handover tools and practices and explore their perspectives on the potential role of AR in addressing these challenges. By adopting a qualitative exploratory methodology, our study aims to elicit user needs, expectations, and concerns surrounding the integration of AR in high-acuity ICU environments for nurses during their handover process.

Through in-depth interviews with front-line nursing staff, our study generates empirically grounded contributions to the design of AR systems for ICU handover contexts. First, we demonstrate how fragmented access to patient data across systems such as Cerner[1], handwritten notes, and verbal memory contributes to cognitive overload and inconsistent information transfer. Second, we identify opportunities for AR to alleviate cognitive demands through embedded ISBAR checklists, spatially organized prompts, and real-time task reminders. Third, we find strong support for situated visualisations, such as anatomical overlays and dynamic vital sign displays, as tools to enhance clinical understanding, facilitate medical education, and bridge verbal-visual communication gaps. Fourth, we highlight the need to balance standardization with personalization, advocating for semistructured AR interfaces that accommodate individual preferences while preserving consistency and safety. Fifth, we discuss critical concerns about usability and data privacy, emphasizing the importance of ergonomic headset design, low-fatigue interaction methods, and secure access controls. Finally, we uncover expectations for AR to support collaborative handover by enabling shared visual access, parallel interaction, and continuity planning across nursing teams.

Collectively, our findings inform concrete design implications that move beyond theoretical speculation, offering a user-informed foundation for the development of AR applications that are technically feasible, clinically relevant, and socially adoptable. Situated within the fields of information systems and human–computer interaction, our study contributes to broader efforts to design emerging technologies that enhance communication accuracy, workflow efficiency, and patient safety in complex healthcare environments.

## 2 Related work

This section reviews existing literature in three key areas that inform the direction and design of our research: (1) the nurse handover process, (2) data visualisations for electronic health records (EHRs), and (3) the use of augmented reality (AR) in clinical contexts. These domains collectively reveal a gap in current clinical communication tools, particularly within high-acuity environments like the intensive care unit (ICU), that our research aims to address. Specifically, we seek to investigate how AR technologies can improve the efficiency, clarity, and cognitive support of the nurse handover process by enhancing the way patient information is visualised and contextualised.

### 2.1 Nurse Handover Process

The nurse handover process is fundamental to ensuring continuity and safety in clinical care, especially within ICU settings where patients' conditions are critical. Handover typically occurs at the end of a nurse's shift and involves communicating key patient details to the incoming staff. In practice, however, this process is frequently affected by inconsistent communication styles, time constraints, and interruptions, all of which pose a risk to patient safety [7, 35]. To improve the structure of these interactions, many Australian hospitals have adopted the ISBAR communication tool, a framework designed to guide the handover conversation shown in Figure 2. ISBAR stands for Introduction, Situation, Background, Assessment, and Recommendation, and provides a sequential approach to discussing patient cases. Although ISBAR is widely promoted for its clarity and simplicity, studies show that it is not always implemented consistently or completely in practice, particularly during high-stress ICU shifts [18, 22]. Verbal handovers relying solely on memory, even when supported by ISBAR, are susceptible to omissions and misinterpretations.

In parallel, digital tools have been introduced to support handovers, the most common being Cerner, an electronic health record (EHR) system used extensively in hospitals globally. Cerner allows clinicians to document and retrieve

[1]Cerner system, also known as Oracle Health: https://www.oracle.com/health/

| | |
|---|---|
| **I**<br>**Identity** | **Who you are and what is your role?**<br>> Patient's MRN, Name and DOB<br>> Name and title/role of staff handing over |
| **S**<br>**Situation** | **What is going on with the patient?**<br>> Reason for admission (eg Hyperemesis @12 weeks)<br>> Diagnosis if known (eg Active stage of labour)<br>> Mode of delivery and date (eg LSCS for CTG changes)<br>> Operation and date (eg Vag hyste + A/P repair) |
| **B**<br>**Background** | **What is the clinical background/context?**<br>> Relevant previous history<br>eg Elective LSCS for breech, allergic to penicillin, any social issues of note |
| **A**<br>**Assessment** | **What do I think the problem is?**<br>> Latest clinical assessment, clinical & investigations<br>eg VE: 4 cm ROT -1 @ 7.30<br>Urine output, Labs, Hb, B/P, pulse, temperature and respirations, pain score, patient anxiety |
| **R**<br>**Recommendation** | **What would you recommend?**<br>**Risks- patient/occupational health and safety?**<br>**Assign and accept responsibility/accountability**<br><br>> Actions required after handover (eg, Call surgeon for urgent consult – specify level of urgency with timeframe; "Dr Jones to discuss situation with patient and partner at 10:00 am")<br>> Risks - eg, eclampsia<br>> Assign individual responsibility for conducting any task |

Fig. 2. Illustration of the ISBAR communication tool derived from Clinical handover ISBAR fact sheet published by SA Health, Government of South Australia [37]

a wide array of patient information, from vital signs and medications to lab results and clinical notes. Despite its comprehensive data capture capabilities, Cerner's interface often requires users to navigate through multiple screens and menus to compile a full picture of a patient's status, as shown in Figure 3 [24]. This fragmentation increases the cognitive burden on ICU nurses, who must synthesise and prioritise large volumes of data within a limited timeframe during shift changes.

Furthermore, research by Pinevich et al. [32] indicates that ICU nurses spend approximately 22% of their shifts interacting with EHR systems such as Cerner, reflecting the intensity and time demand of data management tasks. Galatzan and Carrington [15] highlight how this interaction contributes to cognitive overload during handovers, as nurses are required to transform raw data into coherent clinical narratives under pressure. Communication can also be compromised when the EHR does not easily allow for quick overviews or prioritisation, leading to reliance on memory or improvised notes.

Limitations in standardised protocols and EHR platforms reveal a key gap: while tools like ISBAR and Cerner offer structure and data access, they fall short in meeting the cognitive, spatial, and real-time demands of ICU handovers. Our research proposes an AR-based solution that integrates real-time patient data into the clinical environment in a hands-free, spatially aligned format to reduce cognitive load and improve handover clarity and efficiency.

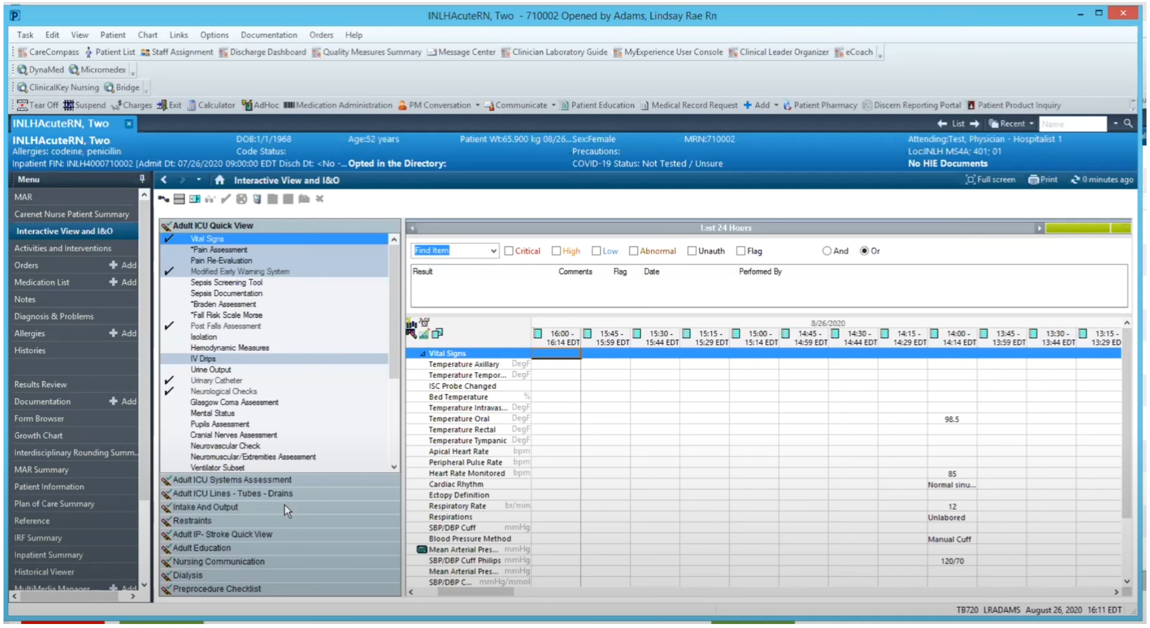


Fig. 3. Screenshot of "Vital Signs Charting" screen on Cerner [1]

## 2.2 Data Visualisations for Electronic Health Records

The move from paper-based to digital records has created new opportunities to improve how clinical information is presented and accessed. Studies have shown that data visualisation can enhance understanding and communication during nurse handovers. However, many electronic systems still struggle with usability, integration, and cognitive support despite better structure and data completeness.

Visualisation tools like WardManager have demonstrated potential in improving communication outcomes. This web-based system structured handover data into categories such as problem lists, medications, allergies, and team to-do items and resulted in a 50% reduction in perceived near-miss events [30]. Similarly, Echo, developed by Thomas et al. [41], used a combination of large screen displays and personal devices to visualise ICU patient data using card-based layouts, colour-coded alerts, and trend glyphs. This system enabled clinicians to rapidly detect anomalies and supported both group discussions and individual assessments. HILARY [18] compared digital dashboards to traditional paper-based ISBAR handover sheets and found that digital interfaces improved both efficiency and user satisfaction. Nurses reported that being able to view patient timelines, coded risk scores, and key statistics on a single interface helped them better understand clinical priorities. These findings support the notion that visual representations can reduce reliance on memory and improve communication quality.

However, these systems also exhibit important shortcomings. Tools like Echo, while effective in static environments, still depend on conventional screens and require manual interaction, which can interrupt clinical workflows. Moreover, many EHR-based visualisations present data in a non-contextual format, forcing nurses to mentally connect disparate information points across tabs or dashboards [24]. In practice, these fragmented interfaces can increase cognitive load rather than alleviate it. Another concern is the limitation of physical hardware. ICU nurses often interact with tablets or wall-mounted monitors, which may constrain screen space, require touch input, and demand visual attention that could otherwise be directed toward patients or colleagues [41]. These conditions are not conducive to seamless or efficient handovers, especially when teams must process and discuss information simultaneously.

These insights indicate a critical need for a visualisation approach that goes beyond flat displays and non-interactive dashboards. Our research addresses this limitation by applying AR technology to present patient information as spatially embedded overlays in the physical environment. By aligning data with physical referents such as the patient's bedside or equipment, we aim to facilitate faster pattern recognition, reduce screen-switching, and support more intuitive information sharing during handovers.

### 2.3 Augmented Reality in Clinical Contexts

Augmented Reality (AR) presents a promising way to address interface and cognitive challenges in current handover tools. By overlaying digital data onto physical surroundings, AR supports situated cognition, helping nurses interpret and act on information in context. Unlike traditional screens, AR provides hands-free access, spatial alignment, and real-time updates, features well-suited to the ICU's fast-paced, multitasking environment. Previous research has demonstrated the feasibility and effectiveness of AR in various clinical scenarios. Wüller et al. [44] and Klinker et al. [21] showed that AR can improve nursing efficiency by supporting real-time documentation and reducing the need to shift focus between digital systems and patient care tasks. More recently, Albrecht-Gansohr et al. [3] evaluated an AR prototype for wound documentation and found that nurses could record pain scores and treatment progress without interrupting care delivery. These results suggest that AR can improve both workflow efficiency and nurse autonomy.From a cognitive perspective, AR has also been found to reduce information overload. Millais et al. [27] showed that users of immersive environments such as AR and VR made fewer errors and reported lower mental workload than those using 2D displays.

The concept of situated and embedded visualisation, discussed by Willett et al. [43] and Bressa et al. [6], reinforces the value of placing information close to its physical referents. For example, overlaying vital sign trends next to a patient monitor or displaying medication schedules above an infusion pump improves immediacy and reduces mental mapping efforts. These principles are especially relevant in handovers, where nurses must quickly evaluate the patient's current condition in relation to treatment goals.

In addition to supporting individual users, AR also enables collaborative immersive analytics. Research by Chen et al. [8] and Tong et al. [42] found that shared AR or VR environments improved communication, task division, and mutual understanding in analytical tasks. Participants using shared spatial views were more engaged and coordinated, which aligns with the collaborative nature of ICU handovers that often involve nurses, doctors, and allied health professionals.

Despite its potential, AR remains underused in nursing handovers, with most applications focusing on education or surgery rather than real-time communication and workflow support. Few systems integrate with EHRs like Cerner or align with protocols such as ISBAR.

Our research addresses this gap by designing and evaluating an AR system tailored to ICU handovers. By enabling spatially embedded, hands-free visualisation, we aim to help nurses extract, prioritise, and communicate information more effectively, advancing AR into a critical yet underexplored area with potential to enhance workflow efficiency and patient safety.

## 3 Method

Our study adopts a qualitative exploratory approach situated within the design science research (DSR) paradigm, as outlined by Hevner et al. [16], to investigate the requirements for an augmented reality (AR) system that supports ICU

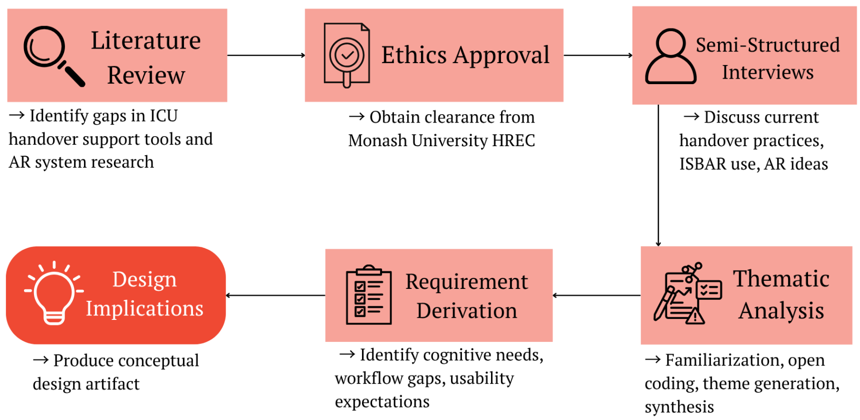


Fig. 4. Research Methodology Framework

nurse handovers. The diagram shown in Figure 4 illustrates the step-by-step methodology adopted in this study, from exploratory data collection to design-oriented outputs, aligned with the early-stage activities of the DSR paradigm. Given the limited prior research on AR in this clinical context, an exploratory approach is appropriate for generating context-specific insights into nurses' communication practices, cognitive needs, and system usability. Within DSR, the research aligns with early-stage activities focused on understanding the environment and problem space, which Hevner et al. [16] describe as essential for producing relevant and useful artifacts.

Exploratory research, as defined by Stebbins [39], seeks to build foundational understanding in under-theorized domains through inductive, flexible inquiry. Creswell and Poth [10] similarly emphasize the value of qualitative exploration for capturing participant perspectives in complex, real-world environments, such as high-acuity healthcare settings. This justifies the use of semi-structured interviews, which enable participants to reflect on current handover practices and imagine how AR tools might support clinical workflows.

Our study produced a set of user-informed system requirements and interface concepts that function as a conceptual design artifact within the DSR paradigm. According to Guideline 1 of Hevner et al. [16], artifacts may include models, methods, and design recommendations, especially in early-stage research. Rather than building a fully functional AR system, this phase focuses on articulating design insights that address a clearly defined organizational problem: communication breakdowns in ICU nurse handovers (Guideline 2). As Peffers et al. [31] note, artifacts of this nature can be appropriately evaluated through informed argument and expert feedback, rather than technical testing, making them a valid DSR contribution even at the conceptual stage.

To inform this design artifact, our study employed a requirement elicitation process rooted in domain-specific, semi-structured interviews with ICU nurses. This approach allowed participants to express both explicit needs and tacit challenges tied to their handover practices. Hickey and Davis [17] emphasize that effective elicitation techniques should be selected based on the context of use, a principle directly reflected in the clinical setting of this study. Similarly, Preece et al. [34] advocate for early stakeholder involvement in interactive system design, underscoring the value of engaging nurses as expert users. These methods ensured that the requirements derived were not only grounded in real-world practice but also actionable for informing future system development.

### 3.1 Data collection

We conducted individual, in-depth, semi-structured interviews with three nurses. Two sessions were held online via Zoom[2], and one in person between December 2024 and March 2025, lasting 45–60 minutes. Interviews were audio-recorded with signed consent forms obtained prior to each session. The study was approved by the Monash University Human Research Ethics Committee (see Appendix A).

Two participants were experienced ICU nurses (Nurse A and B), and the third was a scrub scout nurse (Nurse C). Interviews with ICU nurses explored current handover practices, challenges during shift transitions, cognitive workload, and perceptions of how augmented reality (AR) could enhance handover accuracy, efficiency, or clarity. A structured interview protocol (see Appendix B) guided the discussion, covering ISBAR usage, communication risks, handover tools, and interactions with electronic health records like Cerner.

The scrub scout nurse interview began with the same questions but was later adapted to reflect perioperative workflows. Follow-up prompts focused on identifying shared handover elements relevant to ICU contexts.

Participants also viewed a short video of prior AR health visualisation prototypes, such as digital patient twins and data overlays, which supported discussion on potential system features, interaction methods (e.g., gaze, voice, hand gestures), privacy concerns, and practical ICU integration.

### 3.2 Data analysis

To analyze the interview data, this study employed thematic analysis, guided by the six-phase process of Braun and Clarke [5]. The relevance of this approach in healthcare research is supported by Kiger and Varpio [20], who underscore its validity and methodological rigor within medical education and clinical settings. This method was selected for its flexibility in capturing complex, context-specific experiences, particularly valuable in clinical settings where individual perspectives are critical. Thematic analysis enables inductive theme development, allowing insights to emerge from participant narratives. Well-suited to exploratory research, it focuses on frontline needs and design-relevant patterns. The process included data familiarization, open coding, theme generation, and iterative synthesis, ensuring both rigor and depth. Aligned with a constructivist stance, this approach grounds findings in the lived experiences of ICU nurses.

NVivo[3] 15 was chosen to manage the analysis due to its robust capabilities in qualitative data organization and systematic coding. The software not only ensured consistency in how codes were applied across interviews but also enabled the researcher to track emerging patterns, co-occurrences, and frequency with clarity.

To enhance transparency, Table 1 presents selected participant quotes alongside their corresponding codes and thematic categories, demonstrating the analytical progression from raw data to abstracted themes. This traceability strengthens the trustworthiness of the analysis.

Ultimately, the themes derived through this method inform a set of practical design recommendations, constituting an early but critical Design Science Research (DSR) contribution. Although no system has yet been implemented, the insights have guided the development of a conceptual design artifact, laying the groundwork for iterative prototyping and evaluation in future research cycles, in line with the build-and-evaluate loop central to DSR methodology.

## 4 Findings

The interviews revealed several interrelated challenges and opportunities surrounding ICU handover practices. While all participants operated within the same electronic and procedural framework, their experiences highlighted significant

[2]Zoom video conferencing platform: https://zoom.us
[3]NVivo data analysis tool: https://lumivero.com/product/nvivo/

Table 1. Examples of Quotes, Codes, and Themes from Thematic Analysis

| Quote (Raw Data) | Initial Code | Theme |
|---|---|---|
| "There's just too many tabs… I'm still learning…" – Nurse A | Fragmented interface; information overload | Fragmentation of Information |
| "So, Cerner's big with all sorts of different, at my hospital anyway, there's lots of different parts you can access for your patient... you'd go in any order" – Nurse B | Multiple data sections; unstructured navigation | Fragmentation of Information |
| "If it's in terms of information, it's all scattered. In Cerner, you've got different tabs, like patient background and history, assessments, and then previous surgeries, which are in another tab, like doctors' notes." – Nurse C | Scattered information; multi-tab interface; fragmented patient history | Fragmentation of Information |
| "Everyone just wants to go home… there's always something that's forgotten." – Nurse A | Fatigue; risk of omission | Cognitive Overload and Risk of Forgetting |
| "If the patient's very sick and there's lots to hand over… you've had a really, really busy shift, it can be easy to forget stuff" – Nurse B | Memory lapses after demanding shifts | Cognitive Overload and Risk of Forgetting |
| "That body, maybe next to the patient, that would be a good representation of what's happening inside." – Nurse B | Visualizing internal condition; digital twin | Visualisation as a Cognitive Aid |
| "I think the data with a 3D model is a good idea… like if something updated, it would show up on the virtual figure. That would help with clinical judgment," – Nurse C | Real-time 3D model updates for clinical decision support | Visualisation as a Cognitive Aid |
| "It would be cool to have reminders of what you need to do… so you have an efficient shift." – Nurse A | Task reminders for shift efficiency | Visualisation as a Cognitive Aid |

variation in how information was accessed, communicated, and retained. These recurring patterns formed the basis for six core themes that capture the practical, cognitive, and collaborative dimensions of the handover process. Each is detailed in the subsections that follow.

### 4.1 Fragmentation of Information Across Tools

Participants consistently described challenges in accessing a complete picture of the patient during handovers. Although EHR systems like Cerner were widely used, vital signs, medications, lab results, and notes were scattered across multiple tabs. As Nurse A put it, "There are a lot of tabs… it was hard to navigate," highlighting both the interface complexity and the ongoing learning curve.

Without clear guidelines on how to prioritise information, nurses relied on individual judgment, resulting in handover inconsistency. Nurse B explained, "You look at documentation… then results… then the drug chart," while Nurse C described it as "all scattered," with data like patient background, assessments, and previous surgeries each in different tabs.

To manage this, nurses often used parallel tools. Outgoing nurses typically used Cerner to gather data, while incoming nurses jotted down key points using pen and paper or the computer's notepad. Nurse B observed, "Sometimes people use the notepad… or pen and paper. Or sometimes nothing at all," reflecting wide variation. Nurse A similarly noted, "I use paper and pen when I'm receiving handover, and the other nurse would have a computer," adding that "some people actually don't have anything. They just listen and remember everything."

Together, these insights reveal a deeper issue: while patient data is technically accessible, its fragmented presentation and the lack of standardised handover practices compromise both usability and consistency. In the high-stakes, time-sensitive environment of ICU care, this gap not only increases cognitive burden, but it also poses risks to communication quality and patient safety.

### 4.2 Cognitive Overload and Risk of Forgetting

Many participants reported experiencing cognitive overload during handovers, especially at the end of demanding shifts. For nurses giving handover, fatigue often led to memory lapses. As Nurse B noted, "If the patient's very sick and there's lots to hand over… it can be easy to forget stuff." Nurse A similarly shared, "Sometimes the other nurse or I would miss a lot of things… we always miss information, it's always something that's forgotten."

Nurses receiving handovers also described difficulty retaining rushed or incomplete information. Some used pen and paper to compensate, while others cross-checked details afterward. As Nurse B explained, "I trust what the person is telling me, but I always go back to the computer and check… you can't trust everything everyone says."

Although ISBAR was widely recognised, participants acknowledged that it wasn't always followed consistently. Under pressure, nurses often reverted to memory or a non-linear flow. As Nurse B reflected, "Sometimes people are not doing ISBAR… their head's a bit scattered from the shift."

These insights reveal a recurring issue: ICU handovers remain vulnerable to human error. Despite structured protocols, the lack of cognitive support tools and high reliance on memory increase the risk of miscommunication.

### 4.3 Visualisation as a Cognitive Aid

Participants expressed strong enthusiasm for integrating visual and spatial tools into the handover process, noting their potential to improve understanding and ease cognitive load. A particularly compelling idea was a "digital twin", a real-time anatomical model overlaid with vital signs, interventions, and lab updates. Nurse B described how a virtual body next to the patient could illustrate internal conditions: "That body… next to the patient… would be a good representation of what's happening inside." Nurse C similarly supported a dynamic 3D model that updates with new data, stating, "If something updated, it would show up on the virtual figure. That would help with clinical judgment."

Beyond anatomy, participants also valued features for task management. Nurse A suggested that built-in reminders could support shift efficiency: "It would be cool to have reminders… so you have an efficient shift."

Together, these insights support the use of embedded, situated visualisations, like anatomical overlays and contextual prompts, to improve situational awareness and reduce memory reliance during ICU handovers.

### 4.4 Standardization vs. Personalization

While ISBAR was consistently cited as the standard handover protocol, participants emphasized that nurses inevitably develop personalized routines for communicating patient information. This blend of structure and flexibility was particularly pronounced in the ICU, where the complexity and acuity of patients often necessitated deeper, more tailored communication.

As Nurse B explained, "Everyone develops their own way, but we all base it off ISBAR," suggesting that while ISBAR provides a foundational structure, individual adaptations are common. Nurse A further highlighted the distinct nature of ICU handovers, noting, "In ICU, we look at all the systems… way more sick than usual patients," which often requires more comprehensive coverage than the standard framework anticipates. Similarly, Nurse C reflected on how the protocol is adapted in practice: "ISBAR is alright, but we tweak it… everyone uses it differently depending on the case."

These accounts underscore that while standardization provides consistency, it does not fully capture the fluid and context-sensitive nature of real-world ICU handovers. As such, any supportive technology, such as an AR handover tool, must not only reinforce core ISBAR principles but also accommodate user preferences and clinical variation, enabling flexible application without undermining structure.

### 4.5 Usability, Privacy, and Adoption Concerns

Participants raised several practical concerns about implementing AR in clinical environments, focusing particularly on usability and accessibility. Discomfort associated with wearing headsets, the potential for motion sickness, and the steep learning curve, especially for older or less tech-confident staff, were seen as significant barriers. For example, Nurse A recalled, "I did feel dizzy after... adjusted the headset, and it was fine," highlighting that physical discomfort may require adaptation time. Nurse B added that "older nurses [might] not like that because they struggle sometimes on the computer anyway," pointing to potential resistance rooted in digital literacy challenges.

Despite these concerns, participants also identified advantages. One notable benefit was the potential for enhanced privacy, since AR limits data visibility to the headset user. As Nurse A explained, "Visitors can see the screen... It's not allowed," referring to current shared screen setups that risk exposing patient information in public or semi-private spaces.

In addition to usability and privacy, participants stressed the importance of maintaining access to existing systems like Cerner, ensuring robust data security, and establishing clear policies around the storage and use of AR devices. These insights reflect a balanced perspective: while AR offers promising advantages for ICU handover, its successful adoption will depend on thoughtful integration with current workflows, strong security measures, and attention to end-user experience.

### 4.6 Collaborative Potential of AR in ICU Handover

Participants saw strong potential for AR to enhance collaboration during ICU handovers, particularly through shared visibility, co-interaction, and continuity of care. A consistent theme was the expectation that all staff involved in the handover should access the same visual information in real time. As Nurse A noted, "You'd want them to see what you're seeing as well… it'd be quite weird if I'm the only one wearing headsets and they can't see what I'm talking about." This emphasis on co-viewing reflects a desire for mutual understanding during information exchange.

Shared visualisation was also viewed as beneficial for explaining clinical conditions. “It would be very easy for us to explain… if they can’t see what I’m talking about,” Nurse A added. Nurse B reinforced this point, suggesting AR visualisations could serve as a teaching and communication aid: “All the information popping up… that would be a great teaching tool for all staff members, not just new ones.” He further explained, “Maybe that tool is a good use of being like, ‘Oh, that’s what it actually looks like inside,’” highlighting AR’s potential to make clinical states more interpretable.

Participants also discussed how co-interaction might support more active engagement. Nurse A suggested that the incoming nurse could navigate the AR system during handover, although he noted the risk of distraction. He also described tool-based disruptions: “Sometimes the nurse would steal my mouse and look for it while I’m still doing a handover… all the information that I’m trying to say is gone,” illustrating the need for parallel, non-intrusive access.

Finally, Nurse C envisioned AR as a shared, up-to-date interface that could reflect recent changes in patient data through a virtual 3D model. These perspectives collectively highlight AR’s potential to serve as a shared, structured medium for communicating complex patient information, ultimately supporting safer, clearer, and more coordinated handovers in high-pressure clinical environments.

## 5 Discussion

This study explored ICU nurses’ handover experiences to elicit design requirements for an augmented reality (AR) application intended to support more efficient, accurate, and contextual communication during shift transitions. Drawing from the themes identified in the findings, this section interprets their implications in relation to system design, human-computer interaction, and the broader goals of clinical safety and workflow optimization.

### 5.1 Addressing Information Fragmentation through Spatially Anchored AR Displays

Building on the identified fragmentation of data across EHR tools, a key design implication is the need to move beyond conventional dashboards and toward spatially anchored AR interfaces. Rather than aggregating data into a flat panel, the AR system should contextualize information within the user’s visual environment by linking specific content to meaningful spatial positions around the patient. For instance, patient background information can be positioned near the upper torso, vital signs mapped over the chest and lungs, and actionable recommendations anchored beside the bed.

This spatial organization is not only intuitive but also supported by empirical research. Dhar et al. [11] demonstrate that AR-based educational tools significantly improve learning outcomes by enabling users to interact with anatomical data in three-dimensional space. Their review shows that spatially embedded AR supports comprehension, memory recall, and contextual awareness by allowing learners to explore structural relationships from multiple angles. This affirms the potential of placing clinical data, such as vital signs or medications, in corresponding physical locations to reinforce mental models and improve information handover accuracy.

Additionally, Lee et al. [23] identify a set of design patterns for situated AR visualisation that prioritize perceptual alignment and task relevance. They show that when data is positioned within the user’s physical workflow, such as overlaid in the field of view, cognitive friction is reduced, interpretability is enhanced, and task performance improves. These findings offer compelling evidence that spatially persistent and context-aware interfaces are more effective than traditional dashboards, especially in high-pressure, time-sensitive environments like the ICU.

Together, these studies provide strong validation for implementing spatially distributed AR layouts in clinical handover contexts, helping nurses access critical information more naturally, collaboratively, and efficiently.

## 5.2 Reducing Cognitive Overload via Embedded Checklists and Prompts

The recurring experience of cognitive overload described by participants, especially during or after demanding shifts, highlights a critical need for augmented reality (AR) systems to function as cognitive scaffolds during ICU handovers. Nurses acknowledged that fatigue often compromised their ability to recall key details, with several noting that important information was "always something that's forgotten" during shift transitions. These lapses occurred despite broad familiarity with the ISBAR framework, which participants admitted was often inconsistently followed under pressure.

To mitigate these breakdowns, AR systems should embed structured, interactive ISBAR checklists directly into the user's visual field, anchored to the patient or bedside context, to provide persistent guidance throughout the handover. This approach can help nurses maintain structured communication even during high-stress situations by reducing reliance on short-term memory and preventing deviations from the ISBAR sequence. Findings from Pakcheshm et al. [29] reinforce this strategy: after training ICU nurses to use a standard ISBAR checklist, the completeness of handover communication significantly improved across all five domains, including patient history, condition updates, and care recommendations.

Moreover, as shown in Erikson et al. [13], checklists that are integrated into electronic or digital systems have demonstrated positive impacts on both clinical and process outcomes in the ICU. These tools act as procedural anchors, ensuring that essential content is not omitted, even under time pressure. When translated into AR, such systems can be further enhanced with context-aware prompts (e.g., "Meds due," "Vitals pending") that draw from live EHR data, surfacing critical tasks without the nurse needing to search across multiple sources.

By embedding structured communication aids and situational prompts directly into the handover workflow, AR systems can transform a cognitively taxing process into a guided, reliable experience, reducing the risk of omissions and improving communication quality in real time.

## 5.3 Enhancing Understanding through Situated visualisations

Participants identified a strong need for visual and spatial tools to support handover, particularly emphasizing the value of a real-time 3D "digital twin" that could display dynamic patient data such as vital signs, interventions, and lab results. Nurses noted that such representations would help reduce cognitive load, improve diagnostic clarity, and aid clinical judgment, especially during time-critical decisions or when communicating complex findings. These insights point to a design requirement for the AR system to feature anatomically anchored, data-linked overlays positioned near the patient's bedspace to provide a clear, situated understanding of internal conditions.

This aligns with findings from Moro et al. [28], who showed that AR-based anatomical visualisations significantly improve users' spatial comprehension and support reasoning in high-cognitive-load tasks. Similarly, Esperto et al. [14] demonstrated that holographic 3D models in surgical settings led to more informed decisions, with many clinicians altering their strategies after interacting with visual overlays. These studies confirm that spatially embedded and real-time AR visualisations are effective cognitive aids that can enhance decision-making and reduce abstraction in fast-paced clinical environments.

In the ICU handover context, integrating such features can support both experienced and novice nurses by enhancing situational awareness, minimizing memory reliance, and reinforcing alignment between visual data and verbal communication.

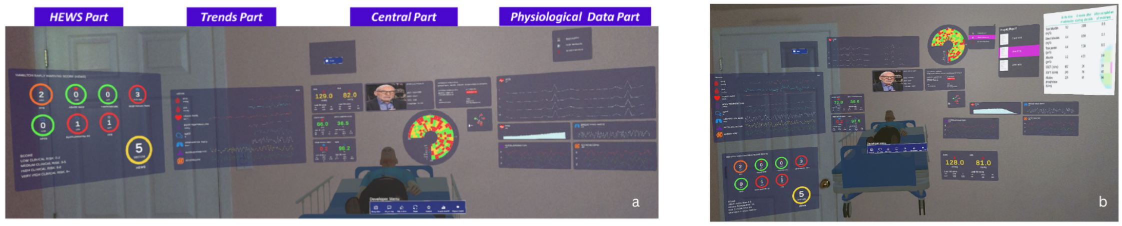


Fig. 5. MiVitals dashboard on Microsoft HoloLens. (a) Default layout with structured clinical panels. (b) User-customized view, zooming into BP panels, repositioning the radial chart, and focusing on physiological signals and liver test results [40]

### 5.4 Balancing Standardization and Personalization in AR Workflows

While ISBAR served as a standardized reference framework, participants emphasized that nurses often personalize their handover routines depending on the complexity of the patient and their own communication style. This tension between structure and flexibility mirrors findings in spatial memory studies involving AR environments. For example, Liu et al. [25] observed that users created their own organizational strategies to support information recall, even when no explicit structure was enforced. These strategies included using environmental landmarks (e.g., furniture) and egocentric cues (e.g., "top-left corner" or a “1–9 matrix”) to mentally organize virtual data in ways that suited their individual preferences.

These findings highlight the value of semi-structured AR interfaces, systems that maintain a consistent underlying framework while enabling lightweight personalization. A practical example is seen in the MiVitals system, which allowed users to move, resize, and arrange interface panels as shown in Figure 5. This personalization capability was associated with improved comfort and perceived usefulness during clinical workflows [40]. Based on this, our AR system should default to a structured, ISBAR-guided workflow, but also support limited customizations, such as repositioning UI elements, toggling the visibility of non-critical sections, or choosing from predefined layouts based on task type. This balance between consistency and adaptability is essential for accommodating different levels of experience while ensuring safety in high-stakes environments like the ICU.

### 5.5 Usability, Comfort, and Data Security Considerations

Finally, concerns were raised about physical comfort, usability, and privacy. The participants mentioned previous experiences with motion sickness and emphasized the need for AR systems that are physically comfortable to use during long or cognitively demanding shifts. To address this, the system design should avoid interaction methods that strain the eyes or body. For example, Jeon et al. [19] found that finger-gesture input led to significantly higher oculomotor discomfort compared to clicker-based input, and that interfaces placed at a viewing distance of 100 cm reduced visual strain. These findings suggest that the AR handover system should favor low-fatigue interaction methods, such as voice or handheld clicker input, and ensure UI elements are positioned at ergonomically optimal distances. A prominent example of this implication can be seen in the MiVitals system, where participants found voice commands to be intuitive and less fatiguing than prolonged gesture use; hands-free control was viewed as essential in multitasking environments like clinical care [40]. This supports the need for interaction designs that minimize physical burden while maintaining functionality during busy shift transitions.

In addition, participants stressed the importance of protecting patient privacy, indicating that sensitive information displayed in AR must not be visible to visitors or unauthorized personnel. This aligns with findings from Ara et al. [4], who emphasized that many existing AR healthcare applications lack standardized security protocols and are vulnerable to external threats such as data sniffing, interception, and unauthorized modification. The authors highlight that augmented platforms often transmit data without encryption or proper access control, increasing the risk of patient information being exposed to unintended parties. To mitigate such risks, the paper advocates for security-aware design approaches that include confidentiality, user authentication, and access regulation during real-time data collaboration. These insights reinforce the need for privacy-aware UI placement and robust access control mechanisms within shared clinical environments, especially where AR content may be visible in open physical spaces.

These findings collectively underscore the importance of designing AR systems that balance physical comfort with stringent data security. To support extended use in clinical environments, the system should emphasize ergonomic, lightweight headsets and favor low-fatigue interaction methods such as voice commands or clicker-based input. To protect sensitive patient information, especially in shared or open ICU settings, the AR system should incorporate robust role-based access controls and context-aware display management. In addition, security features such as auto-locking displays when the device is removed can help prevent accidental exposure of information. One participant also recommended the use of swipe-access lockers for secure device storage, further reinforcing privacy and accountability in real-world workflows.

### 5.6 AR Collaborative Environment

The findings suggest that ICU nurses perceive augmented reality (AR) as a promising means of enhancing collaboration during handovers, particularly by enabling shared visibility and supporting interactive, multi-user engagement. Participants emphasized that both outgoing and incoming nurses should be able to view the same AR content during handover, highlighting the importance of co-visibility in maintaining mutual understanding. As one nurse noted, it would feel disjointed and ineffective if only one person were using the headset while the other lacked access to the same visual information. This indicates a need for AR systems that facilitate synchronized visual experiences, either through dual headset setups or mirrored displays, ensuring that both parties can follow along and respond to the same information cues in real time. This aligns with prior research emphasizing that effective collaboration in immersive environments depends on communication, coordination, and social presence [12], all of which are critical in clinical handover contexts where mutual awareness and shared mental models are essential.

In addition to shared visibility, nurses expressed interest in the ability to interact with AR content independently during handover. The idea that one nurse could navigate the system to explore relevant data while listening to the handover reflects the importance of parallel interaction capabilities. Rather than relying on turn-taking or shared device control, the AR interface should support asymmetrical use, allowing each participant to engage with specific information relevant to their role without interrupting the overall communication flow. This perspective is supported by Matcha and Rambli [26] exploratory study, which found that participants working in AR-based collaborative learning environments often engaged in simultaneous activities, such as passing objects, pointing, reading, and writing, without the need to wait for one another. Their findings demonstrated that AR affords a natural setting for fluid, parallel interaction, enabling multiple users to contribute actively and continuously to a shared task. Applying this to ICU handover, enabling concurrent interaction with patient data may help reduce friction and ensure that information is conveyed clearly, even when the handover involves questions, clarifications, or additional data verification.

Taken together, these findings highlight the need for AR systems in ICU handovers to function as collaborative, real-time platforms. Rather than passive displays, they should support synchronized co-visibility via dual headsets or mirrored views, ensuring both nurses remain aligned on patient data. Interfaces must also allow for independent, asynchronous interaction without disrupting the shared context, which can be achieved through robust synchronization frameworks, such as edge computing. To guide consistent yet flexible workflows, features such as ISBAR-based prompts and contextual cues should be embedded. Designing for this balance between shared understanding and individual control is key to supporting safe, efficient collaboration in high-pressure ICU environments.

### 5.7 Implementation challenges and considerations

While participants acknowledged the collaborative potential of augmented reality (AR) in ICU handovers, they also identified key challenges for successful implementation. A primary concern was integrating AR with existing hospital systems. Although technical pathways exist, such as using Cerner's API to stream real-time patient data, participants noted that such integration is often cost-prohibitive. The expense of linking proprietary EHR systems like Cerner with emerging AR technologies presents a major barrier, particularly in resource-constrained settings.

Beyond cost, nurses stressed that real-time integration is essential for safe and effective handover. Access to the most current patient information, including lab results and diagnostics, was seen as non-negotiable. While manual data export from Cerner is technically feasible, it was viewed as a suboptimal workaround. Delays in data transfer increase the risk of outdated or incomplete records being handed over, potentially compromising clinical accuracy. Ideally, AR systems would synchronize live with the EHR, but achieving this remains complex and costly.

Although participants did not raise explicit concerns about privacy, the use of head-mounted AR displays introduces important considerations. These devices often include cameras and sensors that could inadvertently capture identifiable images of patients, visitors, or staff. While modern AR platforms offer features such as facial blurring and selective recording, hospitals must ensure these settings are properly configured and supported by robust data governance policies. Transparent communication about data collection and anonymization is essential to maintain trust among staff and patients.

Participants also cautioned against information overload and visual clutter. Although not framed explicitly as collaborative concerns, these issues are highly relevant in the cognitively demanding ICU setting. Even though ICU nurses typically manage only one or two patients, the complexity of each case requires constant monitoring and rapid interpretation. Overly complex overlays or poorly structured displays can distract rather than support. Participants emphasized that the AR interface should present only nurse-relevant data in a clear, role-specific format to reduce cognitive burden and support decision-making.

Participants also anticipated several implementation challenges related to training and adoption of AR systems. Many nurses, particularly those with limited exposure to AR/VR or from older generations, may face steep learning curves and hesitation due to unfamiliarity with gesture-based or voice-controlled interactions. Successful integration will require formal training programs, ongoing support, and hands-on practice to help staff, especially new or digitally inexperienced nurses, build confidence and adapt to the evolving handover technologies.

Taken together, these challenges show that while AR holds promise for improving ICU handovers, its design must align with clinical realities. Systems must balance capability with affordability, ensure data currency and accuracy, uphold privacy standards, and minimize cognitive friction. Addressing these considerations will be essential to enabling broader integration of AR into routine ICU practice.

### 5.8 Limitations and Future Work

This study focused exclusively on the use of augmented reality (AR) to support handovers among ICU nurses. While the ISBAR framework offers a shared structure across departments, handover practices and communication priorities vary between clinical settings. ICU handovers often involve dynamic physiological data and critical treatment decisions, unlike other departments that may focus more on broader clinical continuity. Compared to other units, ICU nurses typically process more detailed information during handovers, making them particularly suited for AR-based data visualisation. Accordingly, the findings and design considerations in this study are context-specific and not intended for direct generalisation beyond the ICU.

The study's exploratory nature also presents limitations. While it captured rich qualitative insights and translated them into actionable design requirements, it did not include the development of a fully functional AR prototype or real-world testing. Collaborative features such as synchronized visual layouts and continuity tools were conceptually developed and validated through user interviews but were not implemented or evaluated hands-on, reflecting the study's foundational scope within a one-year timeframe.

Although real-time data integration with systems like Cerner was discussed, this study did not attempt to develop or test such functionality. Participants viewed live data access as ideal for clinical accuracy but acknowledged that full API integration may be cost-prohibitive. Manual data transfer remains feasible but is not preferred in practice and highlights ongoing technical challenges.

Future work will involve developing a high-fidelity AR prototype incorporating collaborative interaction mechanisms, such as co-visibility, role-sensitive content filtering, and asynchronous navigation. This prototype should be evaluated through structured user studies with ICU nurses in simulated handover scenarios to assess usability, cognitive load, and communication effectiveness.

Additional research should explore system performance under common ICU constraints such as interruptions, shift overlaps, and documentation gaps. Real-time feedback in these contexts will be critical for validating and refining the system for practical deployment.

## 6 Conclusion

Our study explored how augmented reality (AR) could enhance ICU nurse handovers by supporting hands-free, spatially anchored presentation of patient information. Through interviews with ICU and perioperative nurses, we identified persistent challenges, including cognitive overload, fragmented access to clinical data, and variability in information recall, that hinder current handover practices. These findings informed the conceptual design of an AR system that enables intuitive interaction with critical data while aligning with nurses' physical routines and clinical priorities.

Rather than replacing standardized communication protocols like ISBAR, our proposed AR interface complements them by making key information more accessible, interpretable, and contextually situated. By visualising patient details around relevant spatial referents, the system may reduce cognitive burden and mitigate the risk of omitted or overlooked information.

Our research contributes to reimagining clinical communication workflows. By embedding visualisation directly into the handover context, we propose a more collaborative, situationally aware, and memory-supported mode of interaction. This approach has the potential to improve continuity of care, reduce handover errors, and ultimately enhance patient outcomes in the ICU setting.

## References


[1] Lindsay Adams. 2021. *Basic Cerner training for students.* Youtube. https://youtu.be/3uwLAM2eFSI?t=759

[2] Jung-Won Ahn, Hye-Young Jang, and Youn-Jung Son. 2021. Critical care nurses' communication challenges during handovers: A systematic review and qualitative meta-synthesis. *Journal of Nursing Management* 29, 4 (2021), 623–634.

[3] 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

[4] Jinat Ara, Faria Benta Karim, Mohammed Saud A Alsubaie, Yeasin Arafat Bhuiyan, Muhammad Ismail Bhuiyan, Salma Begum Bhyan, and Hanif Bhuiyan. 2021. Comprehensive analysis of augmented reality technology in modern healthcare system. *International Journal of Advanced Computer Science and Applications* 12, 6 (2021), 840–849.

[5] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[6] Nathalie Bressa, Henrik Korsgaard, Aurélien Tabard, Steven Houben, and Jo Vermeulen. 2021. What's the situation with situated visualization? a survey and perspectives on situatedness. *IEEE Transactions on Visualization and Computer Graphics* 28, 1 (2021), 107–117.

[7] Lean-Peng Cheah, Debbie H Amott, James Pollard, and David AK Watters. 2005. Electronic medical handover: towards safer medical care. *Medical Journal of Australia* 183, 7 (2005), 369–372.

[8] Lei Chen, Hai-Ning Liang, Feiyu Lu, Jialin Wang, Wenjun Chen, and Yong Yue. 2021. Effect of collaboration mode and position arrangement on immersive analytics tasks in virtual reality: a pilot study. *Applied Sciences* 11, 21 (2021), 10473.

[9] Mai O Colvin, Lewis A Eisen, and Michelle Ng Gong. 2016. Improving the patient handoff process in the intensive care unit: keys to reducing errors and improving outcomes. *Seminars in respiratory and critical care medicine* 37 (2016), 096–106.

[10] John W Creswell and Cheryl N Poth. 2016. *Qualitative inquiry and research design: Choosing among five approaches.* Sage publications, Thousand Oaks, California.

[11] Poshmaal Dhar, Tetyana Rocks, Rasika M Samarasinghe, Garth Stephenson, and Craig Smith. 2021. Augmented reality in medical education: students' experiences and learning outcomes. *Medical education online* 26, 1 (2021), 1953953.

[12] Shahin Doroudian. 2025. Collaboration in Immersive Environments: Challenges and Solutions. arXiv:2311.00689 [cs.HC] https://arxiv.org/abs/2311.00689

[13] Ethan J Erikson, Daniel A Edelman, Fiona M Brewster, Stuart D Marshall, Maryann C Turner, Vineet V Sarode, and David J Brewster. 2023. The use of checklists in the intensive care unit: a scoping review. *Critical Care* 27, 1 (2023), 468.

[14] Francesco Esperto, Francesco Prata, Ana María Autrán-Gómez, Juan Gomez Rivas, Moises Socarras, Michele Marchioni, Simone Albisinni, Rita Cataldo, Roberto Mario Scarpa, and Rocco Papalia. 2021. New technologies for kidney surgery planning 3D, impression, augmented reality 3D, reconstruction: current realities and expectations. *Current urology reports* 22 (2021), 1–9.

[15] Benjamin J Galatzan and Jane M Carrington. 2022. Communicating data, information, and knowledge in the nursing handoff. *CIN: Computers, Informatics, Nursing* 40, 1 (2022), 21–27.

[16] Alan R. Hevner, Salvatore T. March, Jinsoo Park, and Sudha Ram. 2004. Design science in information systems research. *MIS Q.* 28, 1 (March 2004), 75–105.

[17] A.M. Hickey and A.M. Davis. 2003. Elicitation technique selection: how do experts do it?. In *Proceedings. 11th IEEE International Requirements Engineering Conference, 2003.* IEEE, Monterey Bay, CA, USA, 169–178. doi:10.1109/ICRE.2003.1232748

[18] D HILARY. 2021. Evaluating how nurse communication during shift handovers can be improved using interactive data visualisation. *Ph. D. dissertation* 0, 0 (2021), 1.

[19] Hwaseung Jeon, Sunyoung Park, Yuryeon Lee, Hyun K Kim, Muhammad Hussain, and Jaehyun Park. 2020. Factors affecting motion sickness in an augmented reality environment. In *The 13th International Conference on Advances in Computer-Human Interactions.* 439–442.

[20] Michelle E Kiger and Lara Varpio. 2020. Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical teacher* 42, 8 (2020), 846–854.

[21] Kai Klinker, Manuel Wiesche, and Helmut Krcmar. 2020. Digital transformation in health care: Augmented reality for hands-free service innovation. *Information Systems Frontiers* 22, 6 (2020), 1419–1431.

[22] Yanika Kowitlawakul, Benjamin SH 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.

[23] Benjamin Lee, Michael Sedlmair, and Dieter Schmalstieg. 2023. Design patterns for situated visualization in augmented reality. *IEEE Transactions on Visualization and Computer Graphics* 30, 1 (2023), 1324–1335.

[24] 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.

[25] Jiazhou Liu, Kadek Ananta Satriadi, Barrett Ens, and Tim Dwyer. 2024. Investigating the Effects of Physical Landmarks on Spatial Memory for Information Visualisation in Augmented Reality. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR).* IEEE, 289–298.

[26] Wannisa Matcha and Dayang Rohaya Awang Rambli. 2013. Exploratory study on collaborative interaction through the use of augmented reality in science learning. *Procedia computer science* 25 (2013), 144–153.

[27] Patrick Millais, Simon L Jones, and Ryan Kelly. 2018. Exploring data in virtual reality: Comparisons with 2d data visualizations. In *Extended abstracts of the 2018 CHI conference on human factors in computing systems.* 1–6.

[28] Christian Moro, Zane Štromberga, Athanasios Raikos, and Allan Stirling. 2017. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical sciences education* 10, 6 (2017), 549–559.

[29] Behrouz Pakcheshm, Imane Bagheri, and Zohreh Kalani. 2020. The impact of using "ISBAR" standard checklist on nursing clinical handoff in coronary care units. *Nursing Practice Today* 7, 4 (2020), 266–274.

[30] Christina E Payne, Jason M Stein, Traci Leong, and Daniel D Dressler. 2012. Avoiding handover fumbles: a controlled trial of a structured handover tool versus traditional handover methods. *BMJ Quality & Safety* 21, 11 (2012), 925–932.

[31] Ken Peffers, Marcus Rothenberger, Tuure Tuunanen, and Reza Vaezi. 2012. Design science research evaluation. In *Design Science Research in Information Systems. Advances in Theory and Practice: 7th International Conference, DESRIST 2012, Las Vegas, NV, USA, May 14-15, 2012. Proceedings 7*. Springer, 398–410.

[32] 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.

[33] Vahid Pooryousef, Maxime Cordeil, Lonni Besançon, Christophe Hurter, Tim Dwyer, and Richard Bassed. 2023. Working with forensic practitioners to understand the opportunities and challenges for mixed-reality digital autopsy. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–15.

[34] J. Preece, H. Sharp, and Y. Rogers. 2015. *Interaction Design: Beyond Human-Computer Interaction*. Wiley. https://books.google.com.au/books?id=ZC1EDwAAQBAJ

[35] Ahmadreza Raeisi, Mostafa Amini Rarani, and Fatemeh Soltani. 2019. Challenges of patient handover process in healthcare services: a systematic review. *Journal of education and health promotion* 8, 1 (2019), 173.

[36] Lee Ann Riesenberg, Jessica Leisch, and Janet M Cunningham. 2010. Nursing handoffs: a systematic review of the literature. *AJN The American Journal of Nursing* 110, 4 (2010), 24–34.

[37] SA Health, Government of South Australia. 2016. *ISBAR A standard mnemonic to improve clinical communication*. https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/resources/isbar+a+standard+mnemonic+to+improve+clinical+communication Accessed 26 May 2025.

[38] Iliana Stavropoulou, Evanthia Sakellari, Anastasia Barbouni, and Venetia Notara. 2025. Community-based virtual reality interventions in older adults with dementia and/or cognitive impairment: A systematic review. *Experimental Aging Research* 51, 2 (2025), 162–189.

[39] Robert A Stebbins. 2001. *Exploratory research in the social sciences*. Vol. 48. Sage.

[40] Syed K Tanbeer and Edward Roderick Sykes. 2024. MiVitals–mixed reality interface for vitals monitoring: a HoloLens based prototype for healthcare practices. *Computational and Structural Biotechnology Journal* 24 (2024), 160–175.

[41] 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)*. IEEE, 47–54.

[42] Wai Tong, Meng Xia, Kam Kwai Wong, Doug A Bowman, Ting-Chuen Pong, Huamin Qu, and Yalong Yang. 2023. Towards an understanding of distributed asymmetric collaborative visualization on problem-solving. In *2023 IEEE Conference Virtual Reality and 3D User Interfaces (VR)*. IEEE, 387–397.

[43] Wesley Willett, Yvonne Jansen, and Pierre Dragicevic. 2016. Embedded data representations. *IEEE transactions on visualization and computer graphics* 23, 1 (2016), 461–470.

[44] Hanna Wüller, Marcus Garthaus, and Hartmut Remmers. 2017. Augmented reality in nursing: designing a framework for a technology assessment. In *MEDINFO 2017: Precision Healthcare through Informatics*. IOS Press, 823–827.

[45] Mengya Zheng, Xingyu Pan, Nestor Velasco Bermeo, Rosemary J Thomas, David Coyle, Gregory MP O'hare, and Abraham G Campbell. 2022. Stare: Augmented reality data visualization for explainable decision support in smart environments. *IEEE Access* 10 (2022), 29543–29557.

# A Ethics Application

**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:** | 45053 |
| **Application Type:** | Human Ethics Low Risk |
| **Project Title:** | AR-Facilitated Clinical Handover Process in Intensive Care Unit (ICU) Department |
| **Chief Investigator:** | Dr Joe Liu |
| **Approval Date:** | 07/11/2024 |
| **Expiry Date:** | 07/11/2029 |

**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.***

1. The Chief Investigator is responsible for ensuring that permission letters are obtained, if relevant, before any data collection can occur at the specified organisation.
2. Approval is only valid whilst you hold a position at Monash University.
3. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by MUHREC.
4. You should notify MUHREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash letterhead and the Monash University complaints clause must include your project number.
6. Amendments to approved projects including changes to personnel must not commence without written approval from MUHREC.
7. Annual Report - continued approval of this project is dependent on the submission of an Annual Report.
8. Final Report - should be provided at the conclusion of the project. MUHREC should be notified if the project is discontinued before the expected completion date.
9. Monitoring - the project may be subject to an audit or any other form of monitoring by MUHREC at any time.
10. Retention and storage of data - The Chief Investigator is responsible for the storage and retention of the original data pertaining to the project for a minimum period of five years.

Kind Regards,

Professor William Sievert

Chair, MUHREC

CC: Bao Truong, Dr Agnes Haryanto, Dr Ying Yang

**List of approved documents:**

| Document Type | File Name | Date | Version |
|---|---|---|---|
| Explanatory Statement | Explanatory statement | 12/10/2024 | 1 |
| Consent Form | 45053 - Consent form | 12/10/2024 | ICU nurse interview |
| Supporting Documentation | Interview Questions | 17/10/2024 | 1 |
| Supporting Documentation | Interview Invitation | 17/10/2024 | 1 |

Fig. 6. Approval certificate of Ethics application

## B Interview Questions

### Background – Data and Tools

- What tools (e.g., tablets, paper and pens, wall displays, or no tools) do you use every day for the handover process? Please answer this question from both perspectives (i.e., the nurse doing the handover and the nurse receiving the handover).
- What type of handover data do you gather for the upcoming handover process?
- Do you categorise handover information into different priorities?
- In your experience, what are the essential aspects of the nursing handover process?

### Handover Process

- Do you use the ISBAR framework for your handover process?
- What are the strengths of the current handover process?
- What are the weaknesses of the current handover process?
- What are the potential patient risks for a handover process?
- Do you normally fully rely on the handover data, or do you still need to check specific information after the handover?

### Requirements of Augmented Reality Application

- Have you used Virtual Reality (VR) or Augmented Reality (AR) headsets?
- Which steps in the handover process do you think could be replaced or deployed with an AR handover system?
- Which job/role in the handover process do you think could be equipped with an AR system?
- Do you think that it is a good idea to integrate the AR handover system with other tools in current practice, such as tablets, large screens, etc.?
- An AR application could support various interaction methods, such as via controllers, hand gestures, voice input, and gaze input. Which of these interaction methods do you think would be most beneficial for an AR handover system?
- What are the key features that you would look for in an AR handover system?
- What would be the risks you can imagine if you used an AR system for handover?
- The handover data is normally stored within the headset and managed by department staff unless the handover process requires remote collaboration. Would you be concerned about patient data security or privacy issues if the AR handover system were applied to your daily handover process?

### Evaluation Criteria

- What do you think are the benefits of using an AR system for handovers, and how do they compare to any extra effort or challenges it might add for staff?
- How do we evaluate the effectiveness of using AR systems for the handover process?
- How would you evaluate the safety criteria of using AR systems for the handover process?
- How would you evaluate other usability considerations of using AR systems for the handover process?