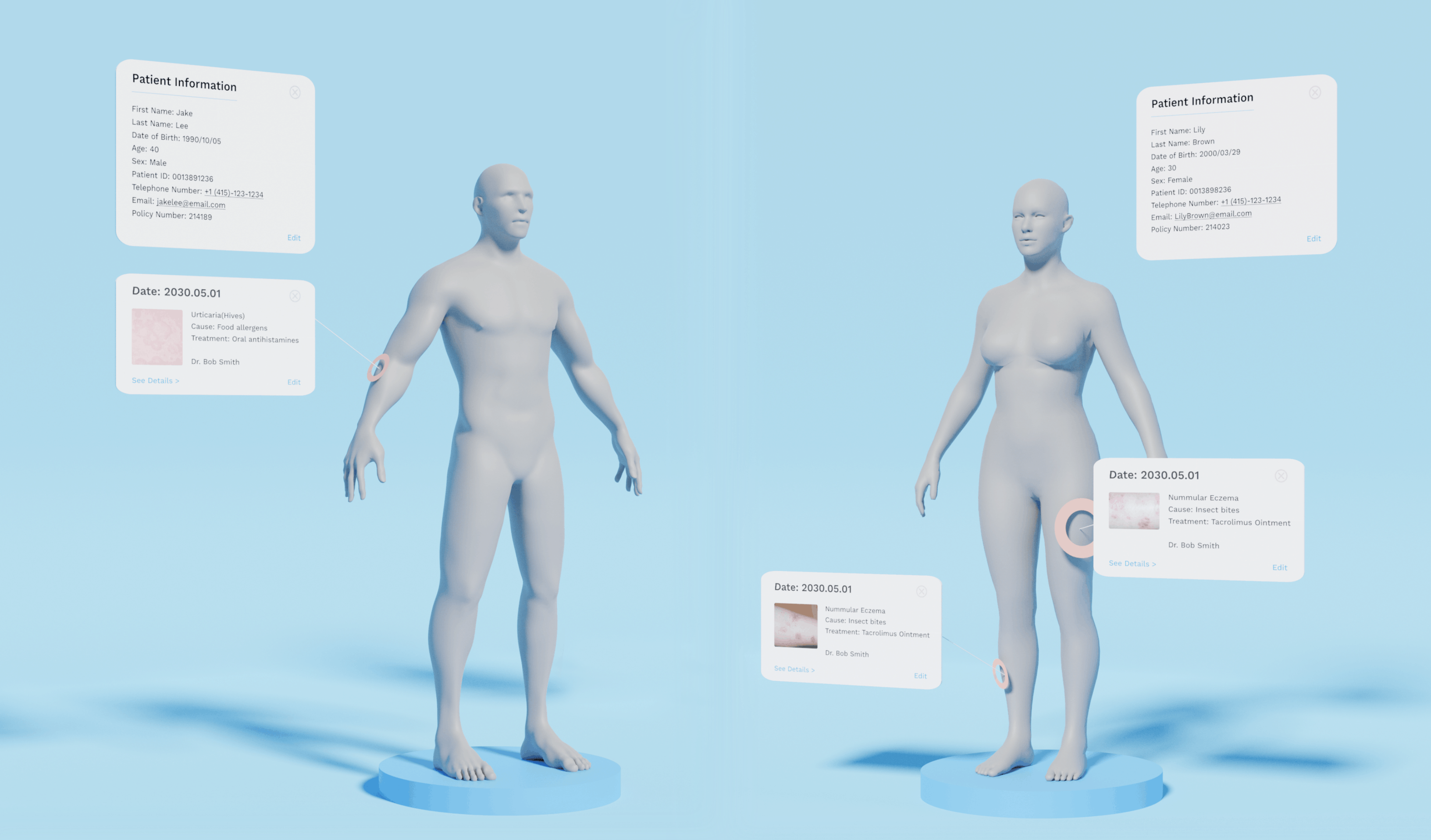

MR-Medicine

Improving Telemedicine Video Consultation with Mixed Reality and User Experience Design

By Grace Jiaqi Yuan

2022

MR-Medicine: Improving Telemedicine Video Consultation with Mixed Reality and User Experience Design

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Abstract

MR-Medicine is a research project exploring how Mixed Reality and User Experience Design can be used to improve patient experience in Telemedicine. It focuses on three main problems identified in the existing telemedicine platforms: 1) unintegrated electronic medical record system, 2) lack of strong presence, and 3) the hierarchical physician-patient relationship. It uses dermatology as a case study to explore possible design solutions for remote healthcare consultation.

MR-Medicine was developed with the Research Through Design methodology and examined with the Descriptive Design Evaluation methods. By creating and evaluating three types of prototypes for Virtual Reality (VR), Augmented Reality (AR), and desktop applications as proofs of concept, the research study suggests findings that may contribute to telemedicine consultation applications' development and how patients and physicians may better interact in the future.

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1. Introduction

This chapter introduces the motivations, problem statement, research questions, goals and objectives, contributions, and scope of work of the MR-Medicine research project.

1.1 Personal Motivation

With the rapid progression of Covid-19 disease on the global scale, remote care became one of the most important strategies for public health. Telemedicine, as a method to offer clinical service from a distance, has been increasingly used. It saves the patient time and energy from travelling, enables real-time monitoring, and reaches further areas that lack the medical service. However, many issues are spotted in the current telemedicine use cases in the Canadian context.

My friends and I have encountered common problems while having telemedicine consultations with physicians. For example, when having a remote consultation with the physician on the phone, physicians tend to use professional terminologies that we cannot understand which causes the jargon issue for us as patients. Confusions and frustration also occur when we need to find reference images online and show our symptoms to the physician through low-resolution cameras. I noticed these issues and started my early research, which led to interesting findings that I would like to expand on with the thesis project.

As an interdisciplinary designer, I want to use my expertise in user experience design and mixed reality development, to take on the responsibility to design for good. Health is a fundamental human right. I would like to focus this thesis research on improving remote health care and mitigating the friction that might occur to patients using telemedicine.

1.2 Motivation Theories Related to MR-Medicine

Innovative technologies have been constantly applied to the field of healthcare and telemedicine such as artificial intelligence and robotics. Mixed reality is one of the innovations that merges the physical reality and the virtual environment. It allows the physical and the virtual objects to exist at the same time and enables real-time interactions (Milgram 1994). As telemedicine mostly relies on the current information technology, bringing in the benefits of mixed reality can potentially help to solve some of the problems in the existing telemedicine use case, and improve the patient experience. With mixed reality technology, more features will be made possible to help patients receive better care and understand the overall consultation process.

The name of MR-Medicine is a proposal of replacing the “Tele- “aspect of telemedicine, which stands for telecommunication technologies, with mixed reality (“MR- “) technologies to explore possible futures in remote healthcare.

1.2.1 Video-based Telemedicine

Referred by the World Health Organization as "healing from a distance," telemedicine is the use of telecommunications and information technologies to provide remote clinical services to patients (World Health Organization 2009). Physicians use it for the transmission of digital imaging, phone and video consultations, and remote medical diagnoses. A great amount of research has been done in the area of surveying telemedicine application usage, especially during the Covid-19 pandemic. 2,041 articles are identified to relate to the use of telemedicine for Covid-19 (Gao et al 2020) and 5,917 relevant titles are identified to be potential theoretical predictors that influence the acceptance of telemedicine (Harst et al 2019).

As more patients adapt to using telemedicine, existing analyses of telemedicine products and services show problems that cause frustration to both patients and physicians, including:

- The Electronic Medical Record (EMR) system does not coordinate with the telemedicine platform and potentially complicates the flow (Varshneya 2022).
- Slow adoption of telemedicine because it creates competition between remote healthcare providers who are not even in the same local network (Linkous 2012).
- Difficulty maintaining continuity of care because patient data does not transfer easily between different care providers (Varshneya 2022).

- Patients may not have the required technical knowledge to use telemedicine technologies (Varshneya 2022) and there can be a lack of instruction to help guide patients.

These issues open a discussion around possible solutions with new technologies and systematic redesign of the patient experience.

1.2.2 Mixed Reality for Telemedicine

To brainstorm ideas that can be implemented in telemedicine with the mixed reality technology to improve the user experience, I compared the capacities of mixed reality and the features of telemedicine and discovered the following opportunities:

- Strong presence of both physician and patient in virtual reality or mixed reality. Presence in VR, defined as the subjective perception of "being there" in a virtual environment (Heeter 2003), is one of the important assets brought by mixed reality technology.
- 3D virtual diagnosis assistants can help the patients with the early steps in the consultation process. This feature is inspired by the virtual avatars commonly used in video games for introductions or tutorials.
- Displaying layered augmented reality information with mobile camera scan for medication and physicians' notes. This approach is often used in map

applications to display location-specific navigation data and layer them on top of the real environment via a mobile camera (Google Maps Live View).

- Using depth camera to improve video resolution and sense of presence. This method has been studied for telepresence for remote caregiving to reduce caregivers' physical contact with Covid-19 infected patients (C. Bohlen et al 2020).
- Immersive consultation in virtual reality at 3D hospital. VR headsets enable users to be in any type of virtual space and present them as their virtual avatars. Medical consultation can also be recreated in VR referring to the real-life experience.
- Integrating electronic medical record system with mixed reality. Mixed reality can be used for displaying systematic information with texts and graphics, therefore there is the potential to display medical records with mixed reality technologies.

These ideas are preliminary and provide initial thoughts on how the research project may progress. Not all ideas are expanded or implemented in the design creations.

1.2.3 User Experience Design for Telemedicine

When I started to investigate the user experience of telemedicine platforms, I discovered a user scenario based on a friend of mine, who had an unpleasant experience at his telemedicine video consultation with a dermatologist. I created a user study that included a persona and a patient journey map based on his experience.

Jake

Patient with skin allergy condition

"I wish the doctor can see my condition more clearly and provide trustworthy solutions."

About Jake

- 22 years old
- Currently studying at U of T
- Good with technologies

Jake is a student at the University of Toronto, majoring in engineering. Jake is usually very healthy, but recently he developed a skin allergy and he has no clue what caused it. Jake reached out to his family doctor, hoping to receive a diagnosis and get prescription medicines to relieve the rash.
After seeing the general doctor, Jake was referred to a dermatologist. Jake has to go through multiple steps to register and book appointments. When have a video call with the dermatologist on his macbook virtually, Jake was unsure about the process and the results.

Goals

- Diagnose the cause of the allergy
- Recover from the allergic reaction

Challenges

- Understand the allergy condition
- Find a more efficient way to contact the dermatologist

Habits

- Jake likes trying out new technologies
- He is usually very self-managing
- He prefers time-efficient solutions to problems
- He is busy with school and his part-time job

Figure 1. Patient persona indicates the main goals and challenges of Jake

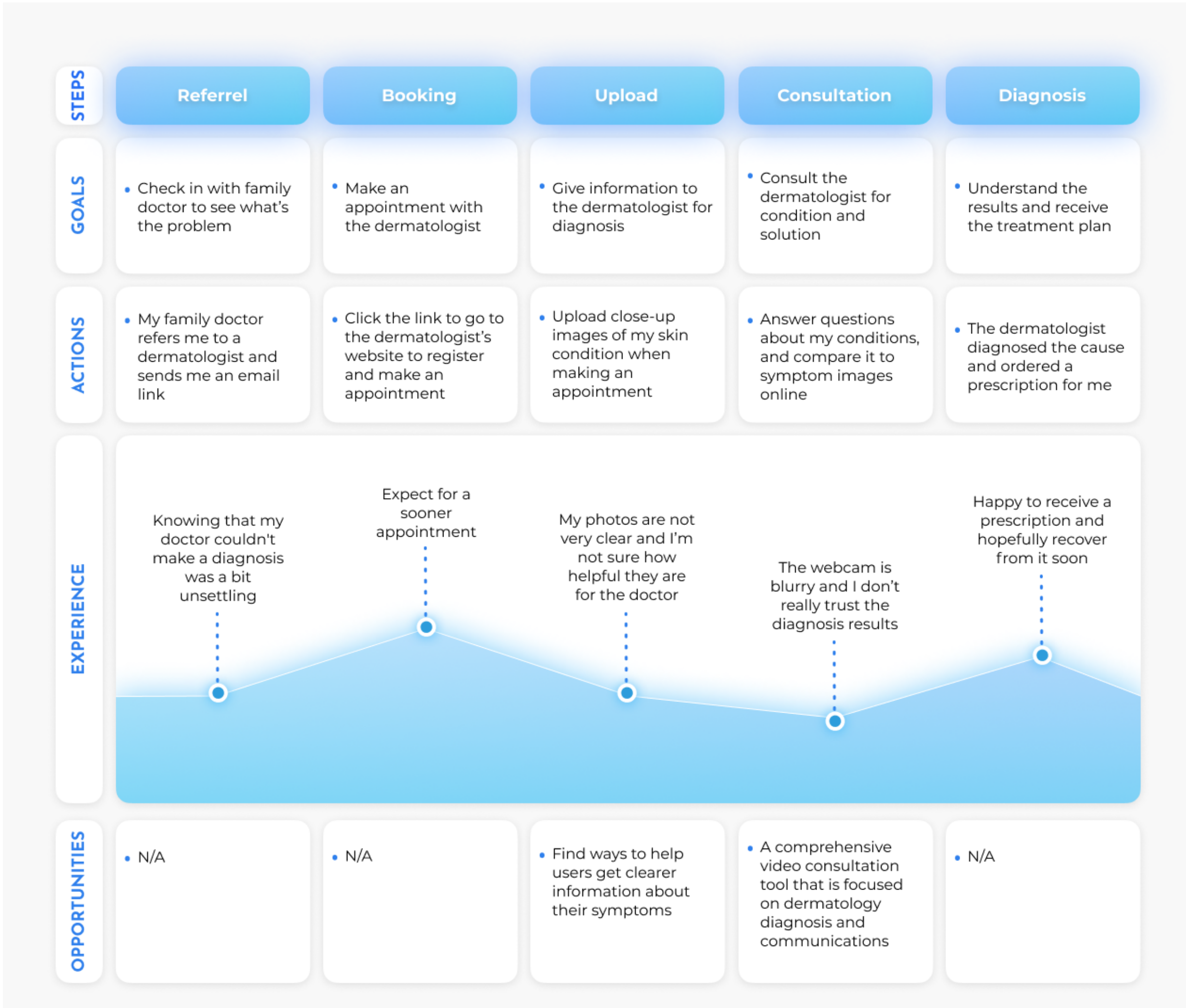


Figure 2. Patient journey map of Jake's experience using telemedicine for a dermatology appointment

In this user case, Jake is a college student who has a skin allergy condition and would like to seek health care from a dermatologist. His main goals are to receive a diagnosis of the allergy condition and recover from it. However, he has some frustrations while going through the process. Jake first checked in with his family doctor and was referred to make an appointment with a dermatologist. During the booking process, Jake uploaded several close-up photos of his symptoms as the patient form requires. When having the video consultation with the dermatologist, Jake was asked to show his symptoms through the webcam as well as provide online reference photos that look like his own skin conditions. Although the dermatologist made a diagnosis, Jake was unsure about the telemedicine process.

After careful examination of the patient experience, here are my discoveries as follows.

Challenges that Jake undergoes:

- Photographs of the skin condition and webcam video call quality are not clear enough to provide accurate information to the physicians.
- Communication during the video call is not efficient as the patient must look for images online for reference.

Opportunities for telemedicine:

- Find ways to document the lesions with a higher definition for easier diagnosis and avoid misdiagnosis.
- Find ways to enhance communication between dermatologists and the patient during the video consultation.

These findings are not comprehensive enough to cover the key issues in a telemedicine video consultation. However, it still offers valuable insights as the first use case study conducted for this research.

As a design process, user experience design can potentially offer the following benefits to improve the mixed reality telemedicine experience:

- Using clear visual cues to indicate the consultation process.
- Granting the patients equal access to information similar to the physicians.
- Allowing patients to interact with the physician in a way that matches the in-person experience.
- Auditing existing telemedicine platforms to analyze pros and cons, learning from UX best practices for telemedicine.

1.3 Combining the Three Themes

My research subject focuses on the intersection of three fields: telemedicine, mixed reality, and user experience design. Mixed reality and user experience design can be seen as two themes that support the promotion of telemedicine adoption and conversion. I would like to combine the benefits brought by the themes: 1) strong telepresence created by mixed reality, and 2) meaningful interaction shaped by user experience design that may improve the user experience and consultation process and implement the benefits to improve telemedicine.

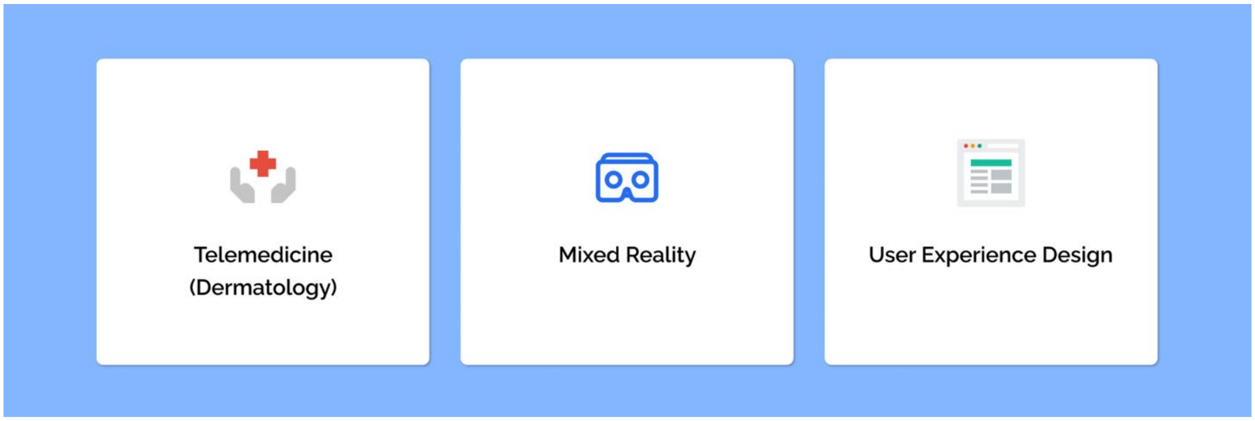


Figure 3. Three main themes that MR-Medicine focuses on

Existing case studies including telemedicine applications, mixed reality software for collaboration, and mixed reality equipment will be examined to provide context and foundations to the research.

1.4 Research Summary

1.4.1 Problem Statement

Three main problems are summarized regarding telemedicine:

- **Record and History:** Electronic medical records system does not coordinate with the telemedicine platform which potentially complicates the flow (Varshneya 2022).

- **Presence:** The lack of physical presence of both patients and physicians may compromise trust and interpersonal connections (Chowdhury, Saifur Rahman, et al 2020).
- **Patient-Physician Relationship:** Telemedicine visits are more physician-centred compared to in-person, with the physician controlling the dialogue and the patient taking a relatively passive role (Agha et al 2009). Patients are not well-informed and do not have access to medical records.

1.4.2 Research Questions

Main Research Question:

- How can the presence created by mixed reality and ease of use shaped by user experience design improve the patient experience in a telemedicine video consultation, for scenarios like dermatology?

Sub Research Questions:

- How can the process of telemedicine video consultation be improved with user experience design and mixed reality?
- How can user experience design and mixed reality improve the medical records for telemedicine?
- How can mixed reality enhance the telepresence of telemedicine?

1.4.3 Goal Statement

MR-Medicine is aimed to answer the research questions by experimenting with design solutions for remote healthcare consultation scenarios. By iterating and evaluating the designs, findings are summarized as the results of the projects. The goal of MR-Medicine is to provide these results as possible future directions and references to the telemedicine discipline.

1.4.4 List of Objectives

- To understand industrial standards, best practices, and gaps in telemedicine, mixed reality, and user experience design through literature review to design better processes for telemedicine applications.
- To explore the potential of 3D-based medical records in mixed reality.
- To create mixed reality telemedicine prototypes to explore design solutions that enhance the telepresence of patients and physicians.

1.4.5 Potential Contributions

MR-Medicine aims to contribute to future telemedicine applications that consider using mixed reality for facilitating the consultation process. The research focuses on the problems of telemedicine technologies and explores innovative solutions to improve the patients' experience. physicians and patients are the target audience of the research and will potentially benefit from the research outcomes.

1.4.6 Scope of Work

MR-Medicine aims to serve only as a proof of concept to show what the telemedicine process can look like in mixed reality. It is not an exhausting search for a complete study of telemedicine. Expert review and experiments with patient participants are out of scope due to the field and access constraints.

As telemedicine does not address all stages of clinical flow, the other stages outside telemedicine are not in the research scope. This study only intends to focus on the video consultation process and the patient experience in telemedicine. Telemedicine, as previously introduced, only refers to the delivery of medical care from a distance with telecommunication technologies (Murphy et al 1974). In contrast, telehealth is an extended scope that incorporates a "broader set of activities, including patient and provider education'' in addition to patient care (Bashshur et al 2011). Telehealth is a broader concept that this research does not cover.

The experiment scope is narrowed down to focus on dermatology scenarios because it is considered one of the specialties that are most suitable for telemedicine video consultation, which heavily relies on visual observation (Hart 2011). The prototype experiment simulates the telemedicine consultation between a physician and a patient, focusing on design concepts and features that can improve the patient experience. Not all the functionalities in the prototypes are fully implemented due to limited time and resources.

As this project involves reimaging an alternative digital medical record system, privacy becomes a concern when it comes to health-related subjects. Although the research prototypes apply a 3D manikin as a way to present medical records, this project is not intended to touch on cybersecurity, digital privacy, or the ownership of information issues. It is more focused on the interaction and realization of using a virtual 3D body and patient data to visualize the medical records.

1.5 Chapter Overview

This thesis paper is divided into six main chapters:

- Chapter 1 introduces the motivation and theories behind MR-Medicine and offers an overview of the focus of the project.
- Chapter 2 covers the literature review and related work about the three fields: Telemedicine, Mixed Reality, and User Experience Design, and summarizes the problems, challenges, and opportunities in the existing disciplines.
- Chapter 3 introduces the methodologies and theoretical frameworks used as the foundation of the research and design process.

- Chapter 4 introduces the iterations of prototypes created for answering the research questions, including VR, AR, and Desktop Dashboard prototypes.
- Chapter 5 focuses on the discussion around the evaluation of the prototypes.
- Chapter 6 concludes the project with final thoughts and future work.

2. Background

To gain a deeper knowledge of the subjects in such an interdisciplinary context, a literature review was conducted on the publications and applications of telemedicine, mixed reality, and user experience design. Problems, challenges, and opportunities are analyzed and summarized to support the design creations.

2.1 Telemedicine Frameworks

Telemedicine, as a process to provide health care remotely, is intended to provide clinical support, overcome geographical barriers, connect users who are not in the same physical location and improve health outcomes (World Health Organization 2009). Telemedicine reaches further patients and allows physicians to monitor the patients in real-time to adjust treatment plans when necessary (Björndell and Premberg 2021). This research studied the development of telemedicine, the relationship and dynamic between patients and physicians, and the typical diagnostic process, to achieve an understanding of how telemedicine applications can be designed to improve the patient experience.

2.1.1 Telemedicine Diagnostic Process

Like any clinical service, to deliver health care with telemedicine, physicians must follow a standardized process to complete patients' diagnoses. The rising issue of diagnostic errors has brought harm to an unacceptable number of patients. To analyze the problem, the Committee on Diagnostic Error in Health Care developed a conceptual model (Balogh et al 2016) to identify opportunities for improvement.

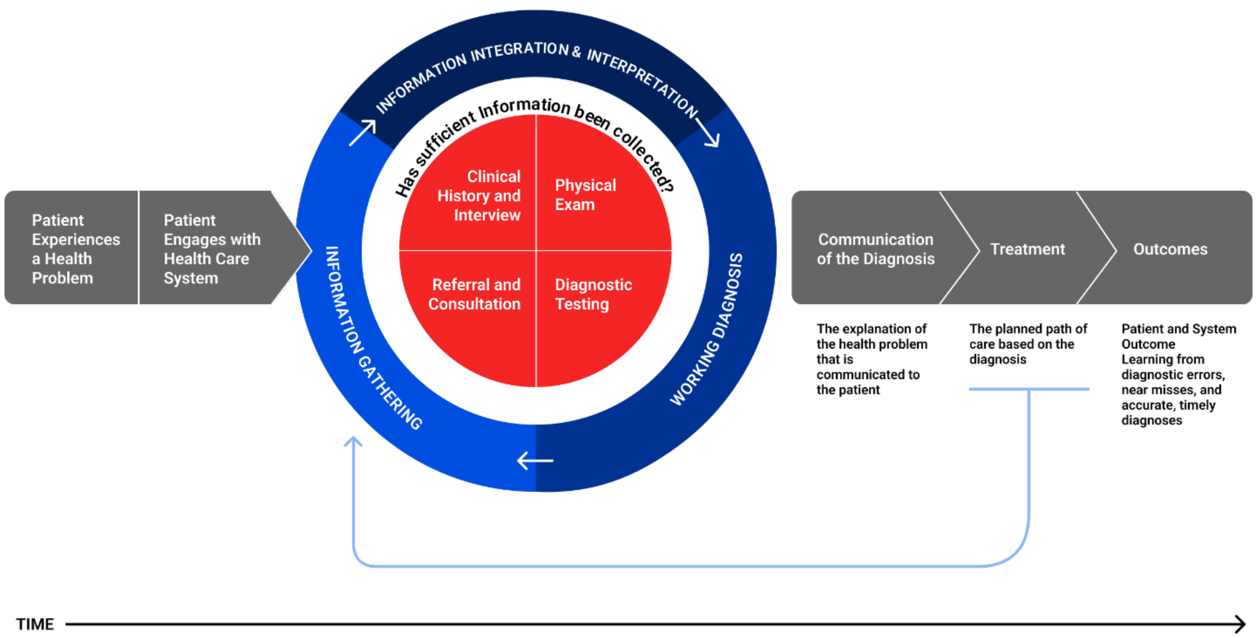


Figure 4. Diagnostic process diagram based on the diagram from *Improving Diagnosis in Health Care* (Balogh et al 2016)

It is illustrated that issues are mostly discovered during the information integration and interpretation, working diagnosis, and information gathering steps.

Created based on the above diagram, this process model provides a guideline for designing the prototype user flow in a telemedicine context.

	The Diagnostic Process	The MR-Medicine Process
1	The patient experiences a health problem	The patient develops a symptom and decides to seek health care remotely
2	The patient engages with the health care system	The patient uses a telemedicine platform to contact the health care provider
3	Information gathering	The patient fills out forms regarding their basic information, history and current conditions, and uploads images of the symptoms if relevant
4	Information integration and interpretation	The information provided by the patient is integrated into the telemedicine system and reviewed by the physician
5	Working diagnosis	The physician diagnoses the health problem based on the provided information
6	Communication of the diagnosis	The physician communicates the diagnosis to the patient via phone call or video conferencing

7	Treatment	The physician sends out a treatment plan to the patient on the telemedicine platform or via email
8	Outcomes	The physician checks in with the patient to see the treatment outcomes

Table 1. The diagnostic process applied to telemedicine

User experience design principles are also integrated into each step to provide the users with a frictionless consultation experience, where both physician and patient are aware of where they are in the process, and what they are supposed to do. However, my prototypes will only focus on from step 2 to step 8, simulating scenarios for first-time patients. This diagnostic process is used in Chapter 5 for evaluating the prototypes with Descriptive Scenarios.

2.1.2 Telemedicine During the Covid-19 Pandemics

Telemedicine has urgently been adopted as a safer means of providing medical care (Smith et al 2020) and the shift from office-based care to home-based care accelerated during the Covid-19 pandemic (Ramaswamy et al, 2020). Computer literacy and technology access has been improved to facilitate distance (Blandford et al 2020). With the rise of video conferencing technologies, telemedicine starts to take on more complicated forms. As of today, most telemedicine video consultations taking place on personal devices such as phones and computers are no different from normal video conferencing tools for personal and business use. It is important to identify specific user needs and incorporate corresponding features for telemedicine video consultation to improve the patient experience.

2.1.3 Patient-Physician Relationships

The topic of patient-driven care and patient self-management rises as we enter the information age (Greenhalgh et al 2010). Research has shown that telemedicine visits are more physician-centred compared to in-person, with the "physician controlling the dialogue and the patient taking a relatively passive role (Agha et al 2009)." However, based on multiple study outcomes, physician-centred communication is less successful in addressing the needs of the patient. Patient-centred consultation style benefits patient satisfaction with an increased satisfaction rate (Agha et al 2009; Chandra et al 2018). The patient-centred style usually requires the physician to pay particular attention to the patient, regarding their symptoms, ideas, concerns, and expectations. Physicians and patients should negotiate to achieve a shared understanding of the nature of the problem and agree upon the treatment plan (Kinnersley et al 1999).

The lack of physical presence also raises potential issues between the physicians and patients. "A healthcare provider's physical presence can express empathy and compassion non-verbally, the lack of physical presence in the digital provision of care may compromise trust and interpersonal connections for some patients. (Chowdhury et al 2020).” Therefore, it is important to enhance the sense of presence in telemedicine to achieve the same level of trust and empathy as in-person care.

This project intends to explore the dynamic of patient-centred care and help patients to understand their health conditions with ease, through the implementation of strong telepresence and a clear consultation process.

2.1.4 Electronic Medical Records

Electronic Medical Records (EMR) systems are commonly used by hospitals to keep and update their paper-based medical records (Gharajeh 2018). A comparative analysis has been done and suggests that the EMRs adopted in hospitals provide higher quality healthcare service than the hospitals using paper-based records (Chinnasamy et al 2020). Although physicians are largely positive about integrating telemedicine with EMRs, concerns have been raised around the multiple themes (Davidson et al 2013). EMRs also face various challenges related to health data integration and interoperability, user interface and user experience design, health data visualization, and security (Adamu et al 2020). MR-Medicine intends to explore potential solutions to improve the health data visualization and user experience design of the EMRs.

2.1.5 Telemedicine Applications

A selection of existing telemedicine applications is analyzed below. With the findings, my prototypes can refer to the telemedicine best practice and avoid creating friction for the patient experience.

2.1.5.1 VisualDX

As a diagnostic clinical decision support system, VisualDX (www.visualdx.com) offers applications across the platforms, on mobile phones, tablets, and desktops. It uses a professional and minimalist user interface style because it is designed for healthcare providers who seek efficiency.

Figure 5. VisualDX on iPad, iPhone, and Android Devices (www.visualdx.com/resources/how-visualdx-works/mobile-access/)

As a decision support system, the features are helpful for not only physicians but also patients. VisualDX uses a reference library to inform the patients during the consultation to replace the same in-person process. The library includes thousands of diseases with medical information and images on an inclusive range of skin types and age groups, uploaded by certified physicians. VisualDX is committed to improving equity and supporting patients with dark skin tones. As lesions on darker skin can look quite different from those on light skin due to pigmentation, reference images of disease on dark skin can not only be used to educate healthcare professionals but also bring trust and confidence to the physician-patient relationship. A dataset with recommended medications and treatments is also embedded for physicians to review with the patient in real-time. It offers pre-written handouts for the patient with ease of sharing.

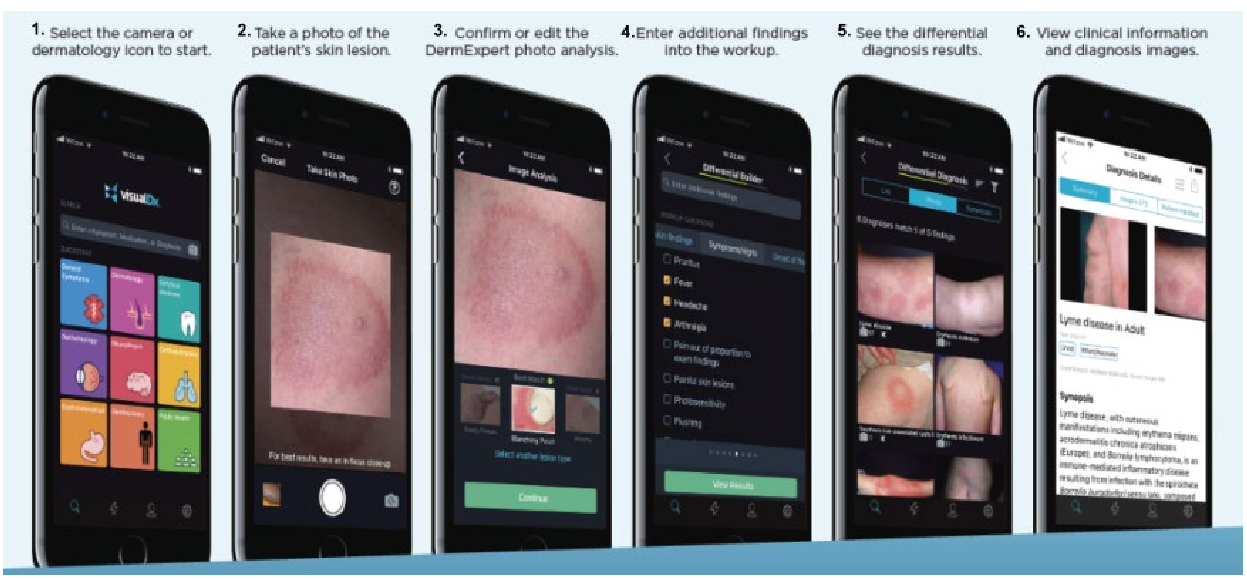


Figure 6. DermExpert Mobile App User Flows (DermExpert via the VisualDX IOS Mobile App med.mercer.edu/library/DermExpert.htm)

VisualDX has a specialized solution for dermatology called DermExpert (www.visualdx.com/clinical-solutions/derm-expert/). It is an artificial intelligence-powered image recognition add-on for general practitioners. After snapping a photo of the lesion and uploading it, DermExpert will provide a few options of lesion type for confirmation, ask a few additional questions, and then generate the diagnostic search results. By using dataset and machine learning technologies, this feature is a powerful tool that speeds up the diagnosis process and increases the accuracy of diagnostic for non-dermatologists.

2.1.5.2 CloudMD

CloudMD (www.cloudmd.ca) is a telemedicine application that allows the patient to book appointments with physicians and consult with them remotely through video calls. It can be accessed via mobile applications and the website.

Figure 7. CloudMD Mobile App Interfaces (www.cloudmd.ca)

CloudMD uses a more friendly and welcoming visual style compared to VisualDX, as it is patient-oriented. The overall user experience is easy to follow and straightforward. The main feature is the appointment booking system. When booking an appointment, the patient needs to fill in their basic information and complete an assessment. The easy navigation of CloudMD ensures patients understand each step in the process and communicate with healthcare professionals easily.

2.1.6 Telemedicine Support 2D/3D Manikins

Human-shaped models or images of human bodies have been used in healthcare information systems as a tool for annotation and visualization. Precedent applications include use cases for showing different layers of the human body from inner organs to muscles and skins.

2.1.6.1 The Semantic Body Browser

The Semantic Body Browser (http://sbb.cellfinder.org) is a JavaScript Web Application for exploring human bodies from the organ to the subcellular level with anatomical illustrations (Lekschas et al 2014).

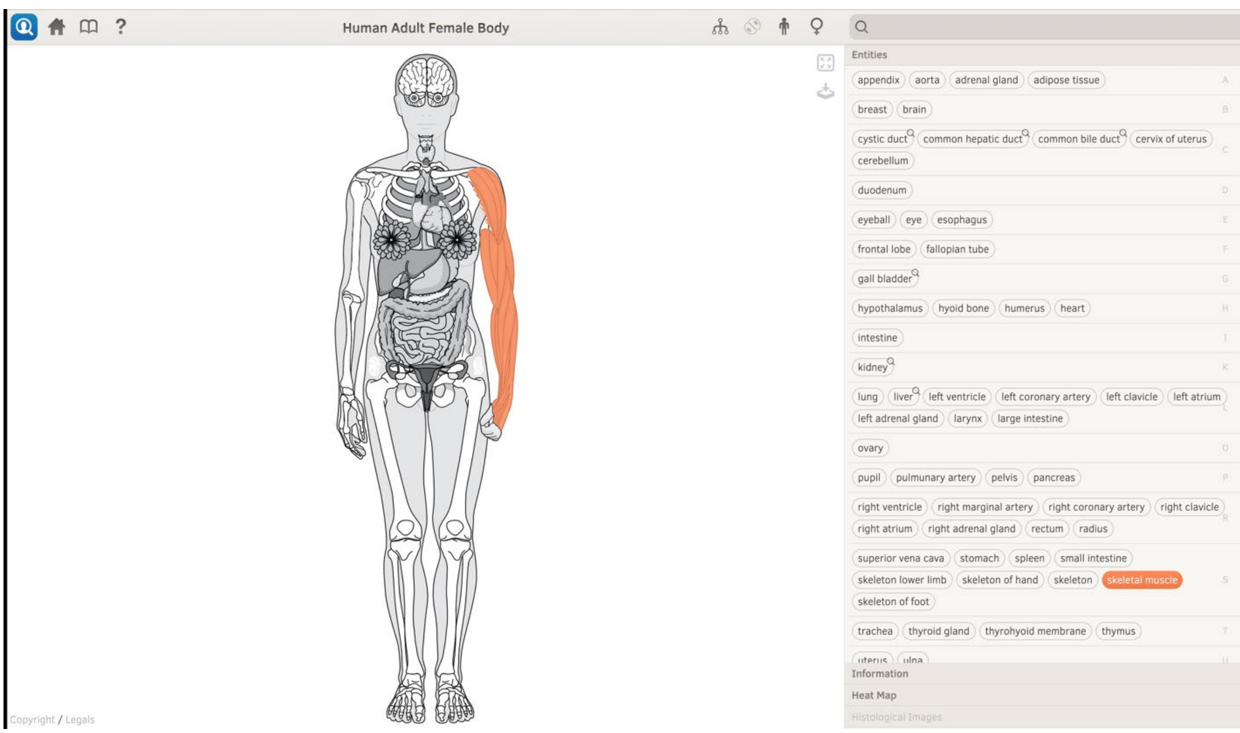


Figure 8. The Semantic Body Browser (http://sbb.cellfinder.org) for exploring body structure and organs

The straightforward and intuitive interaction design of the Semantic Body Browser offers easy access to biological information. This type of visualization tool can be potentially integrated into the telemedicine platform for demonstration and annotation during the consultation.

2.1.6.2 Modernizing Medicine

In the dermatology use case, Modernizing Medicine (www.modmed.com) is an EMR system that uses 2D images of human bodies for information gathering. It offers tools and systems that help physicians to manage patient records, notes, and treatment plans, including 2D images of human manikins for notetaking and recording patient conditions. It also facilitates the consultation process by providing interview questions and generating a consolidated report based on the notes and answers to the questions.

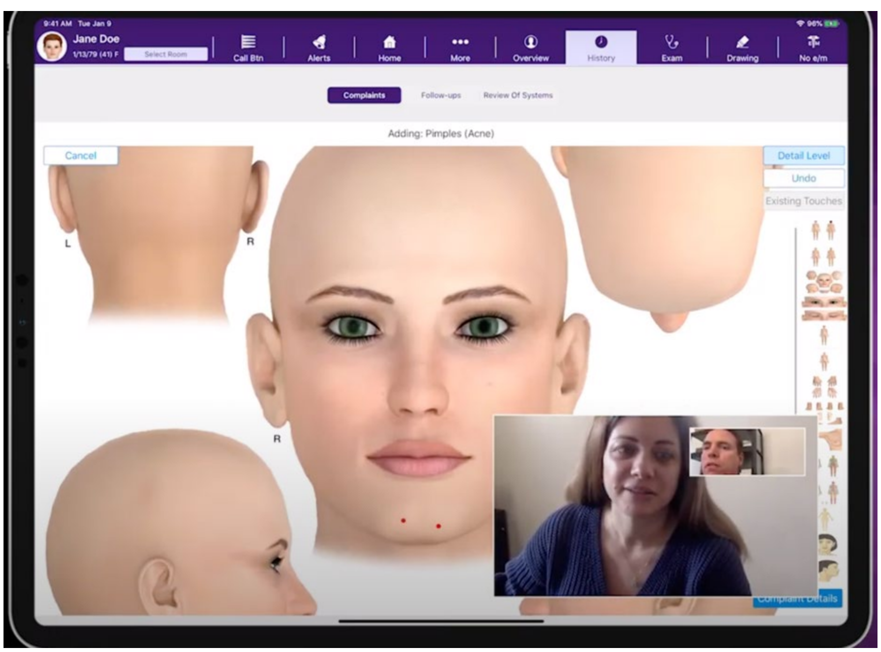


Figure 9. Modernizing Medicine dermatology use case – a dermatologist is adding notes to a set of 2D manikin images based on the patient's descriptions of the symptoms (https://www.youtube.com/watch?v=EM0JUxm4zjo)

Modernizing Medicine offers an integrated solution to physicians. However, it will also be helpful if the patients can have equal access to this type of tool that visualizes and simplifies the information-gathering process.

2.2 Mixed Reality Frameworks

By studying the foundational mixed reality frameworks and existing mixed reality platforms as case studies, the benefits of mixed reality technologies are discovered.

2.2.1 Mixed Reality Theory: Milgram's Taxonomy

Almost 30 years ago (1994) Paul Milgram introduces a virtuality continuum in his "A Taxonomy of Mixed Reality Visual Displays." As illustrated in the diagram, the real environment, and virtual environment are shown as two opposite extremums. A mixed reality environment is where the "real world and virtual world objects are presented together within a single display (Milgram 1994)." This is the first time that mixed reality is defined, and this classification later became the grounded framework for much of the mixed reality research. This paper helps define where my thesis sits in the spectrum of mixed reality. Along with Zeltzer's AIP Cube (Zeltzer 1992), these mixed reality frameworks provide methods to analyze the most suitable scenarios for my study within the RV continuum.

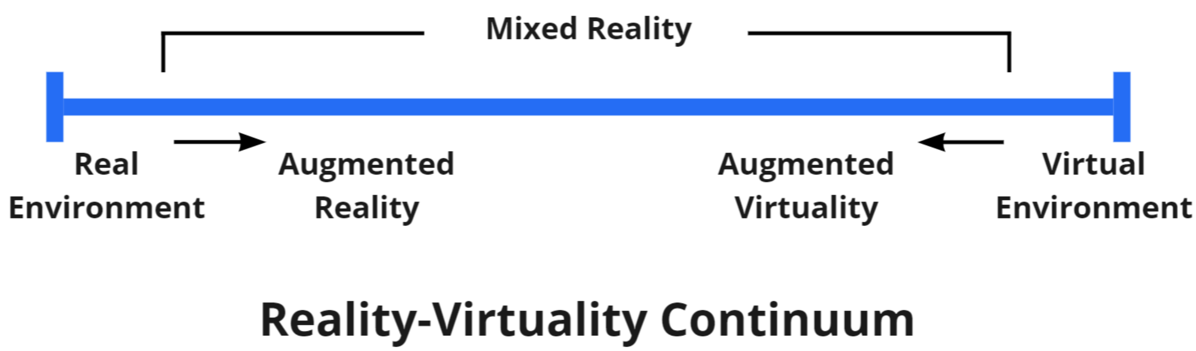


Figure 10. Reality-Virtuality Continuum diagram, redrawn based on Milgram's Continuum (Milgram 1994)

Although the Reality-Virtuality Continuum is regarded as the traditional notion of mixed reality, based on Speicher's report on mixed reality definitions and literature review, the continuum is only one of the six existing notions and there is no commonly agreed definition of mixed reality in the industry (Speicher et al 2019).

2.2.2 Mixed Reality Theory: Zeltzer's AIP Cube

In David Zeltzer's "Autonomy, Interaction, and Presence," he presents a taxonomy for measuring computer graphic simulation systems (1992). It is a coordinate system based on three components: autonomy, interaction, and presence (AIP). The three axes represent the three components. The origin (0,0,0) represents the situation of the early

1960s where no autonomy, interaction, or presence exists. The corner of (1,1,1) represents the ultimate state of the simulation, with "fully autonomous agents and objects that act and react according to the state of the simulation, and that are equally responsive to the actions of the human participant(s)." He also mentions that at (1,1,1) the sensory stimulation should be indistinguishable from in a real environment.

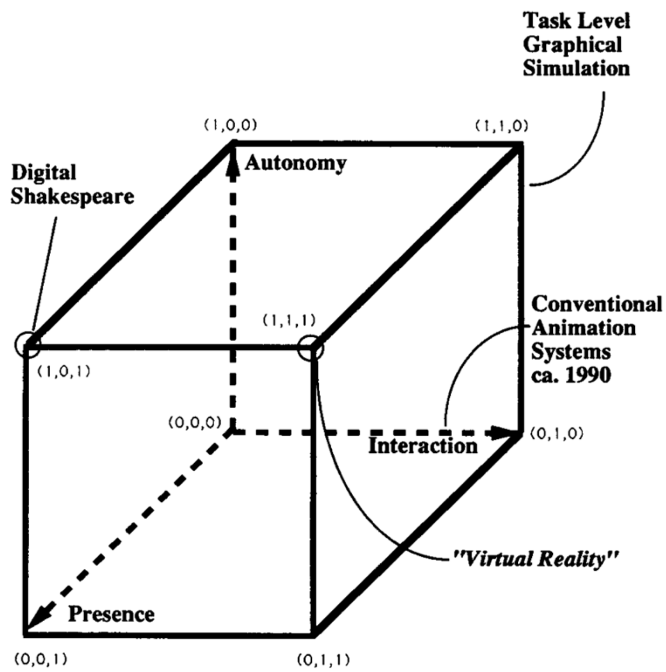


Figure 11. Zeltzer's AIP Cube (Zeltzer 1992)

Zeltzer's AIP Cube provides qualitative measurements of the mixed reality applications. This framework is used for constructing user scenarios upon which the prototypes are built.

2.2.3 Mixed Reality Applications and Related Work

The following mixed reality applications are studied to draw inspiration from the existing work to help design the MR-Medicine creations.

2.2.3.1 Google Starline

Google Starline is an immersive and realistic video conferencing technology google has been researching to recreate presence for people who are not physically together (Bavor 2021). This project incorporates innovative technologies including volumetric videos, computer vision, machine learning, spatial audio, and real-time compression. The light field display system developed creates a sense of volume and depth without the need for additional glasses or headsets. The video is displayed on a large screen which allows the image of users to be presented in life-size.

Figure 12. Google Starline Videoconferencing (Bavor 2021, https://blog.google/technology/research/project-starline/)

This project is a case study that inspires MR-Medicine, from both mixed reality technologies and presentation perspectives. They share the same focus on video conferencing technology that bridges people located in different areas. The technologies used in Starline altogether create a strong presence of the users, which makes the meeting experience more realistic.

2.2.3.2 Spatial.io

Other social VR platforms also provide good precedential examples for interaction design and virtual environment setup. Spatial.io (https://spatial.io) is a metaverse platform that allows users to host virtual events and exhibitions. Recently it expanded its products into NFT virtual lands.

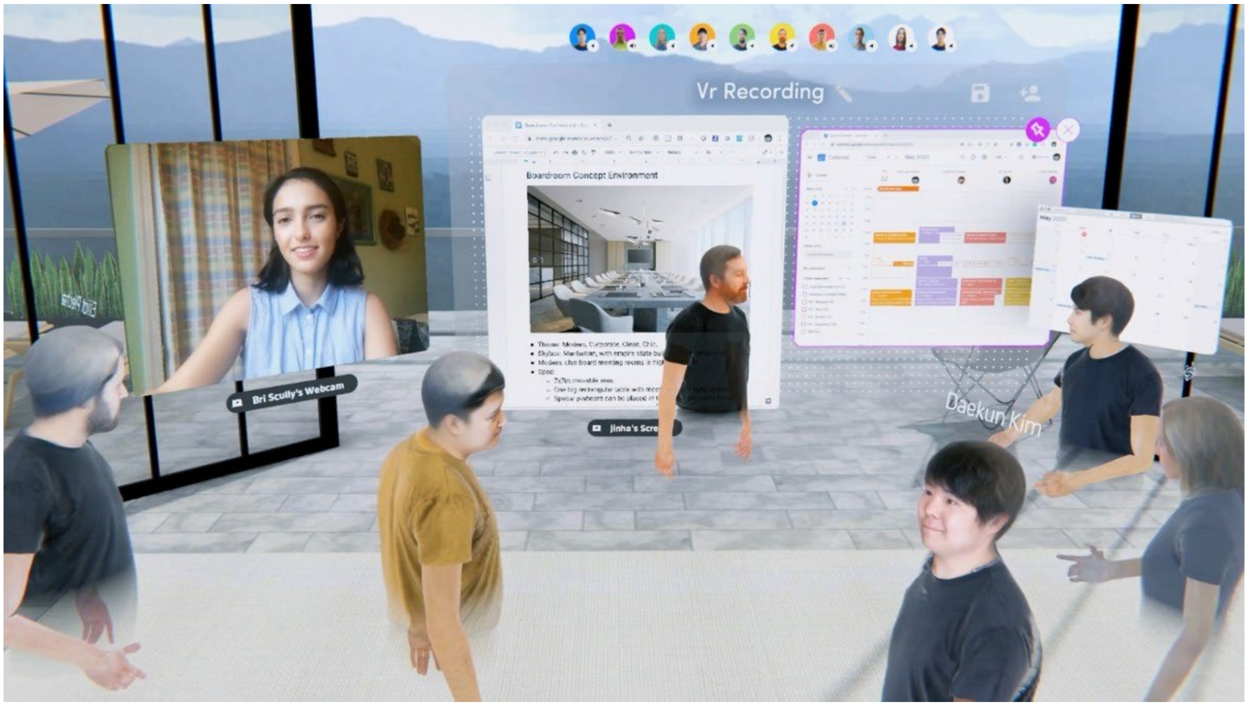


Figure 13. Spatial.io (https://spatial.io/) is being used for teamwork in VR

Unlike other social VR, the avatars in Spatial are realistic looking because they use the users' headshot photos and map the facial features on the avatar models, instead of using cartoon-styled faces. Users can also customize their skin tone and shirt colours. By using the users' actual faces, the users' identities are transferred to the avatars and the presence is enhanced.

2.2.3.3 Microsoft Mesh

Microsoft Mesh (www.microsoft.com/en-us/mesh) is a mixed reality application that projects users' avatars or real appearances to create telepresence for working together remotely. The virtual representation of users not only communicates messages but also reflects eye contact, facial expressions, and gestures. The app can be accessed on HoloLens 2, VR headsets, mobile phones, tablets, or PCs – using any Mesh-enabled app. Mesh not only allows the users to work on 3D content together, but also uses it for education, training, and even remote healthcare. It can also connect with Teams and other Microsoft software. The extensive application of Mesh indicates the variety of fields mixed reality can be integrated into.

2.2.4 Mixed Reality for Remote Healthcare

At the crossover of mixed reality and telemedicine, Kawashiri and his team researched performing an accurate joint assessment for rheumatoid arthritis, using HoloLens (Kawashiri et al 2021). It is an example of the crossover of mixed reality and telemedicine. A system has been developed that can assess joints accurately in three-dimensions images in real-time, using Azure Kinect DK (depth sensor), HoloLens 2, and Microsoft Teams. The research team plans to use artificial intelligence for implementing a function to quickly catch and automatically evaluate the patient's anxiety and changes in facial expressions at the time of examination, a function to record dialogue with the patient in chronological order, a function to support the detection of swollen joints, and function to automatically analyze the questionnaire. This project is advanced and inspiring in the way it integrates the different technologies with telemedicine in a specific field. The integration of depth sensors and mixed reality shares a technical similarity with Google Starline. The implementation of artificial intelligence for diagnosis has also been seen in VisualDX. The use of artificial intelligence in medicine or telemedicine seems promising as it can effectively compare the symptoms to its large database. It may potentially generate a more accurate result than a human physician can in a rare disease case.

Other research has been done to study the integration of mixed reality and telemedicine. HoloLens2 has been used for protecting healthcare workers during the Covid-19 pandemic (Martin et al 2020); 3D hologram using depth cameras has been studied to provide remote care (Sekimoto et al 2020); live 360-degree virtual reality streaming was explored for telemedicine application (Teng et al 2018). These studies provide context and inspiration for what mixed reality technologies can be incorporated into the research creations.

2.3 User Experience Design Frameworks

To create a good user experience design for MR-Medicine, Nielson’s heuristics have been studied to guide and measure the research creations.

2.3.1 User Experience Design Heuristics

For designing and evaluating the prototypes, Nielson's 10 usability heuristics (Nielson 1994) are commonly accepted as the essential principles. These heuristics offer various perspectives on how to design a comprehensive user experience with visual elements.

Here are the 10 heuristics as follows:

1	Visibility of system status	Users should be informed of the current state of the system and receive feedback when they take action. They will learn the outcomes of their previous interactions and determine the next steps.
2	Match between the system and the real world	The system should use languages and visual signifiers that are familiar to the users to help them understand how the interactions work.
3	User control and freedom	Provide users with options to redo and undo actions and exit the current interaction whenever they want.
4	Consistency and standards	The system should follow industry and platform conventions to prevent causing users confusion.

5	Error prevention	The system should prevent errors and frustrations by removing memory burdens, supporting undo, and warning users.
6	Recognition rather than recall	Make options and elements visible to let users recognize the information and minimize users' memory load.
7	Flexibility and efficiency of use	Provide accelerators, personalization, and customization options to carry out flexible user flow.
8	Aesthetic and minimalist design	The content and design should focus on essential information to support primary goals.
9	Help users recognize, diagnose, and recover from errors	Present error messages in the way the users understand and offer solutions to solve the errors.
10	Help and documentation	Provide help documentation whenever the users may need it and allow for easy search.

Table 2. Nielson's 10 Usability Heuristics (Nielson 1994)

These heuristics are used as the criteria throughout the design process. They can be applied not only to a 2D interface or experience but also to augmented reality and virtual reality.

2.3.2 User Experience Design and Mixed Reality

Nielson's heuristics are expanded in the "10 Usability Heuristics Applied to Virtual reality" article by Alita Joyce (2021). Oculus Quest (www.oculus.com/quest-2/) was used as an example for demonstrating how heuristics can be reflected in VR applications in detail.

1	Visibility of system status	Use visual cues to present real-time reflection of the current system state for both the interaction in the VR application and for the VR hardware equipment.
2	Match between the system and the real world	Build the VR interaction and 3D system based on real-life experience to help users predict and understand how things function.
3	User control and freedom	Provide users with options to cancel or go back when they are in the middle of interaction in VR.

4	Consistency and standards	Use interaction design standards that users are already familiar with outside VR to mitigate confusion.
5	Error prevention	Prevent system errors by warning users and letting users confirm before taking an action, especially for potential physical harm when using VR.
6	Recognition rather than recall	The system should try not to ask users to remember additional information. For example, provide users with labels on icons to avoid forcing the users to remember the meaning of the icons.
7	Flexibility and efficiency of use	VR applications should cater to both new and experienced users by offering options for customization.
8	Aesthetic and minimalist design	VR systems could be more complicated than traditional systems, so it is important to focus on the essentials and prioritize the primary options.

9	Help users recognize, diagnose, and recover from errors	Provide a clear explanation of the problems and helpful solutions to guide users to recover from the issues when errors occur in VR.
10	Help and documentation	Due to the complex nature of VR interactions, not only Help and the Documents should be included in the systems, but also video tutorials, frequently asked questions, and live support might be necessary to provide help to the users.

Table 3. Nielson's 10 Usability Heuristics Applied to VR (Joyce 2021)

The user experience design and interaction design for telemedicine should follow the above heuristics.

2.3.3 User Experience Design and Telemedicine

Most research around the intersection of user experience design and telemedicine has been focusing on patient experience. There are many available datasets regarding patient satisfaction rates gathered through surveys (Ramaswamy et al 2020). In the field, qualitative research, and interviews of patient experience with telemedicine have also been conducted by multiple research teams across the world, for both general care and specialties. These research outcomes also contribute to the findings mentioned in the telemedicine literature review section, especially on the topic of the patient-physician relationship. However, user experience design represents a new practice that might take a long time to establish in most healthcare organizations as it is not a driven factor and the expense and commitment to deploy cannot be made lightly (Jones 2013).

2.4 Summary of Chapter 2

The literature review and related work examination suggest issues, challenges, and opportunities around telemedicine, mixed reality, and user experience design. The research findings create a rich foundation for design theories and help me narrow down the research directions. These findings are later integrated into the design frameworks and criteria.

During the literature review, issues related to telemedicine are exposed.

- Patients may have difficulty understanding the consultation process during a telemedicine appointment.
- EMRs may face issues of health data integration, user interface and user experience design, health data visualization, and security.
- Telemedicine visits are more physician-centred compared to in-person visits.

- The lack of physical presence may compromise trust and interpersonal connections for some patients.

Based on research around mixed reality, the following benefits can be experimented with to solve the above issues:

- Using avatars to create a stronger presence and offer the users a sense of immersion.
- Allow the users to virtually interact with each other and the environment in the same way as in real life.

The following benefits of user experience design may also contribute to the telemedicine issues:

- Speed up the process for a shorter consultation period by implementing easy and simple interactions and preventing potential frustrations.
- Facilitate the patients to achieve a better understanding of the overall process and their health issues, by presenting information clearly and guiding the patients through the process.

The advantages of different applications are connected and condensed together to generate potential solutions:

- To improve the process of telemedicine video consultation, the existing diagnostic process should be followed and implemented with mixed reality and user experience design principles that help the users to understand how the flow work and which stage they are currently at.

- To improve the EMR in telemedicine, mixed reality can be part of the experience to help integrate and visualize the health data.
- To enhance the telepresence of telemedicine, mixed reality technology can be used to create an immersive experience for the users. It helps to shape a sense of closeness to mitigate the feeling of isolation brought by the physical distance and strengthen trust between the patients and physicians.

3. Methodologies

Chapter 3 introduces the methodologies and the theoretical design process used for developing the thesis research. It covers the ideation and development of the conceptual framework and the key features for the prototypes.

3.1 Methodology

> *"Unlike design practice, where the making focuses on making a commercially successful product, design researchers engaged in critical design create artifacts intended to be carefully crafted questions. These artifacts stimulate discourse around a topic by challenging the status quo and by placing the design researcher in the role of a critic."* (Zimmerman et al 2007)

The Research Through Design is a methodology used by researchers to "generate new knowledge by understanding the current state and then suggesting an improved future state in the form of a design (Zimmerman, J., Forlizzi, J. 2014)." It proposes an iterative design process that involves critical reflection on the people, context and subjects around the situation that can be potentially improved. It is also defined as "a research approach that employs methods and processes from design practice as a legitimate method of inquiry (Zimmerman et al 2010)."

Using Research Through Design as the overarching methodology to develop the research, I want to generate findings and knowledge by designing and creating multiple iterations of designs. These design creations are based on knowledge acquired during the literature review process. Each design iteration should aim to answer the research questions. The designs should be evaluated, and the findings should be incorporated into the next iteration. With the knowledge gathered during the making process, the newer prototypes have richer materials and theories to work with.

3.2 Methods

Literature review, Prototyping, and Descriptive Design Evaluation are selected methods used for background research, creation, and evaluation.

3.2.1 Literature Review

As a systematic way of collecting and synthesizing previous research (Baumeister and Leary 1997; Tranfield et al 2003), literature review, is selected as a method to show evidence and uncover advancements and gaps in the three fields MR-Medicine focuses on. In Chapter 2, a literature review is conducted around the existing surveys, publications, theories, and applications of telemedicine, mixed reality, and user experience design. For telemedicine, the literature review in Chapter 2.1 is not an exhausting search for a complete study, it rather focuses on exploring the problems and areas that can be further improved. Because this method tends to help provide an overview of areas in which the research is disparate and interdisciplinary (Snyder 2019), potential interdisciplinary (user experience design and mixed reality) solutions to the problems of telemedicine are discovered in the Chapters 2.2 and 2.3 and summarized in Chapter 2.4 to set up a foundation for the design creations.

3.2.2 Prototyping

Virtual prototyping, defined by Song et al from the University of Pennsylvania, refers to the process of simulating the user, the product, and their combined physical interaction in software through the different stages of product design, and the quantitative performance analysis of the product (Song et al 1999). It emphasizes human-product interaction and the function of virtual prototyping in product design and analysis (Wang 2002). Using the virtual prototyping method, digital prototypes in computers, mobile phones, and VR headsets in Chapter 4 are developed to incorporate and experiment with the research findings from the literature review. The prototypes enable a study of the behaviours of the complex telemedicine system and patient experience before building fully functional hardware or software products.

3.2.3 Descriptive Design Evaluation

The design evaluation method is selected from Hevner's *Design Science in Information Systems Research* (2004). Under the Design Evaluation chapter, Hevner introduces 5 methods to evaluate the quality, utility, and efficiency of design artifacts, including 1) Observational, 2) Analytical, 3) Experimental, 4) Testing, and 5) Descriptive. Due to constraints of the field and limited access to the patients, human participants are not recruited. Therefore, the previous four methods are not suitable for this research. Descriptive evaluation is selected because it matches appropriately with the MR-Medicine prototypes according to Hevner's statement: "descriptive methods of evaluation should only be used for especially innovative artifacts for which other forms of evaluation may not be feasible. (Hevner 2004)" Under Descriptive evaluation, he also listed two methods:

1. "Informed Argument: information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility.
2. Scenarios: construct detailed scenarios around the artifact to demonstrate its utility (Hevner 2004)."

Both methods are used for evaluating the prototypes. *Informed Argument* makes use of Nielson's 10 Heuristics in Chapter 2.3.1 as criteria to evaluate the utilities. *Scenarios* construct a persona's experience through the Telemedicine Diagnostic Process in Chapter 2.1.1 to demonstrate how the utilities of MR-Medicine perform during the process. Each prototype is demonstrated in the futuristic context, which is 5 years from now, in 2027. The scenarios assume that by 2027, mixed reality, especially virtual reality, is more commonly accepted by a larger user group. Chapter 5.1 expands on the evaluation method and flow.

3.3 Research Process Overview and Breakdown

The project timeline follows the process depicted below. After summarizing research findings during the knowledge gathering process, the results are transformed into design principles that were later represented through sketches, Figma wireframes, and Blender renderings during the ideation. Three iterations of all three types of prototypes have been created. The later iterations were built on top of the feedback and reflection from the early iterations. An evaluation was conducted to examine the quality and utility of the final prototypes.

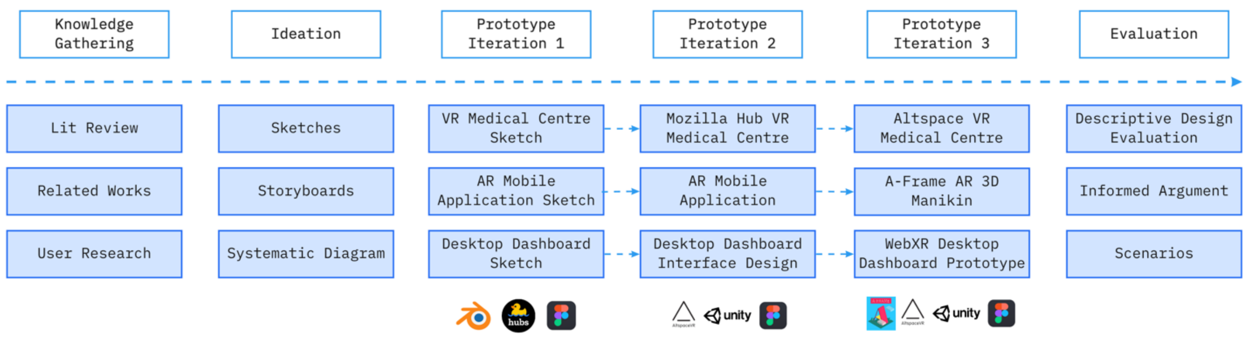


Figure 14. The project research process of MR-Medicine from knowledge-gathering, design and ideation, prototyping, to evaluation.

Here is the research process listed in order as follows:

1. Knowledge Gathering: literature review, related works, and user research
2. Design Ideation: sketches, storyboards, and systematic diagram
3. Prototype Iteration 1: VR Medical Centre sketch, AR mobile application sketch, desktop dashboard sketch
4. Prototype Iteration 2: Mozilla Hub VR Medical Centre prototype, AR mobile application interface designs, desktop dashboard interface designs
5. Prototype Iteration 3: AltspaceVR Medical Centre prototype, A-Frame web-based AR 3D manikin prototype, web-based desktop dashboard prototype
6. Evaluations: Descriptive design evaluation with informed arguments and scenarios

3.4 Design Process

3.4.1 The Presence and Scenario Cube

I was inspired by Milgram's taxonomy and Zeltzer's AIP Cube to adapt the use of a coordinate system to develop a presence and scenario model for this research project. Here I colour-coded the coordinates for easier reference. The three axes represent the virtual environment, the patient's access to AR, and the physician's access to VR. This diagram illustrates the eight possibilities where patients and physicians are engaged with various levels of presence in mixed reality, depending on their access to the digital device.

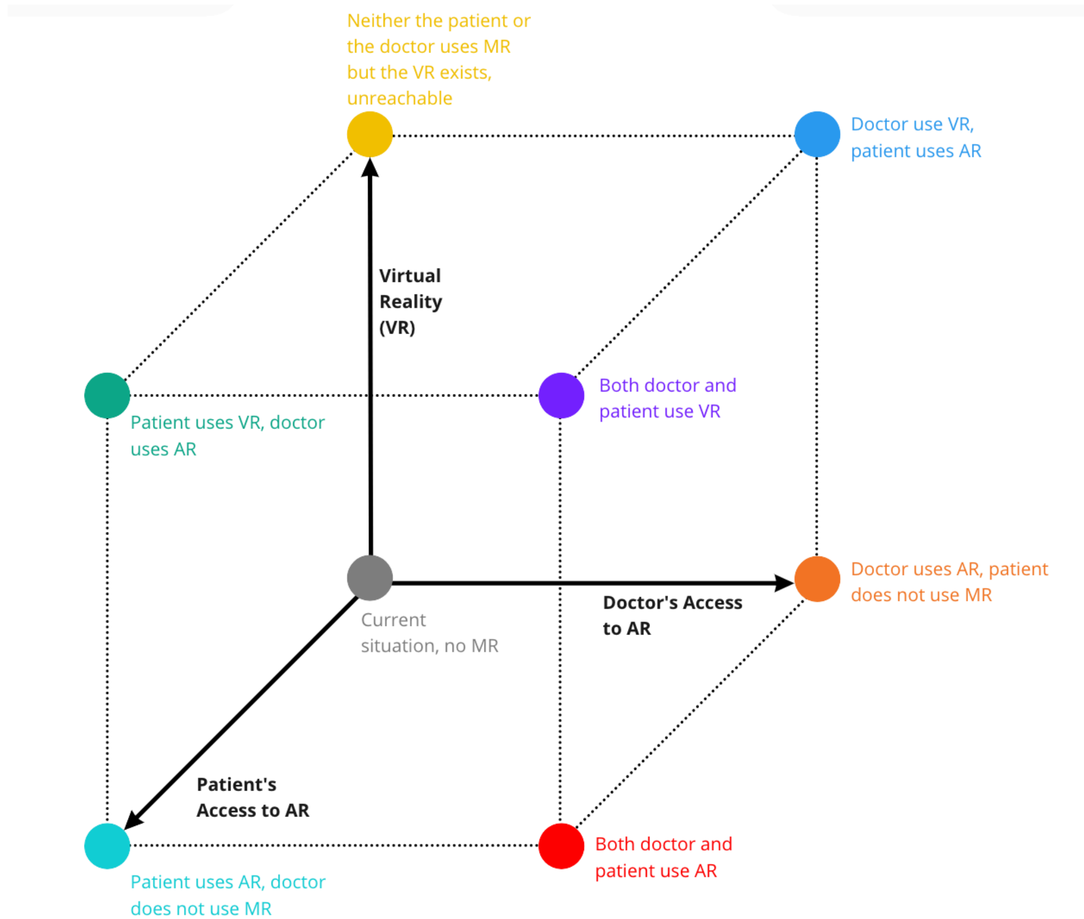


Figure 15. Telemedicine Prototype Presence Model

Here are the eight scenarios:

1. Grey: The current situation - no MR is involved in the video consultation process.
2. Yellow: Neither physician nor patient uses MR, only virtual avatars or the consultation record is in a VR. This scenario is unreachable because the users are not able to look at things in VR.
3. Teal: Patient uses AR, physician does not use MR.
4. Orange: Physician uses AR, patient does not use MR.

5. Red: Both physician and patient use AR.
6. Purple: Both physician and patient use VR.
7. Green: Patient uses VR, physician uses AR.
8. Blue: Physician uses VR, patient uses AR.

For this study, I decided to explore and expand on the purple, red, and grey circles:

1. Purple: Both physician and patient use VR.
2. Red: Both physician and patient use AR.
3. Grey: The current situation where no MR is implemented.

These scenarios where the physician and the patient have equal access to the same type of equipment are selected for prototyping. The three scenarios are explored through VR prototypes, AR mobile prototypes, and desktop dashboard prototypes, from patients' perspectives. Each type of prototype is distinctive from the other due to the technology affordance but contains similar features.

3.4.2 System Overview Diagram

Referring to the best practice from existing telemedicine platforms such as CloudMD and VisualDX, the typical features include Virtual Assistant Diagnosis, Appointment System, Video/Audio Consultation, EMR, Medication and Treatment Handout, and Diagnostic Report. As I am focusing on the exploration of improving the video consultation experience for the three scenarios mentioned above, I created an MR-

Medicine system diagram to demonstrate the components that I would cover for the experiment. This diagram does not indicate all stages in the clinic flow, it only focuses on the relevant features for this research project.

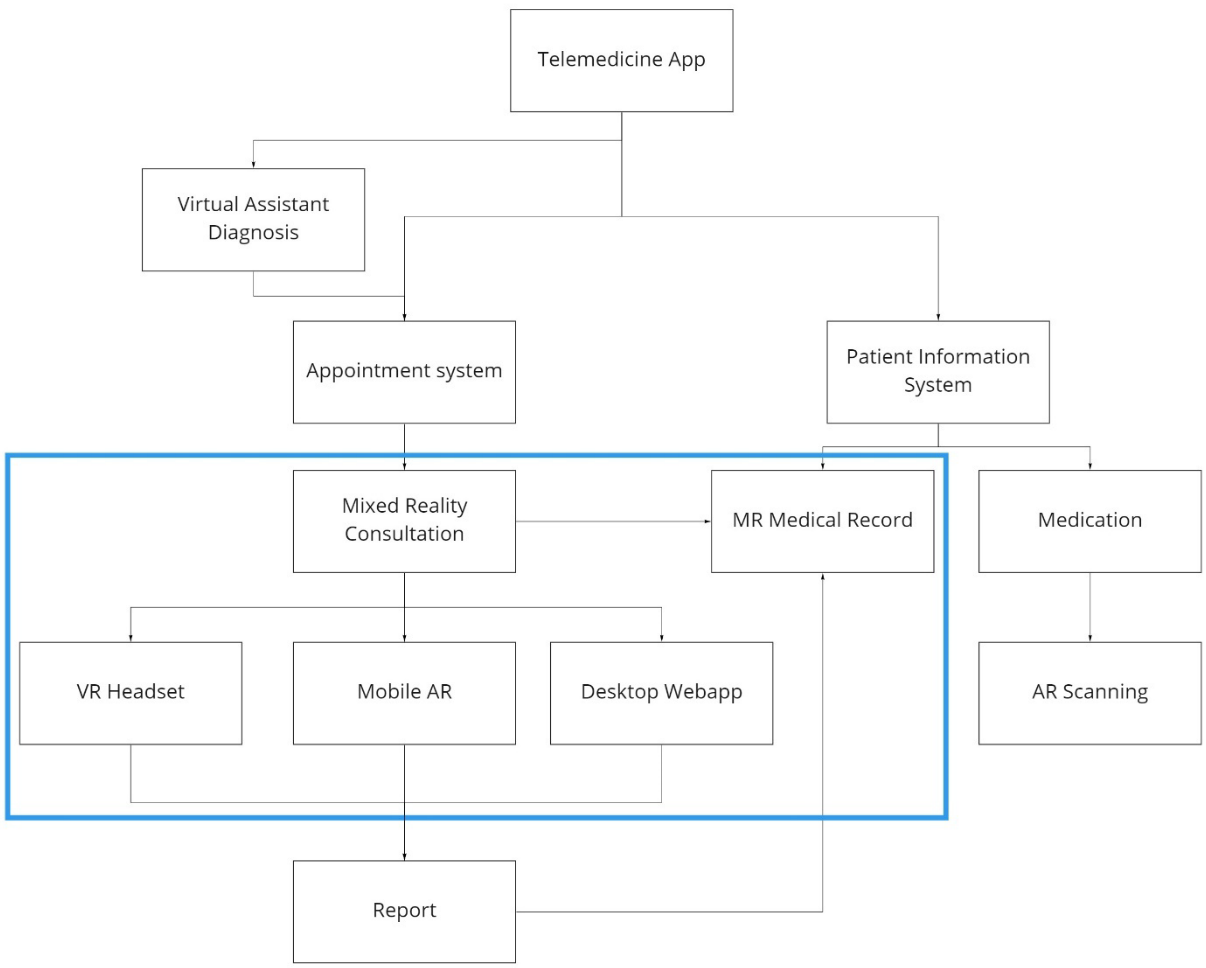


Figure 16. The system overview diagram shows that the highlighted areas within the blue box are the focus of the research creations.

The prototypes focus on the mixed reality medical record system and consultation features, experimenting with three different applications: VR Medical Centre, AR Mobile Application, and Desktop Dashboard.

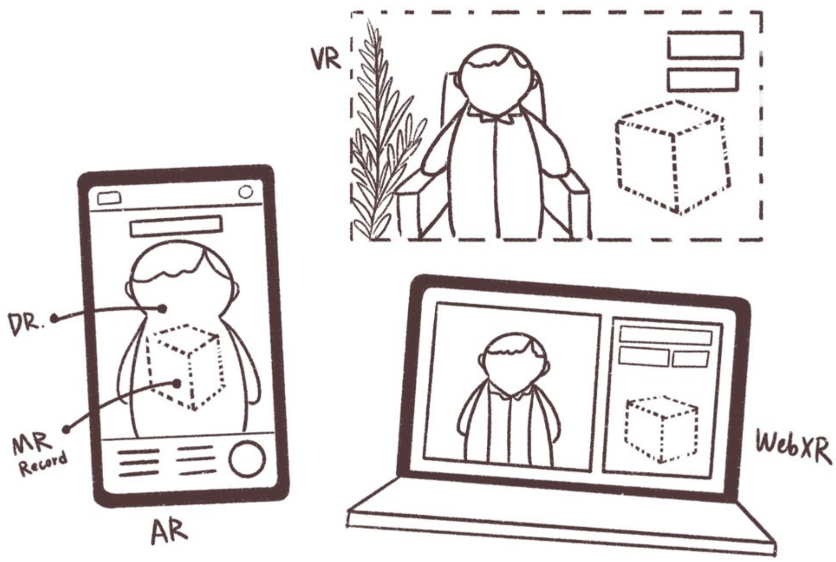


Figure 17. Sketch for the three types of prototypes: VR, mobile AR, and desktop

The VR prototype is a simulated experience where the user will be immersed in a Virtual Medical Centre that is separated from the real world. The AR prototype is an enhanced real-world experience with virtual elements presented to assist the consultation process. The traditional Desktop Dashboard involves user interface and interaction designs using a 3D viewer.

3.4.3 EMR and 3D Manikin

The 3D manikin is a key feature and uncommon solution proposed by MR-Medicine. Inspired by the examples in Chapter 2.1.6, it is a 3D human body for hosting information and records of the patient and an intuitive visualization tool that makes medical records more accessible.

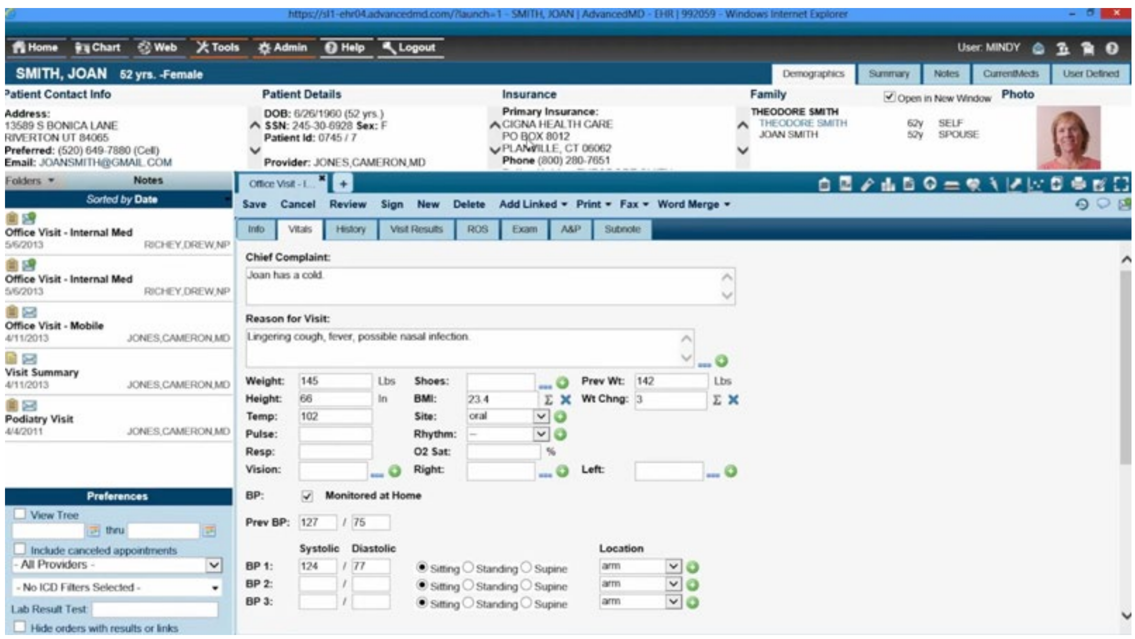


Figure 18. A normal EMR by Nextech (www.nextech.com) for comparison

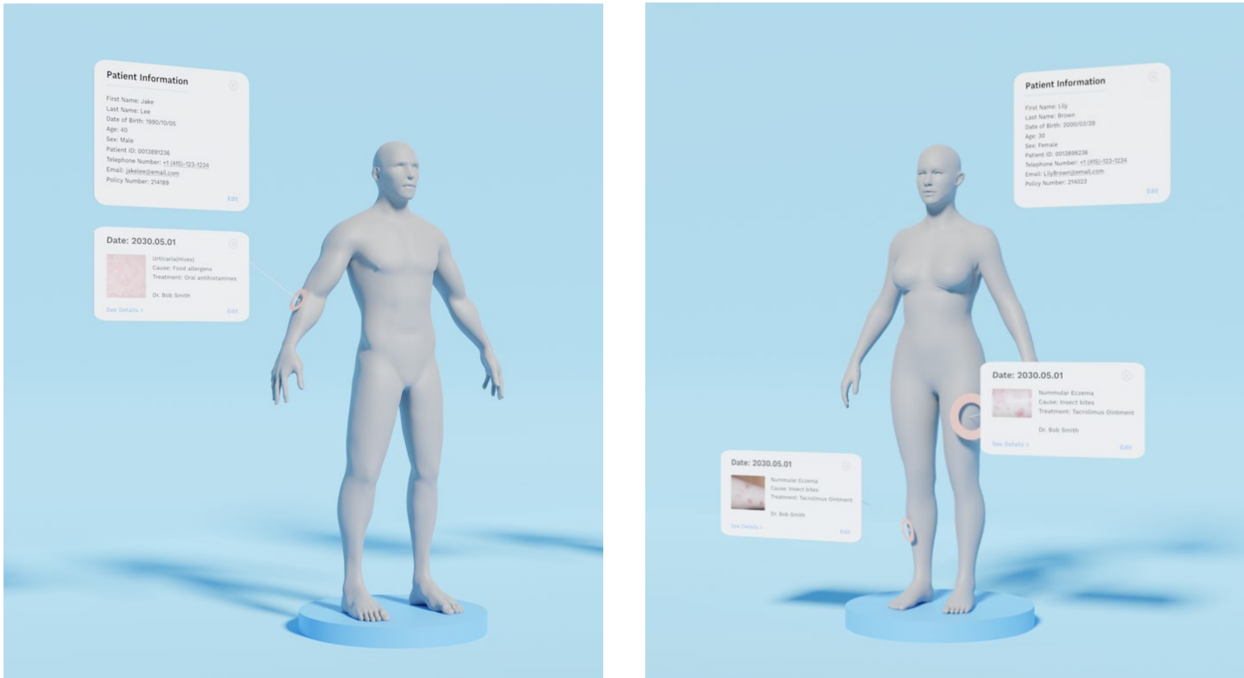


Figure 19. The male and female 3D manikin for hosting patient medical records

This suggested new system will bring benefits and ease of use to both patients and physicians.

For patients: 1) patients can map the photos they took onto the 3D body, on the specific area, 2) patients will have access to their records and be able to understand their conditions better, 3) patients will be able to keep the 3D body to host their medical records for long term.

For physicians: 1) physicians can add reference photos to the 3D body, 2) physicians can write notes, treatment plans, and records and tag them to the specific body sites, and 3) the 3D body can be easily transferred between different physicians. This feature is incorporated in all prototypes, as an asset to facilitate the consultation process.

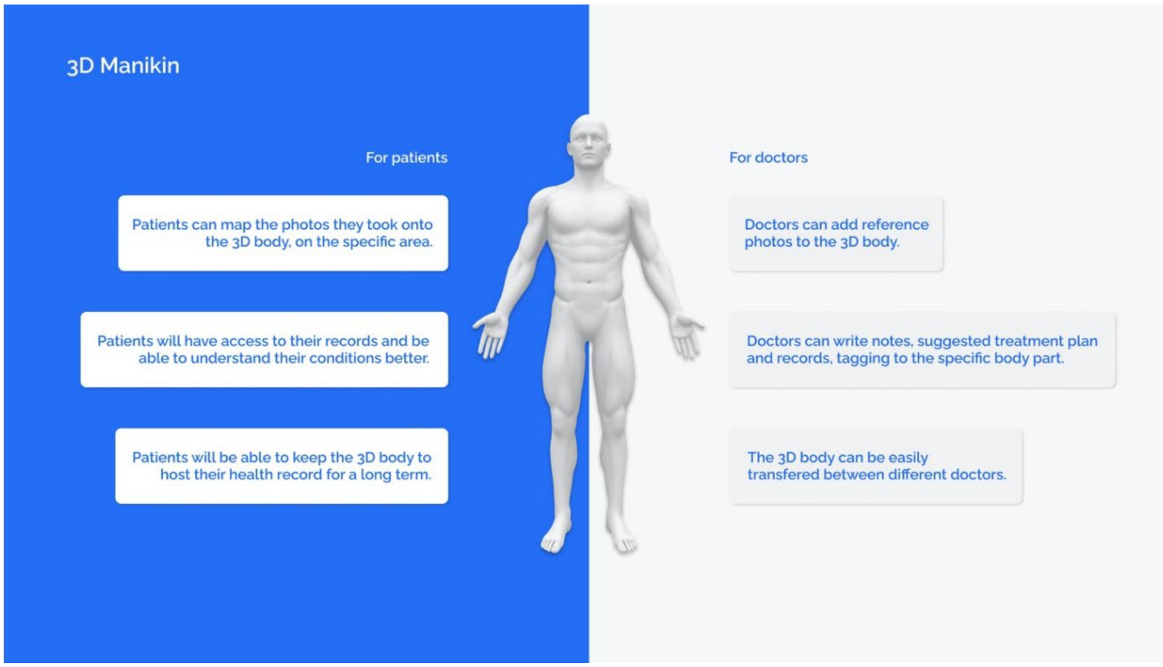


Figure 20. The benefits of using 3D manikin for patients and physicians.

Based on the literature review findings in Chapter 2.1.4, the patient-centred consultation style greatly benefits the patient satisfaction rate (Agha et al 2009; Chandra et al 2018). As a new medical record system, this feature provides the patient with opportunities to self-manage.

It is also a solution that helps answer the research questions. By introducing this visualization tool to telemedicine consultation, 1) the process of information gathering, and communication may become easier 2) the medical records are stored and represented in an integrated way, and such a model may improve the continuity of care as different physicians can review the records easily, 3) the telepresence is enhanced while this model is used in VR and AR scenarios, as the recognition of patients' body information recreates the real conditions. Due to the limitations of time and resources, the 3D bodies used in the prototypes will be limited to the male and female models in the above images. For future development, patients should be able to customize their 3D manikins and adjust their height, weight, body shape, skin colour, facial features, etc. They can also choose to cover certain body sites as they wish if they are uncomfortable displaying the entire 3D body.

3.4.4 Summary

The above frameworks bridge the research findings from the literature review and the research creations. They established a foundation for my experiments and prototypes. With the outcomes of Chapter 3, I move forward to develop the prototypes for VR, AR, and desktop, with the focus on the following two key design features: 1) providing a clear consultation process and 2) 3D manikin for hosting patient medical records.

4. Prototypes

Chapter 4 covers the prototypes and experiments built for this research project. Created with the Research Through Design methodology, each iteration undergoes the ideation, design process, development, and evaluation process.

4.1 Prototype 1 – Developing the VR Prototype

The development of the VR prototype includes three iterations introduced in the following chapters.

4.1.1 Iteration 1 – VR Medical Centre Sketch

The renderings were created with Blender and Figma, to depict the VR medical center prototype. The environment was set as a welcoming and calm doctor's office, with two connected rooms. Patient and physician shall be virtually present in the same room, see and hear each other's avatars. They can discuss the medical condition in the first room and review the 3D manikin in the second room.

Figure 21. VR prototype sketches demonstrate how patients and physicians may interact in VR

4.1.2 Iteration 2 – Mozilla Hubs VR Medical Centre

The first VR prototype was done in Mozilla Hubs (https://hubs.mozilla.com) to quickly test out the main idea of situating the virtual consultation in a doctor's office. I loaded an office model package from Sketchfab in the Mozilla room creator and added the 3D manikin in the office. With Mozilla's framework, multiple users can access the room at the same time, and the room owner has control over the access.

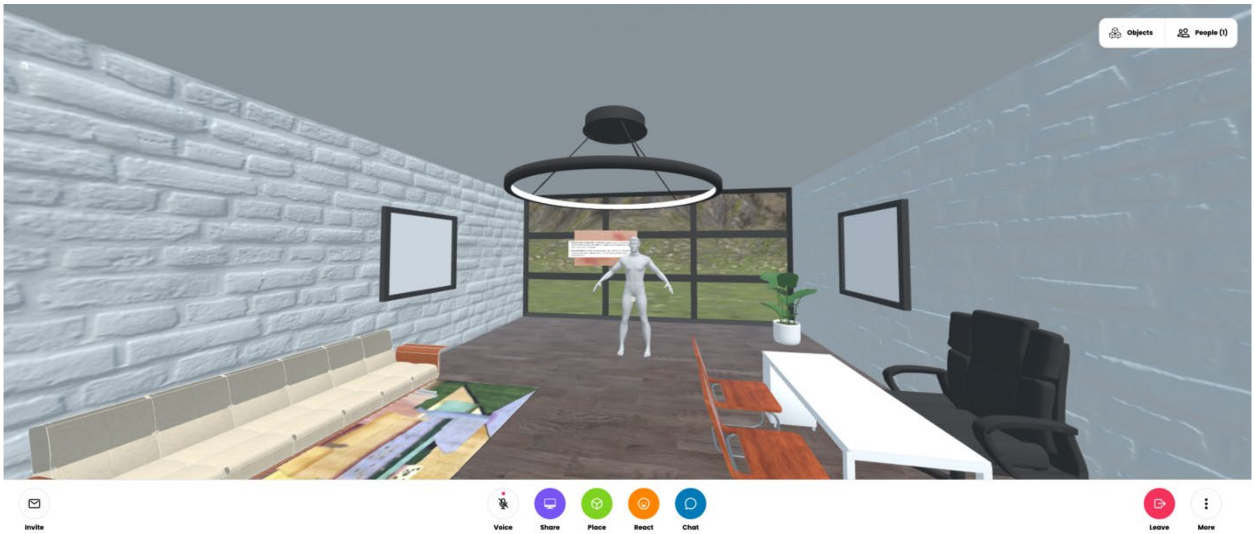


Figure 22. Mozilla Hub VR prototype to test out the virtual doctor's office idea

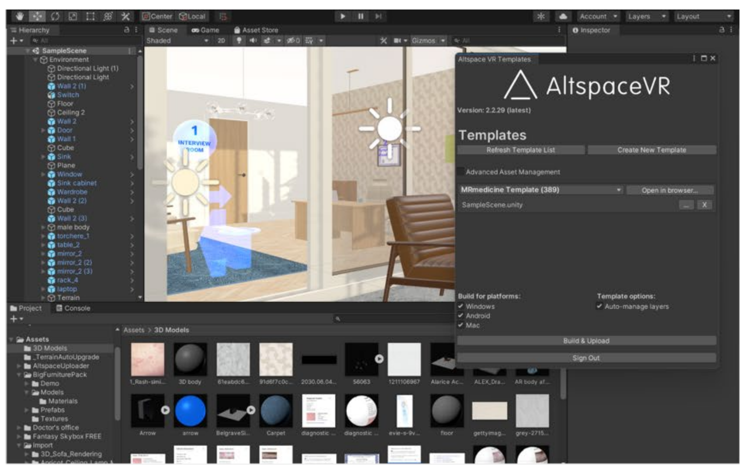
For this early exploration, I experimented with the design concept in Mozilla Hubs. Situating the consultation in the doctor's office seems appropriate because it tends to match reality. Both patient and physician should be able to recognize and navigate without confusion.

Mozilla Hubs brings benefits such as adding models and texts that can be pinned to a specific place in the room, adding external links for reference, and creating a sense of presence with a multiuser avatar system. However, Mozilla Hubs has many limitations: the room building does not support large 3D files; the lighting and shading mode is limited and does not look realistic, and it can be glitchy when the assets are too large. The general VR consultation experience does not reach my level of expectation, therefore I moved away from Mozilla Hubs and experimented with other tools.

4.1.3 Iteration 3 - AltspaceVR Medical Centre

After researching VR platforms with capabilities for customization and world-building, I decided to move forward with AltspaceVR (www.altvr.com). It offers many functionalities that my prototype can benefit from, including a built-in multi-user system, web browser projection feature, and world-building tools. AltspaceVR offers two world-building solutions, 1) build or modify a world directly in AltspaceVR with the World Editor tools, and 2) build a world template in Unity with the AltspaceVR Unity uploader. For this prototype, I used both methods to create different components. The 3D space was built in Unity, and the interactive components were created with World Editor.

Altspace World Editor



Altspace Unity Uploader

Figure 23. Altspace World Editor vs. Unity Uploader

The making process was as follows. Firstly, I created a world template on AltspaceVR's website called MR-Medicine Template. Then I downloaded the AltspaceVR sample scene Unity package and built my world from there. All the base static 3D environment was built in Unity. Multiple packages for 3D prefabricated models were downloaded from the Unity Asset Store and used in both the interior and the exterior space. When the spatial design was done, I logged in to my AltspaceVR account in the Unity Uploader plugin and uploaded the models to the MR-Medicine Template. The template was used to create usable builds across all platforms including Android, VR, and Desktop.

Secondly, I went to the AltspaceVR website to create a world called MR-Medicine World and chose to use the MR-Medicine Template for this world. The world was set to be private and only people who were given access can enter it. This restriction ensures the privacy of the session. Once the world was set up, I entered the world by typing the world code in AltspaceVR to enter the world. I tested the environment regarding scales, user circulations, and lighting, and revised the design accordingly. Apart from the 3D environment, interactive components were added to the space with AltspaceVR built-in World Editor. I added the web browser projection screen to the rooms, enabling the physician and patient to look at external online reference libraries together.

The assets added through the World Editor are on a different layer separated from the 3D models uploaded from Unity. They can both be updated as standalone layers and will reflect the updates in the same world.

Here is an overview of the VR consultation process. The VR Medical Centre is situated in an isolated natural scene with trees and mountains under the sunset. The building has only one level, which ensures a linear circulation that is easy for users to navigate through. There are three rooms in the Medical Centre: 1) Interview Room, 2) Symptom Visualizer, and 3) Diagnostic Results. Both patient and physician will move through each room following the consultation steps together.

Figure 24. AltspaceVR Medical Centre exterior environment

The design of the experience assumes that the physician is already familiar with how the system works and will guide the patient through the consultation if the patient has never used it. The patient will have equal access to the same amount of information as the physician does, with the help of visual guides throughout the space. This concept aims to challenge the physician-centred dynamic in the telemedicine process and improve patients' experience.

Figure 25. Physician's desk with patient's information displayed on a floating card

The physician is supposed to enter the world first, to prepare and review the patient's information and medical records. They will enter the room and stand behind the desk. A card with the patient's information is floating above the desk.

Figure 26. The AltspaceVR tip with a welcome message.

When the patient arrives in the world, they are spawned right outside the office door. They will be greeted by an AltspaceVR tip that can be customized under the world information on the AltspaceVR website. The welcome message informs the patient that the physician is already here and will call them to come in when ready. It also reminds the patient to unmute the microphone so they can talk to the physicians via voice chat.

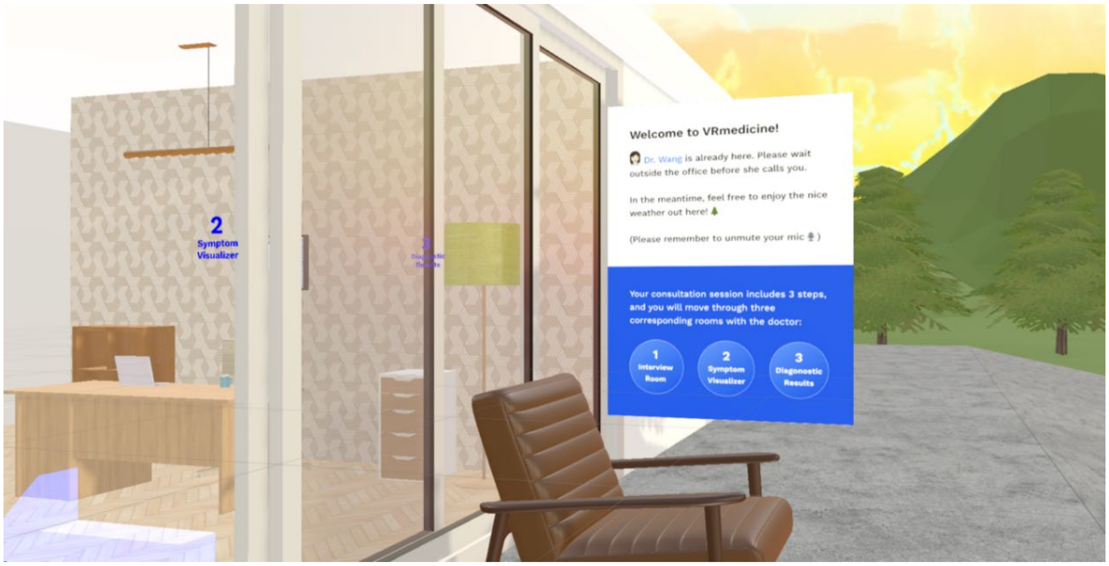


Figure 27. The waiting area outside the Medical Centre.

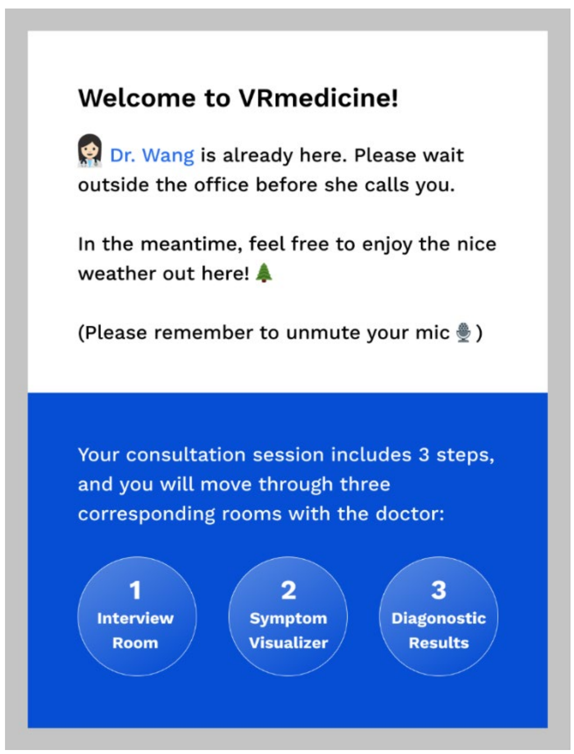


Figure 28. Welcome message in the waiting area with a brief guide of the process that the patient will go through with the physician.

Another floating card with more detailed information, including a brief introduction of the consultation process, is on the right side of the patient. A chair is placed next to the card to indicate it as a waiting area.

Figure 29. The physician greets the patient outside the VR Medical Centre.

The Interview room is the first space where the patient and physician meet. The physician will stand behind the desk and the patient will stand in front of the sofas, indicated by a transparent blue ring on the floor as a wayfinding guide. This spatial setup aims to match the real environment in a doctor's office, to create a sense of familiarity so that the users can recognize the environment. I want to create a welcoming and comfortable environment that helps to ease the patient's nerves. It is designed to be spacious with lots of bright colours.

While staying in this room, the physician will ask questions displayed on a floating card that can be seen by everyone. This visualization is to help the patient understand the process and questions asked by the physician. The question prompts should be customizable by the physicians based on different patient scenarios for future development.

Figure 30. Physician and patient meet in the Interview Room, both standing at their designated locations.

Figure 31. The Interview Room space is designed to match an actual doctor's office with furniture and amenities

Figure 32. Question prompts are displayed on a floating card in the room

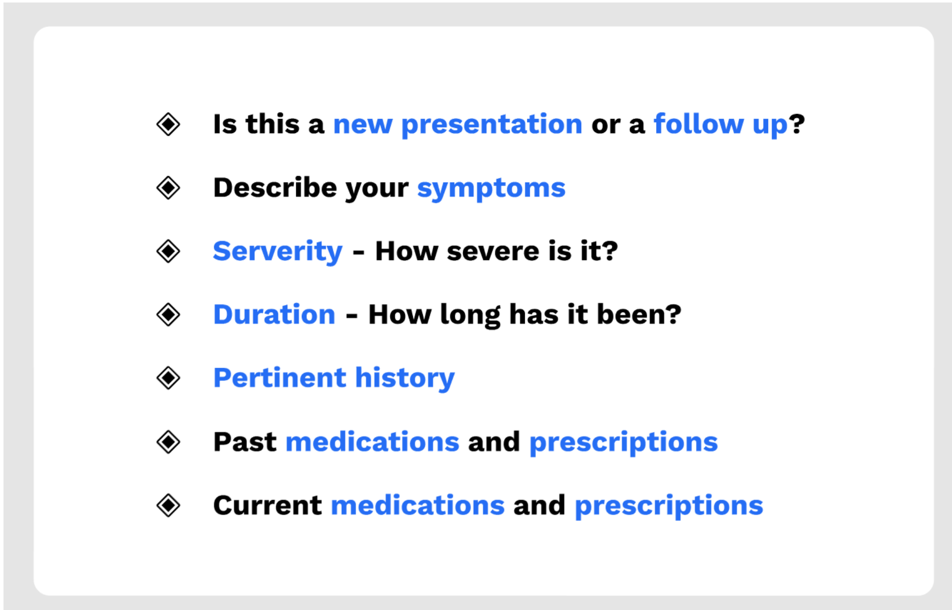


Figure 33. Interview questions for both physician and patient to look at while conducting the consultation

After the initial interview is completed, the physician and the patient will move to the next room, which is the Symptom Visualizer. On the left wall, medical records are displayed on white panels to show the patient's history. Each panel shows a summary of the previous diagnostic result, including a close-up image of the lesion, the type of the disease, treatment, body site, and the physician's name. These records will help the physician to understand what might cause the current condition and explain to the patient visually.

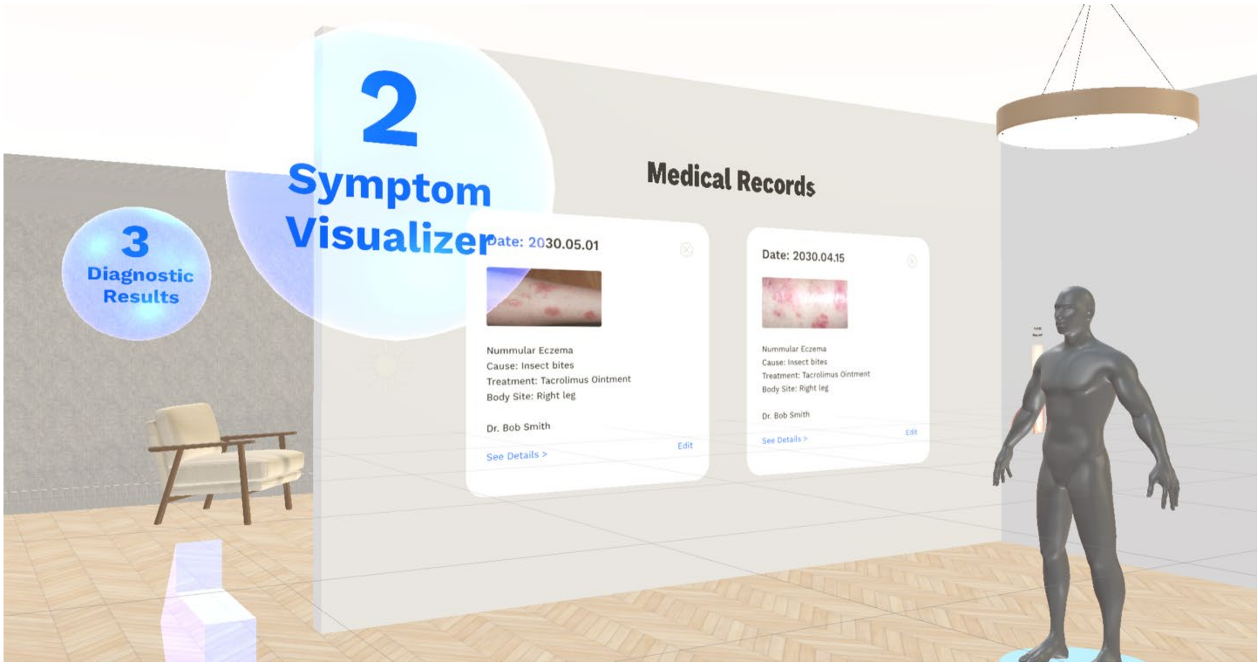


Figure 34. Medical history panels in the Symptom Visualizer room

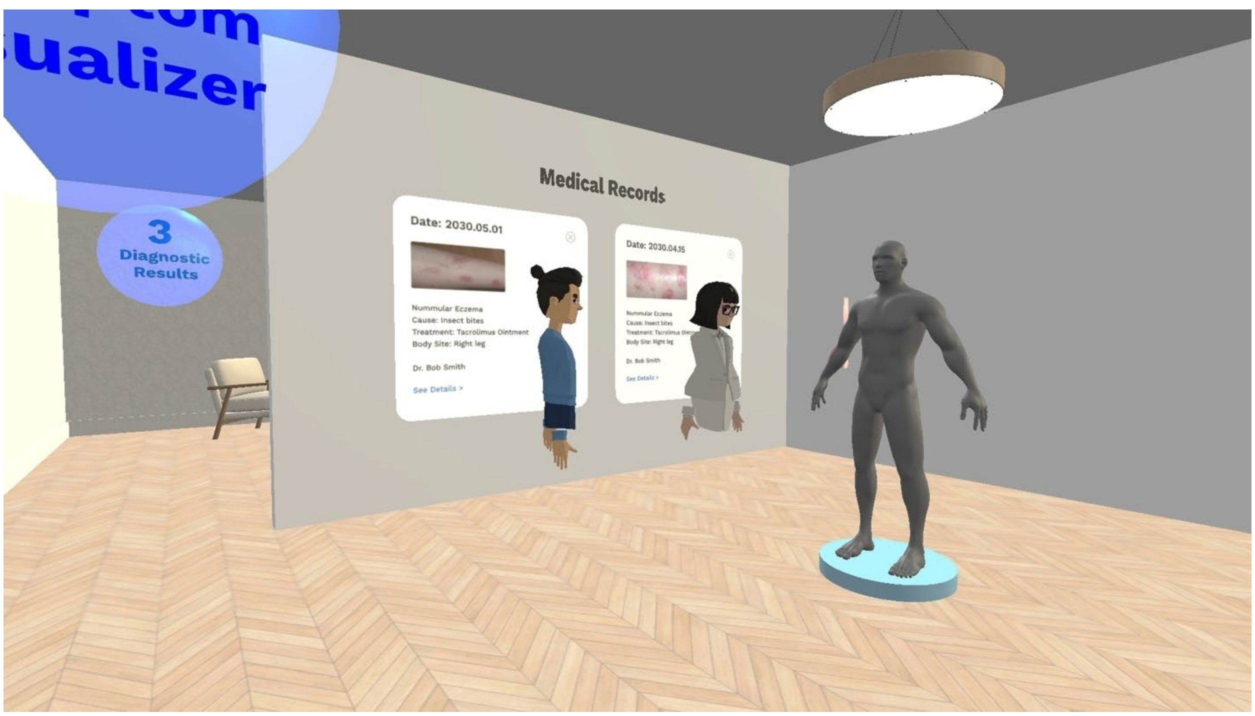


Figure 35. Physician and patient stand in front of the 3D manikin

In the middle of the room, a 3D human body represents the patient with their current conditions and symptoms. As mentioned, this model should be customizable for future development to reflect the patient's appearance. The patient should be able to upload images of their symptoms before the consultation, using the same mobile application as the AR prototype. Although the functionalities for the image integration system are not implemented yet, the design concept is presented in both VR and AR prototypes. They can choose the corresponding body site of the symptom. As an example, in the screenshot below, the patient has a skin rash on the right forearm, and one of the close-up photos is mapped to the 3D manikin. The date that the photos are uploaded is attached to the images. The patient and physician can walk around, look at the images together, point their fingers at the locations of the manikin, and understand the scale of the lesions. All information in this demo is static currently and future work will be toward making it more dynamic.

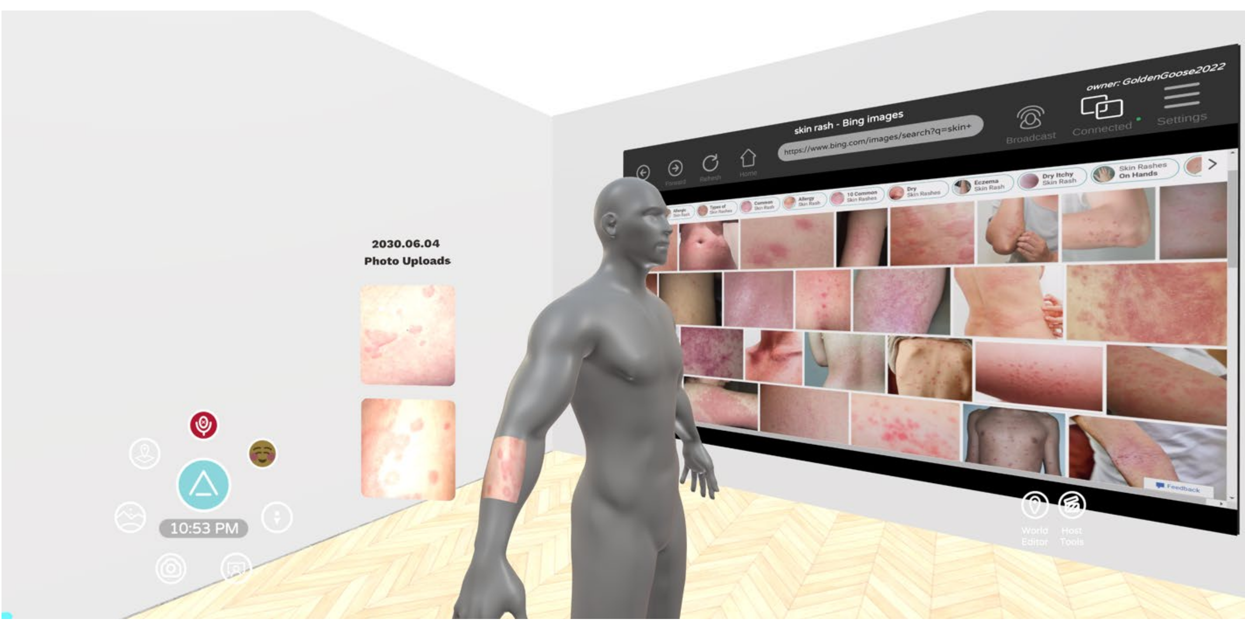


Figure 36. Physician's web browser using AltspaceVR built-in browser projector feature

On the right side of the room, a web browser projector is linked to the physician's browser. This AltspaceVR feature allows the patient and physician to look at online reference libraries or other resources together in VR.

Figure 37. Physician and patient look at the 3D manikin together

Once the physician gathers enough information for diagnosis or decides that another physical exam is needed, they can move to the next room, which is the Consultation Results Room. The physician will write up and display the diagnostic results in this room and explain to the patient the disease, treatment options, risks, side effects, and the expected results. Another web browser projector is installed in the room for the physician to show any information related to the diagnosis and treatment, from external libraries or online resources.

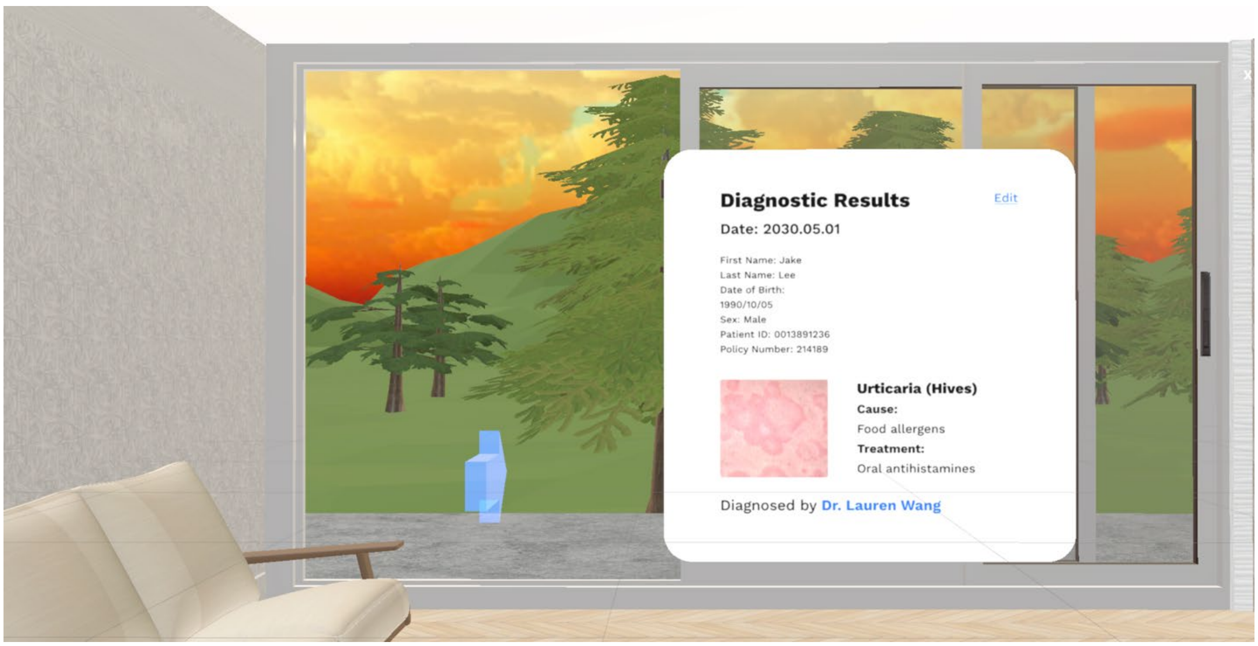


Figure 38. The diagnostic results are displayed on a floating card in the third room

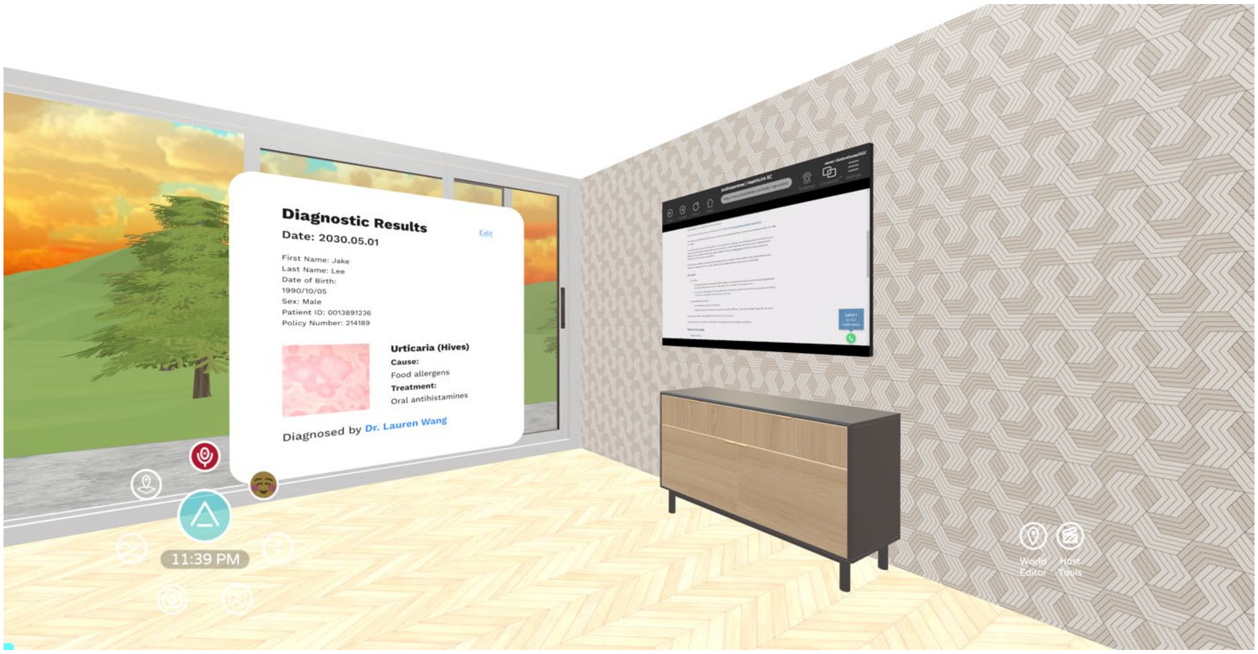


Figure 39. A web browser projector is attached to the wall to show external references or medication information

Figure 40. Physician and patient look at the diagnostic results card together

Once the consultation is finished, the patient can either exit the room or quit AltspaceVR or quit immediately.

Figure 41. Physician and patient chat before leaving the VR Medical Centre

4.2 Prototype 2 – Developing the AR Prototype

The AR Mobile Consultation App experiment consists of two components: a mobile prototype for the register and consultation process, and an AR 3D manikin for the medical records reviewing system.

4.2.1 Iteration 1 – AR Mobile Application Sketch

The base features of the AR prototype are sketched in Figma. It shows the basics of the application: an AR 3D manikin in the user's real space within a video chat framework. The user should be able to see which step of the consultation they are currently at, indicated by the status bar on the top. The user can also turn on/off the voice and video as they wish and communicate through text chat.

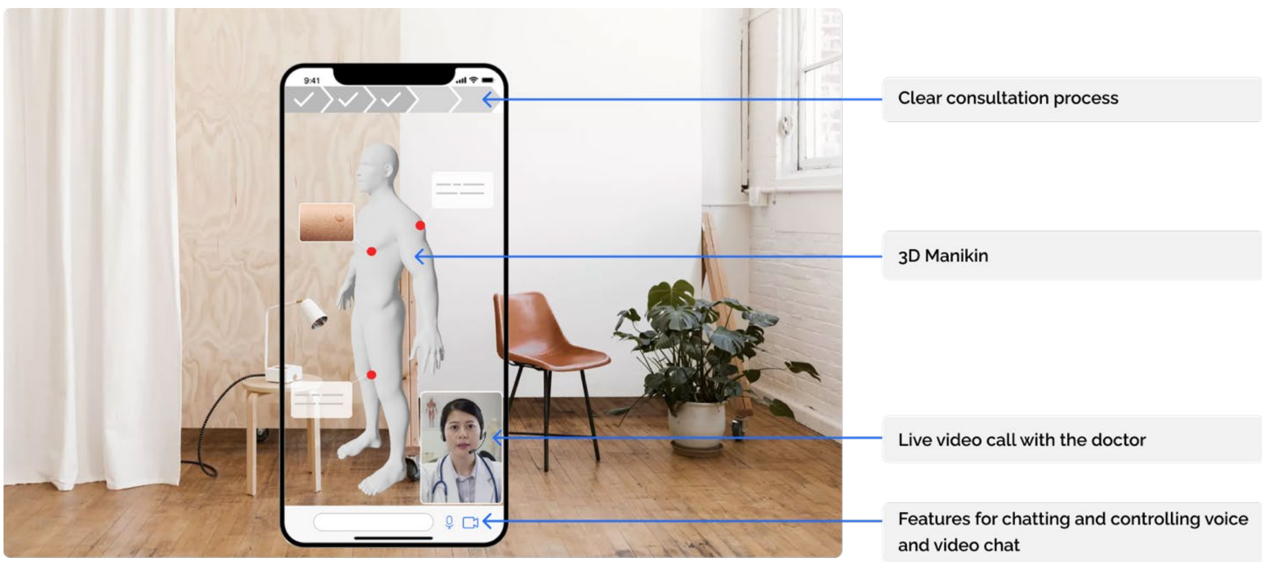


Figure 42. AR mobile prototype sketch

4.2.2 Iteration 2 – AR Mobile Application Prototype

Wireframes and low-fidelity prototypes were designed to map out the flow of the overall mobile experience. Patients will go through the appointment booking process first to submit information regarding their symptoms. On the first screen, patients can select if they would like to see a general physician or a specialist, which in this scenario, will be a dermatologist. Once confirmed, the patient will be asked to select and describe their symptoms and upload their lesion images and select where the lesions are on the 3D manikin. The application will automatically map the images on the corresponding body sites on the 3D manikin. The manikin will be displayed later during the consultation session. This same appointment booking system is supposed to be used for the VR prototype so that patients can complete the booking process on their phones.

To review previous health records, users can scroll and toggle the date of the record to hide and show the records on the 3D manikin. They will be able to toggle on multiple dates to compare the conditions.

The physicians will follow the question prompts to ask the patients about their conditions. This feature helps to standardize the telemedicine process and make the process transparent to the patients.

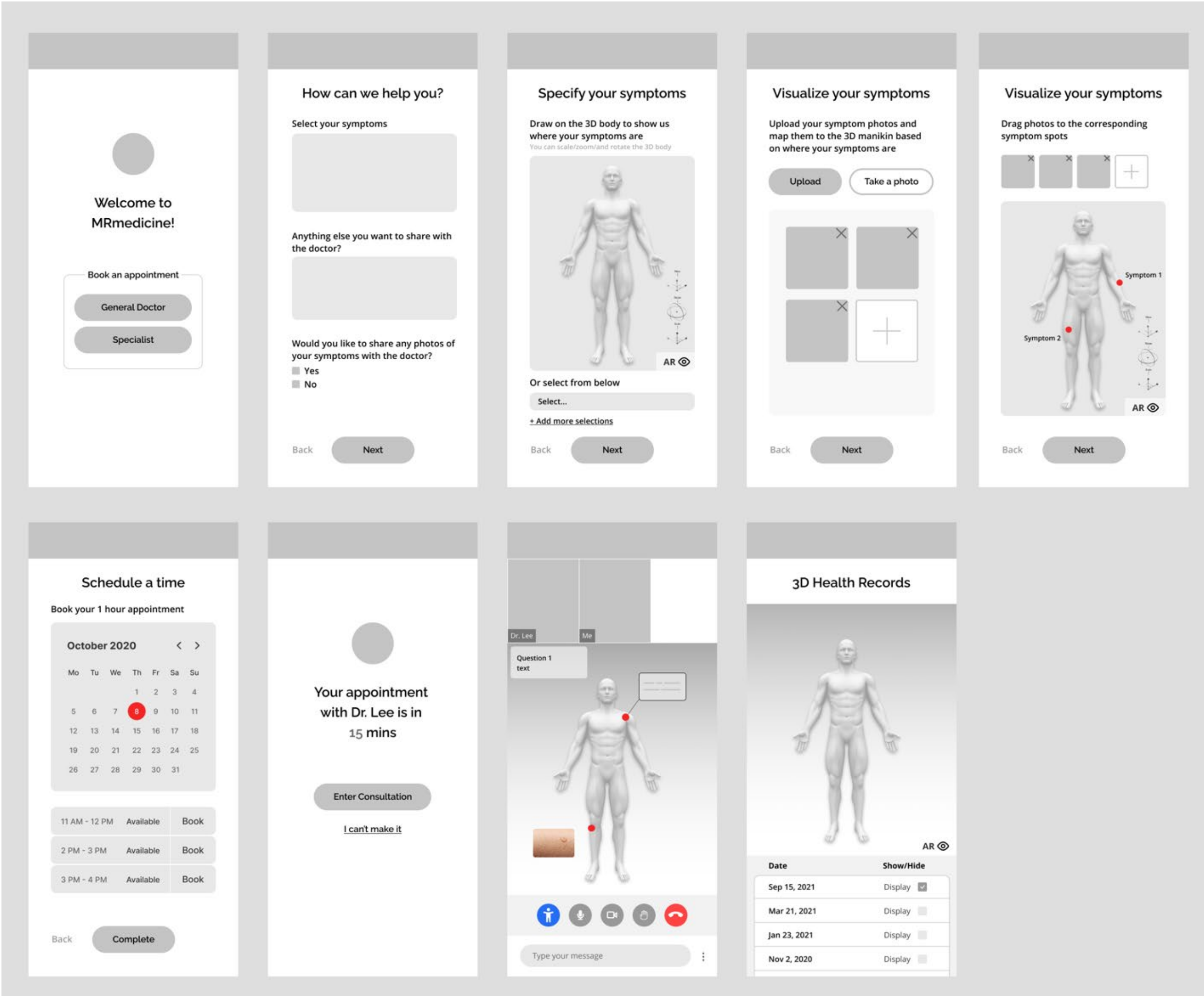


Figure 43. AR mobile low-fidelity prototype

Moving on to the high-fidelity prototype, I implemented colours and image assets to add a visual style that suits the professional healthcare application context.

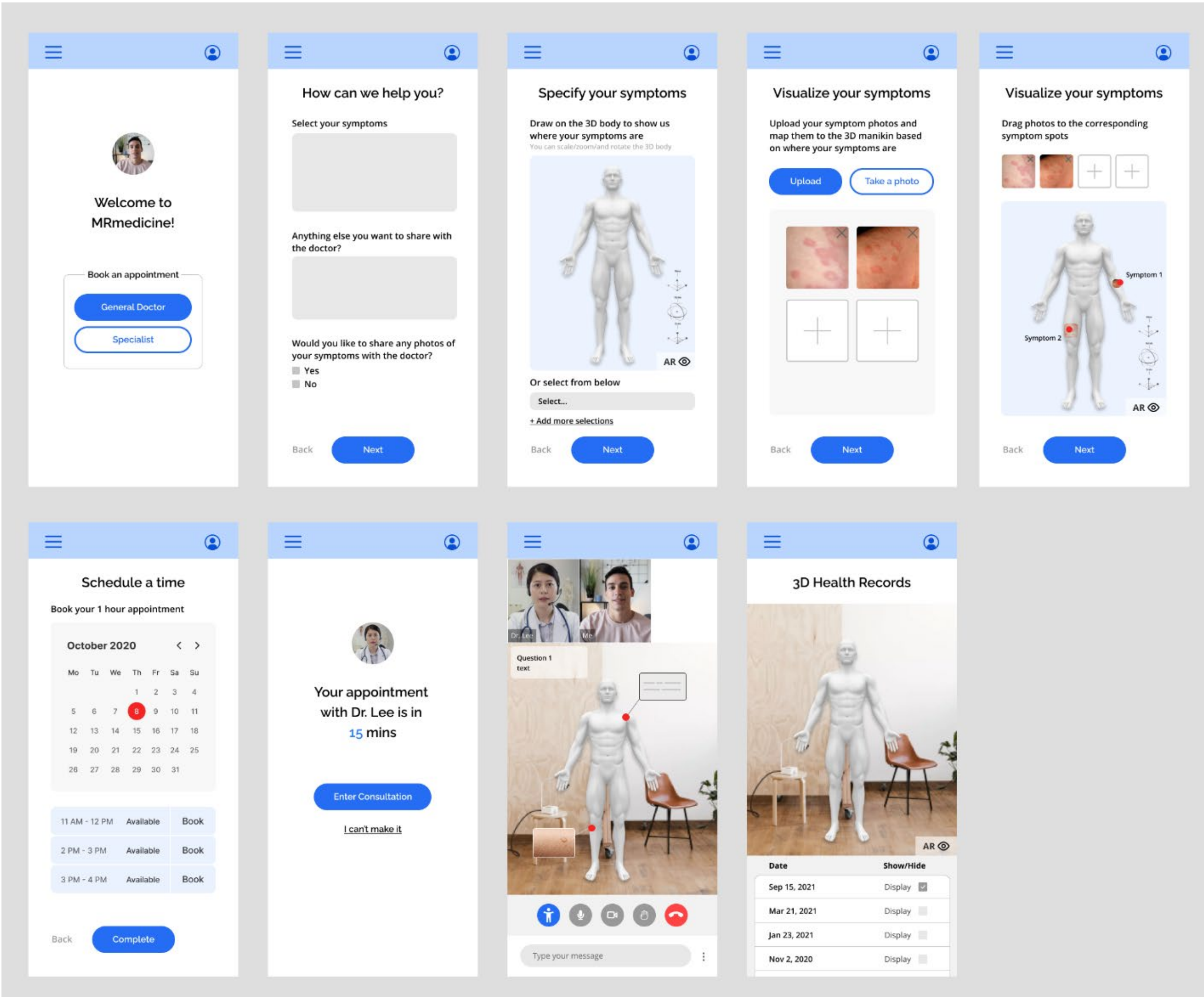


Figure 44. AR mobile interface designs

4.2.3 Iteration 3 – AR 3D Manikin

To test out the AR 3D manikin, I built an HTML webpage with A-frame's marker detection augmented reality function. The other parts of the telemedicine process are not implemented in iteration 3 because they are not the key features for exploration and existing telemedicine applications have already covered a good amount of the features.

By pointing the camera at the target market, which in this case is a Hiro marker, users will be able to see their 3D manikin with basic information and medical history, displayed on separate panels floating around the lesion areas. The patient information channel display patient's name, date of birth, age, sex, patient ID, telephone number, email, and policy number. Each record panel displays the diagnostic result, cause, treatment, physician's name, date, and an image of the lesion. The panel can be expanded to offer a more detailed review.

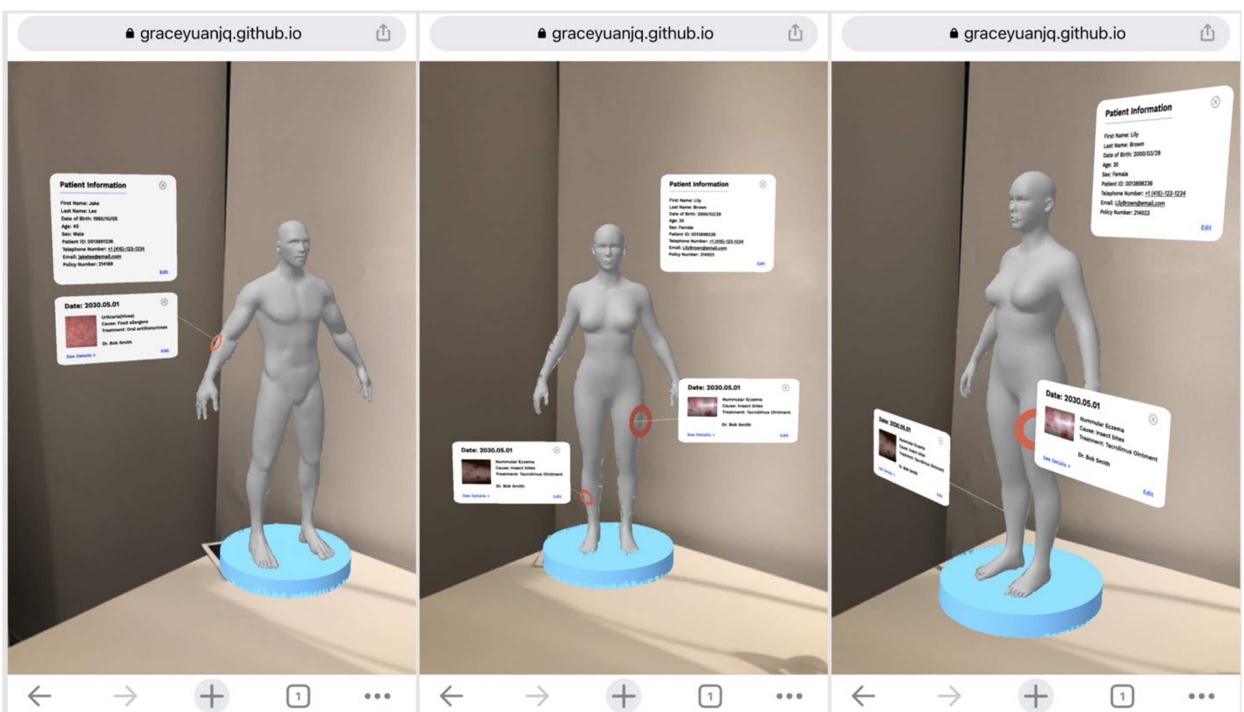


Figure 45. HTML-based AR 3D manikin

The AR prototype has one distinct limitation regarding camera access on mobile phones. As the AR application uses the front camera, and the video call uses the back camera, these two programs compete and only one of them can run at one time. This means that to use the AR functionality to review the 3D manikin and patient symptoms, the video call needs to be sacrificed and replaced with an audio call. This is a barrier that current mobile devices may not overcome.

4.3 Prototype 3 – Developing the Desktop Dashboard Prototype

The desktop experiment consists of three iterations of creations introduced in the following chapters.

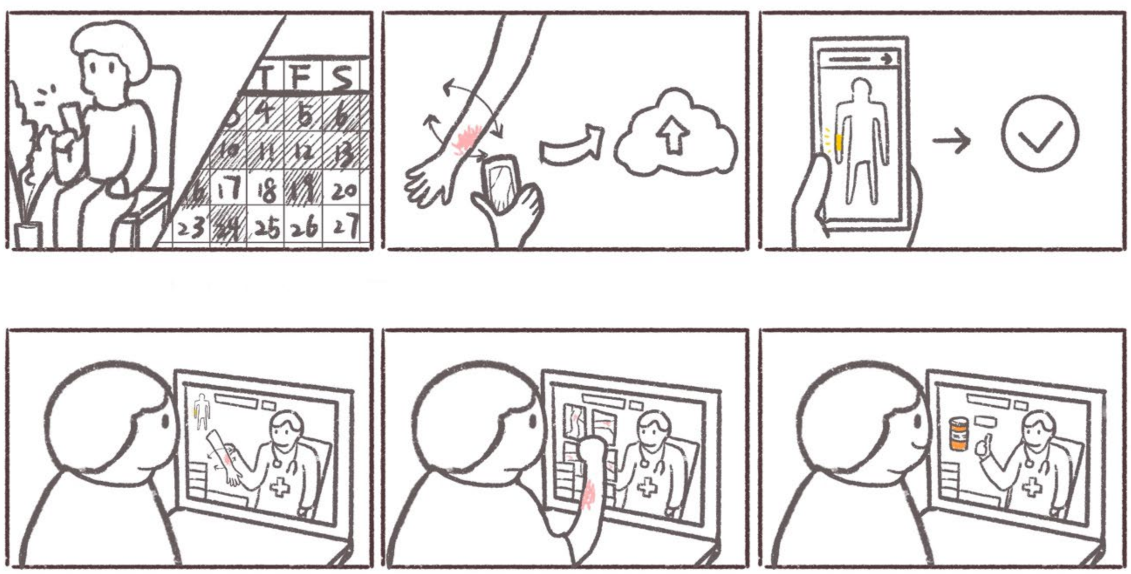
4.3.1 Iteration 1 – Desktop Dashboard Storyboard

During the planning stage, several sketches and renderings were created to describe what the desktop solutions can look like. The first storyboard was drawn during the ideation to explain the overall ideal experience from the patient's perspective. There are two main work experience flows here: 1) pre-consultation: the patient uploads a scan of the lesion area while booking an appointment, the scan is mapped to a 3D manikin, 2) in the consultation: the patient and physician look to review the patient's

3D manikin together, compare to reference images to come to a diagnostic result, and the patient receives treatment plan and medication.

Figure 46. Storyboard of the desktop consultation experience

4.3.2 Iteration 1 – Desktop Dashboard Sketch and Interface Design



The desktop prototype is a dashboard application for consultation and diagnosis. It is an experiment to demonstrate how the 3D manikin can be applied to the non-mixed-reality dashboard.

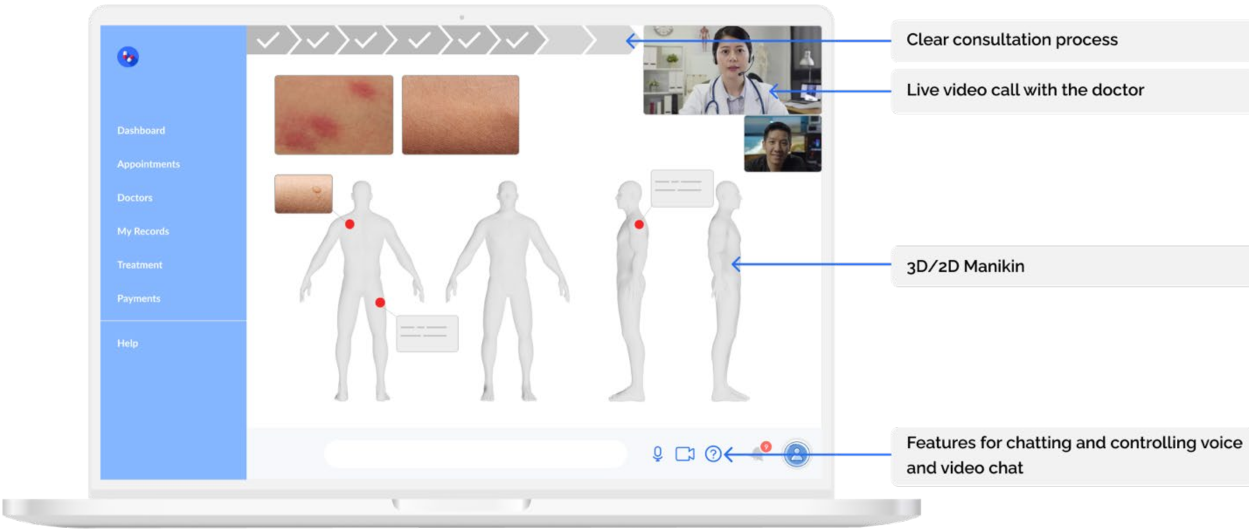


Figure 47. Desktop prototype design sketch

In this scenario, the physician and the patient will have a video conference and look at the 3D manikin together. However, the manikin is only displayed as a 3D model on the screen. Users can zoom/scale/rotate the manikin on the screen, but it cannot be projected in the real world. On the menu of the dashboard, users have options to book an appointment or check existing appointments, browse, and connect with physicians, look that their medical records, review treatment plans, and check payments.

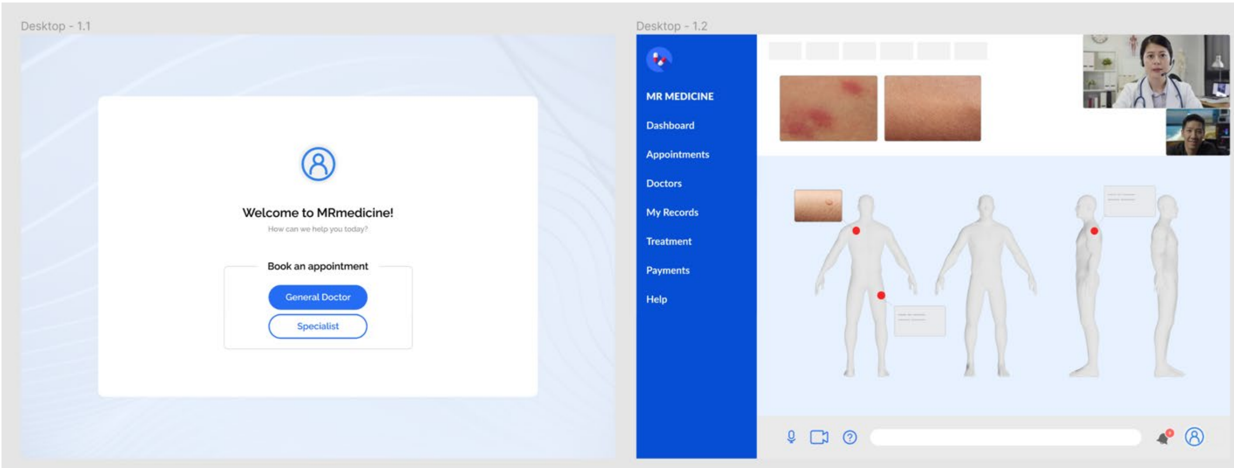


Figure 48. The desktop prototype interface designs

Moving on to interface design in Figma, I added a landing screen to expand on what the desktop application could look like. The dashboard has a minimal design with a blue colour scheme. The third iteration is a partially functional prototype that was built based on the interface design in Figma.

4.3.3 Iteration 3 – Web-based Desktop Dashboard Prototype

The third iteration is a web-based desktop dashboard prototype built with Webflow (https://webflow.com) and <model-viewer>(https://modelviewer.dev). Users can go on to the landing page and click the “Enter Consultation” button to enter the modelled video consultation scenario.

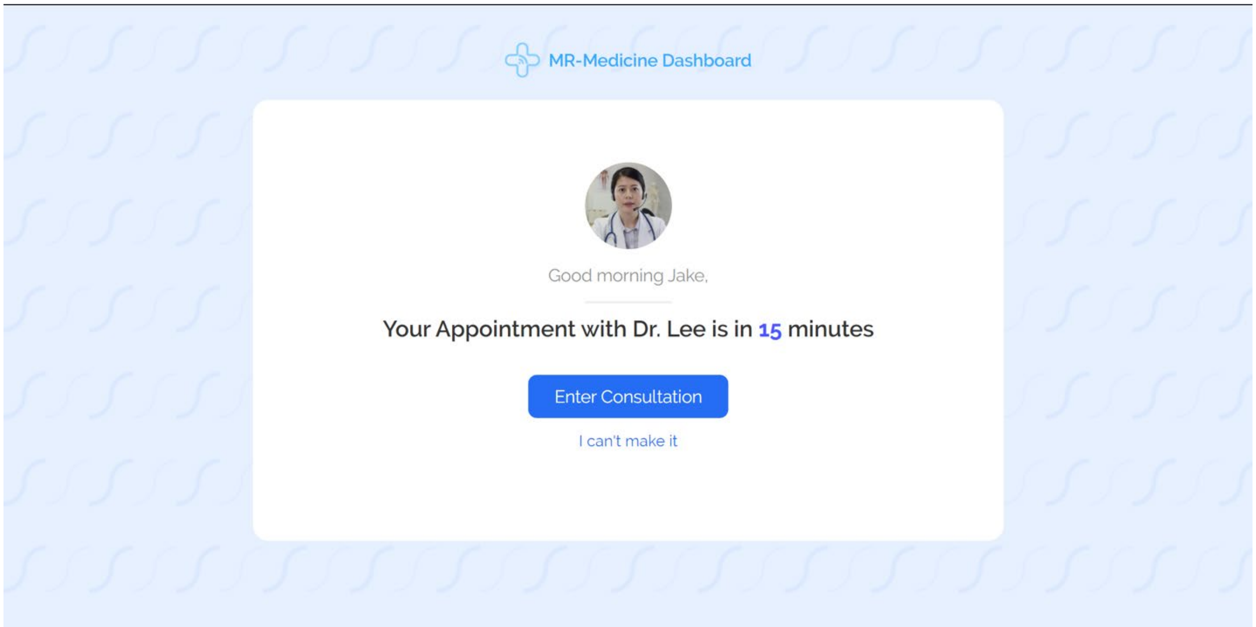


Figure 49. Desktop dashboard prototype landing page

Although the interface appears to be complete, this prototype is not fully functional or interactive. Existing telemedicine applications have already covered quite comprehensive functionalities. MR-Medicine as a research project does not aim to comment on all the existing features. The prototype is largely non-functional, such as the video feeds and chat functionalities, as the 3D manikin and UI placement are the overall focus. Therefore, only the manikin model is interactive. Users can drag, scale and zoom in/zoom out on the 3D manikin to view the medical records.

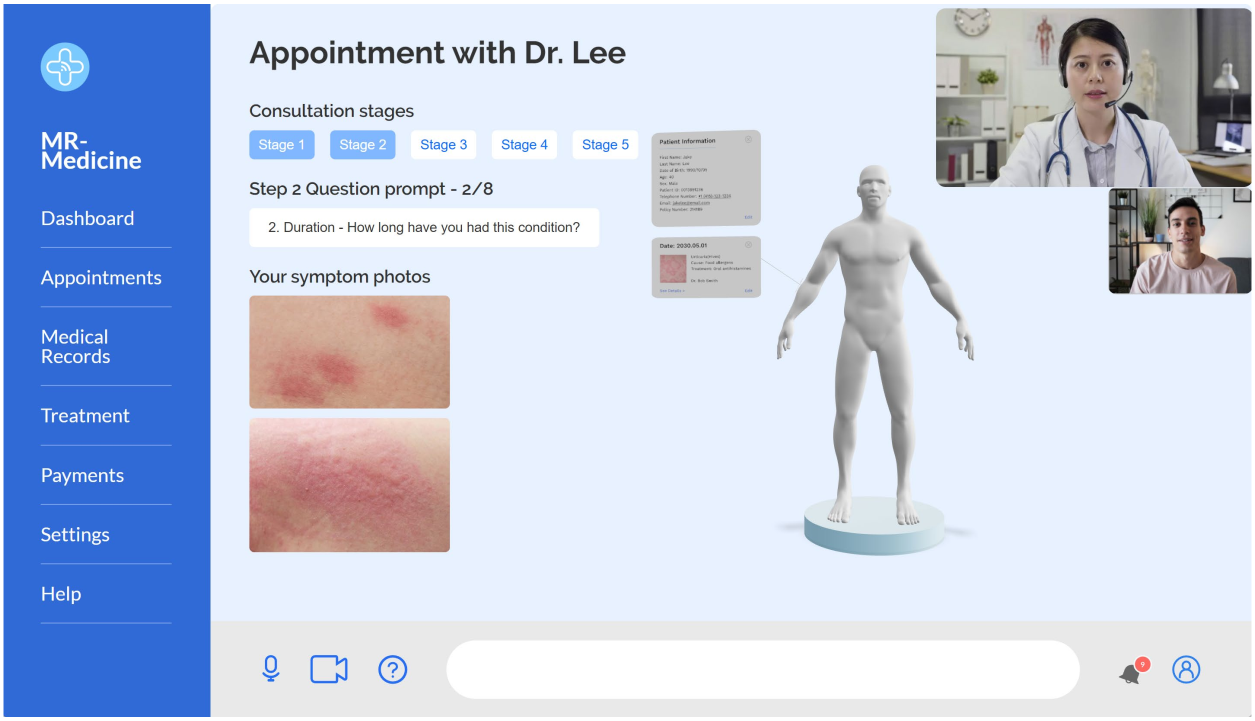


Figure 50. Static dashboard prototype with an interactive 3D manikin

During the appointment, users can see the stages of the consultation, and which step they are at right now. The name of the steps can be replaced according to needs. Physicians can follow the question prompt to ask the patient for relevant information. Patients will be able to see the prompt as well to understand the process better.

4.4 Chapter Summary

The above prototypes show that each media has its affordance that has a great impact on the experience design and consultation process. All the prototypes are designed from the patients' perspectives. Three categories of prototypes share similar features around the 3D manikin and appointment booking process. However, the designs vary tremendously based on the platforms.

4.4.1 VR Prototype Summary and Reflection

The VR prototypes aim to cover the major portion of the telemedicine process, from information gathering, information integration, and working diagnosis, to the communication of the diagnosis. They are iterated based on the development of the 3D designs. The Medical Centre 3D environment has been and most of the features are implemented in the environment rather than the avatars or interactions. The interactions between users rely on the existing features in the VR platforms. Functionalities including editing the medical records, creating treatment plans, and updating the 3D manikin are not implemented yet. The designs are static but aim to suggest how these features can be for future telemedicine consultation in VR.

4.4.2 AR Prototype Summary and Reflection

The AR prototypes show the overall flow of how a mobile telemedicine experience can be on the interface level. Not all features are implemented to be functional because it focuses on the process of appointment booking and the displaying of the 3D manikin. It proposes a system where the patient can upload the symptom photos when booking the appointment, and the photos will be mapped to the 3D manikin for review during the consultation. As the prototypes are designed for mobile devices, the features are more condensed.

4.4.3 Desktop Prototype Summary and Reflection

The desktop dashboard designs aim to create a telemedicine application that is intuitive and easy to use. The actual design focuses on the implementation of the 3D manikin and does not include all parts of the consultation process. The physician and the patient will be able to view and interact with the 3D manikin together which grants the patient equal access to information as the physician. In such a non-mixed-reality application, the 3D manikin still offers similar functionality as the VR and AR prototypes but lacks the sense of presence that bridges the physical space and the virtual consultation.

5. Discussion

Chapter 5 covers the evaluation of the prototypes in Chapter 4, using the Descriptive Design Evaluation method.

5.1 Descriptive Design Evaluation

Descriptive Design Evaluation methods (Hevner 2004) are selected to examine the utilities of the final prototype iterations. It includes two sub-methods: *Informed Argument* and *Scenarios*, which are used in combination to provide a comprehensive understanding of the prototypes. The evaluation results are subjective. For future work, experts shall be invited to validate the outcomes however it is out of scope for the current research.

For the *Informed Argument* method, Nielson's 10 heuristics (Nielson 1994) from Chapter 2.3.1 are used as criteria to measure the user experience design for the telemedicine prototypes. They are selected for comparing the MR-Medicine prototypes and the existing telemedicine platforms. As this project does not involve expert review or participant usability testing, the evaluation only focuses on the mixed reality interactions and interfaces for telemedicine. The heuristics are valid as Nielson's 10 heuristics are commonly accepted for the interaction design and user interface design evaluation; however, they are not specifically catered to healthcare applications or telemedicine scenarios. Therefore, Nielson's 10 heuristics have limitations when applied to medical approaches. The evaluation could be extended for a more in-depth assessment with the Experience Critique method for healthcare service design from *Design for Care: Innovating Healthcare Experience* (Jones 2013) for future work if patient participants and expert evaluators are recruited. This method fits MR-Medicine's use case scenario as the framework "extends the heuristic review with an empathic framework for relating an interactive experience to a persona's information-seeking behaviour and activities. (Jones 2013)"

To construct a context for the *Scenarios* method, a partial speculative approach is used around the artifacts to demonstrate their utilities and examine how useful they are in a subject way. Jake's persona from Chapter 1.2.3 will be used to demonstrate how a patient will go through the Telemedicine Diagnostic Process from Chapter 2.1.1 using MR-Medicine. The speculative scenarios of the VR, AR, and desktop prototypes demonstrate MR-Medicine's features against the futuristic context in 5 years.

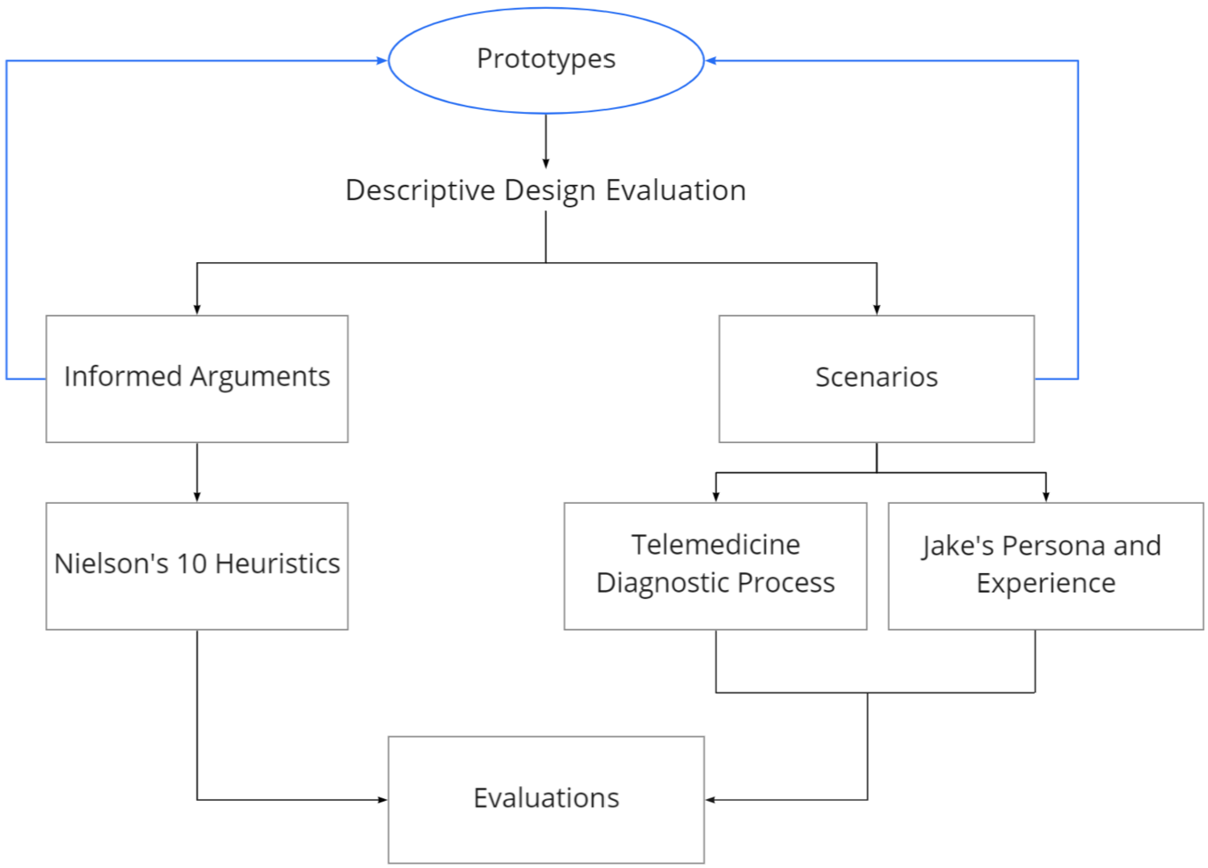


Figure 51. Descriptive design evaluation method for examining the utility of the prototypes

Initially, user-centred design evaluation and usability testing were selected as the evaluation method. However, due to the constraints of the field and access to the patients, human participants were not recruited, and the methods were not used.

5.2 MR-Medicine VR Evaluation

5.2.1 Nielson's 10 Heuristics Evaluation for AltspaceVR Medical Centre Prototype

The following table makes use of Nielson's 10 User Experience Design heuristics (Nielson 1994) to examine the usability of the AltspaceVR prototype from Chapter 4.1.3. The 10 heuristics for VR (Joyce 2021) is not used because it does not apply to other AR and desktop prototypes for comparison.

	Heuristic	MR-Medicine VR Utility	Checklist
1	Visibility of system status	Users can see the telemedicine flow, and which step they are at, indicated by the room signages. The AltspaceVR user status can be seen on the control panel on the left side of the display.	✓
2	Match between the system and the real world	The 3D Medical Centre office tends to match the real-world doctor's office environment.	✓
3	User control and freedom	Users can cancel the interactions or leave the consultation anytime.	✓

4	Consistency and standards	The interaction design utilizes AltspaceVR's built-in features which follow the standard human-computer interaction outside VR.	✓
5	Error prevention	There is currently no warning or notice to prevent potential errors before the users edit anything.	✕
6	Recognition rather than recall	Essential information regarding the patient and consultation process is displayed in the space to inform the users and minimize memory load.	✓
7	Flexibility and efficiency of use	No customization option is available for setting the consultation process or the 3D Medical Centre environment. Users can customize their avatars in AltspaceVR.	✕
8	Aesthetic and minimalist design	Both 3D and user interface designs are minimal and only display useful information.	✓
9	Help users recognize, diagnose, and recover from errors	Users can open the AltspaceVR diagnostic panel from settings to see their system status.	✓
10	Help and documentation	AltspaceVR has online documentation (https://docs.microsoft.com/en-us/windows/mixed-reality/altspace-vr/) but	✕

		not in the VR application. MR-Medicine does not have any documentation.	

Table 4. Nielson's 10 heuristics evaluations for MR-Medicine AltspaceVR Medical Centre prototype

The above checklist shows that the VR prototype can be said to meet 7 out of 10 criteria in Nielson's User Experience Design heuristics. Error prevention, Flexibility and Efficiency of Use, and Help and Documentation should be considered and improved for future work.

5.2.2 Scenarios for MR-Medicine VR

In 5 Years 2027: VR becomes popular for entertainment, education, and remote meetings. A growing number of people start to adopt VR and use VR for remote collaboration sessions. VR telemedicine is in rapid development. A small portion of physicians and patients become experienced users of the MR-Medicine VR and use it for remote health care.

	Stages	Actions	Jake's Experience with MR-Medicine Utility
1	Jake experiences a health problem	Jake discovers that he has a skin allergy condition on his right arm.	Not available

2	Jake engages with the health care system	Jake contacts his family doctor and is referred to a dermatologist.	Not available
3	Information gathering	Jake is asked to fill out a form with his information and medical history, and upload photos of his skin allergy.	Not available
4	Information integration and interpretation	The photos Jake uploaded are mapped onto his 3D manikin for the dermatologist to review. The dermatologist invites Jake for a consultation to discuss further and work on the diagnosis.	Jake finds it intuitive that his photos are mapped to a 3D manikin for embodied visualization. He thinks the medical record is well integrated.
5	Working diagnosis	Jake receives a link to the MR-Medicine AltspaceVR consultation from the dermatologist. Jake happens to own a VR headset, so he downloads AltspaceVR and joins the consultation session with the world code. In the first interview room, the	Jake thinks it requires effort to attend the consultation in VR and the experience is new to him. He finds the AltspaceVR Medical Centre 3D environment looks like a doctor's office in real life and feels the physician's strong presence as they show up and interact as avatars. The consultation process diagram

		dermatologist asks him some questions regarding the symptoms. Moving to the second room with the 3D manikin as a symptom visualizer, they look at his medical records and symptom photos together. The dermatologist shows him online reference photos to compare the symptoms via a browser projector on the wall.	and interview questions displayed in the rooms help Jake to understand the overall flow and which stage they are at in the process. Jake finds it efficient that the physician can show him reference photos from external online resources in the consultation. Overall, Jake feels well informed during the process.
6	Communication of the diagnosis	The dermatologist shows Jake's potential development of the symptom on the 3D manikin and the diagnostic result on a floating card in the last room.	Jake finds the 3D manikin useful for visualizing the change and development of the symptoms.
7	Treatment	The dermatologist provides Jake with a treatment plan, prescribes medication for him, and shows him information about the medication, searched and	Jake finds it informative to see the medication information.

		displayed via a browser projector on the wall.	
8	Outcomes	Jake checks in with the dermatologist from time to time as he recovers. He keeps uploading photos of his right arm to keep the 3D manikin updated.	Jake keeps his medical record up to date. He feels satisfied with the experience and feels good about his relationship with the dermatologist.

Table 5. Scenarios for MR-Medicine VR in 2027

The VR prototype does not support the first three stages of the diagnostic process as it is only focused on the actual consultation experience. The early stages should be studied and covered in future iterations of MR-Medicine.

5.3 MR-Medicine AR Evaluation

5.3.1 Nielson's 10 Heuristics Evaluation for AR Mobile Prototypes

The following table makes use of Nielson's 10 User Experience Design heuristics (Nielson 1994) to examine the usability of the AR mobile prototypes from Chapters 4.2.2 and 4.2.3 as a combination.

	Heuristic	MR-Medicine AR Utility	Checklist

1	Visibility of system status	The title at top of the screen shows the current task or stage the user is at.	✓
2	Match between the system and the real world	The information-gathering process and video consultation match the clinic flow.	✓
3	User control and freedom	Users always have the option to go back to the last step or quit the application as they wish.	✓
4	Consistency and standards	The application design follows the standard mobile interface design.	✓
5	Error prevention	There is currently no warning or notice to prevent potential errors before the users edit anything.	✗
6	Recognition rather than recall	Users do not need to remember the features as they are clearly labelled.	✓
7	Flexibility and efficiency of use	No customization option is available for setting up the consultation process or the interface.	✗
8	Aesthetic and minimalist design	The design aesthetic is minimal with a white and blue colour palette. Only essential information is displayed.	✓

9	Help users recognize, diagnose, and recover from errors	There is no system diagnostic tool available for the AR prototypes.	✕
10	Help and documentation	There is no help or documentation available for the AR prototypes.	✕

Table 6. Nielson's 10 heuristic evaluations for MR-Medicine mobile AR prototype

The above checklist shows that the AR prototype is said to meet 6 out of 10 criteria in Nielson's User Experience Design heuristics. The error prevention and help utilities are missing in the prototypes. These can be interesting future work to explore with expert evaluators and patient participants under usability testing.

5.3.2 Scenarios for MR-Medicine AR

In 5 Years 2027: AR becomes a basic feature in many mobile applications. MR-Medicine AR 3D manikin is now integrated into the mobile telemedicine platforms as part of the new mixed reality medical record system. Patients and physicians still have the option to review 2D or text-based medical records.

	Stages	Actions	Jake's Experience with MR-Medicine Utility

1	Jake experiences a health problem	Jake discovers that he has a skin allergy condition on his right arm.	Not available
2	Jake engages with the health care system	Jake contacts his family doctor and is referred to a dermatologist. Jake downloads the mobile app to book an appointment.	Jake downloads the mobile app on his phone and grants camera and microphone access to the app. Jake is curious about the process.
3	Information gathering	Jake is asked to fill out his symptoms and upload photos of his skin allergy.	Jake finds the information-gathering process straightforward.
4	Information integration and interpretation	The photos Jake uploaded are mapped onto his 3D manikin according to the body site he selects. Jake books an appointment from the available calendar slots.	Jake finds it intuitive that his photos are mapped to a 3D manikin for embodied visualization. Jake can view the 3D manikin in AR on his phone. He thinks the medical record is well integrated.
5	Working diagnosis	Jake joins the consultation at the booked time. The dermatologist asks Jake questions regarding his medical history, current symptoms, and potential causes, following the prompts provided by the	Jake finds the 3D manikin useful as a mediator between the dermatologist and himself. He thinks it is a good system for marking up the symptoms on the body site and saving physicians' notes. As they look at the 3D manikin together in

		MR-Medicine system on the left of the screen. They look at the 3D manikin in AR together. The models displayed on both ends are in synchronization and they can see where on the manikin the other person would like to point out. The dermatologist adds notes to the manikin as they are speaking.	synchronization, Jake feels the physician's presence as he can see the manikin's movement live whenever the physician moves or updates the manikin.
6	Communication of the diagnosis	The dermatologist shows Jake's potential development of the symptom on the 3D manikin and adds the diagnostic result to the manikin.	Jake finds the 3D manikin useful for visualizing the change and development of the symptoms and keeping a record of his conditions.
7	Treatment	The dermatologist provides Jake with a treatment plan, prescribes medication for him, and shows him information about the medication.	Jake finds it informative to see the medication information.
8	Outcomes	Jake checks in with the dermatologist from time to	Jake maintains the connection with the dermatologist and

		time as he recovers. He keeps uploading photos of his right arm to keep the 3D manikin updated.	keeps his medical record up to date. He feels satisfied with the experience and feels good about his relationship with the dermatologist.

Table 7. Scenarios for MR-Medicine AR in 2027

The AR prototypes cover more stages than the VR prototype. They present potential design solutions for patient engagement and information gathering stages.

5.4 MR-Medicine Desktop Evaluation

5.4.1 Nielson's 10 Heuristics Evaluation for Desktop Prototype

The following table makes use of Nielson's 10 User Experience Design heuristics (Nielson 1994) to examine the usability of the desktop dashboard prototype from Chapter 4.3.3.

	Heuristic	MR-Medicine Desktop Utility	Checklist
1	Visibility of system status	Users can follow the preset prompt to conduct the consultation and see which stage they are at in the consultation process.	✓

2	Match between the system and the real world	Users should be familiar with the language and visual elements in the interface as they are typical and easy to understand.	✓
3	User control and freedom	Users can exit the interaction as they wish because this is a web-based application.	✓
4	Consistency and standards	The interface design follows the standard Telemedicine and video conferencing app designs.	✓
5	Error prevention	There is currently no warning or notice to prevent potential errors before the users edit anything.	✗
6	Recognition rather than recall	Users do not need to remember the features because they are clearly labelled.	✓
7	Flexibility and efficiency of use	No customization option is available for setting up the consultation process or the interface.	✗
8	Aesthetic and minimalist design	The design aesthetic is minimal with a white and blue colour palette. Only essential information is displayed.	✓
9	Help users recognize, diagnose, and recover from errors	There is no system diagnostic tool available for the desktop prototypes.	✗

10	Help and documentation	There is no help or documentation available for the desktop prototype.	✕

Table 8. Nielson's 10 heuristic evaluations for MR-Medicine desktop dashboard prototype

The desktop prototype is said to meet 6 out of 10 criteria in Nielson's User Experience Design heuristics. Like the AR prototypes, it does not support the users with error prevention and documentation and should explore those criteria with patient participants and expert evaluators.

5.4.2 Scenarios for MR-Medicine Desktop

In 5 Years 2027: Specialized desktop telemedicine applications are commonly used for remote healthcare. Doctors and patients are familiar with the telemedicine process and are comfortable using the different information systems integrated into the applications to help understand the conditions and diagnose.

	Stages	Actions	Jake's Experience with MR-Medicine Utility
1	Jake experiences a health problem	Jake discovers that he has a skin allergy condition on his right arm.	Not available

2	Jake engages with the health care system	Jake contacts his family doctor and is referred to a dermatologist. Jake goes to the MR-Medicine website to book an appointment.	Jake thinks the website is minimalistic and straightforward.
3	Information gathering	Jake is asked to fill out his symptoms and upload photos of his skin allergy.	Jake finds the information-gathering process easy to follow.
4	Information integration and interpretation	The photos Jake uploaded are mapped onto his 3D manikin according to the body site he selects. Jake books an appointment from the available calendar slots.	Jake finds it intuitive that his photos are mapped to a 3D manikin for embodied visualization. He thinks the medical record is well integrated.
5	Working diagnosis	Jake joins the consultation at the booked time. He grants camera and microphone access to the website. The dermatologist asks Jake questions regarding his medical history, current symptoms, and potential causes, following the prompts provided by the MR-Medicine system on the left	Jake finds the 3D manikin useful as a mediator between the dermatologist and himself. He thinks it is a good system for marking up the symptoms on the body site and saving physicians' notes. As they look at the 3D manikin together in synchronization, Jake feels the physician's presence as he can see the manikin's movement live

		of the screen. They look at the 3D manikin together. The models displayed on both ends are in synchronization and they can see where on the manikin the other person would like to point out. The dermatologist adds notes to the manikin as they are speaking.	whenever the physician moves or updates the manikin.
6	Communication of the diagnosis	The dermatologist shows Jake's potential development of the symptom on the 3D manikin and adds the diagnostic result to the manikin.	Jake finds the 3D manikin useful for visualizing the change and development of the symptoms and keeping a record of his conditions.
7	Treatment	The dermatologist provides Jake with a treatment plan, prescribes medication for him, and shows him information about the medication.	Jake finds it informative to see the medication information.
8	Outcomes	Jake checks in with the dermatologist from time to time as he recovers. He	Jake maintains the connection with the dermatologist and keeps his medical record up to

		keeps uploading photos of his right arm to keep the 3D manikin updated.	date. He feels satisfied with the experience and feels good about his relationship with the dermatologist.

Table 9. Scenarios for MR-Medicine Desktop in 2027

Many steps in the desktop prototype scenarios stay the same as the AR prototype scenarios because they were designed following the same principles for screen-based patient experience.

5.5 Summary

MR-Medicine uses the Research Through Design method to develop potential mixed reality solutions to improve the telemedicine video consultation experience. The prototypes propose and inform design possibilities for the development of mixed reality telemedicine. The evaluation speculates the telemedicine consultation scenario in the future when mixed reality becomes more accessible and common in daily life. By evaluating the research outcomes, I examined the quality and utility of the prototypes, as proofs of concept.

Based on Informed Argument heuristic evaluations of the user experience and interface design:

- All prototypes manage to meet at least 6 out of 10 criteria, and the VR prototype meets 7 out of 10. These results suggest that the prototypes are designed to follow the user experience design principles and should serve the users with ease of use.
- The missing opportunities are around providing help, documentation, error prevention and interface customization capability for the users. These criteria are highly technical for the proof-of-concept design prototypes but should be taken into consideration for future work to improve the prototypes' usability.
- The heuristics evaluation has inherent subjectivity and expert evaluators are still needed to help determine clearly how well the prototypes address the heuristics for future work.

Descriptive arguments for utility are debatable but based on the scenarios the following are potential takeaways, which remain to be validated by expert evaluators and patient participants for future development. Based on Scenario evaluations of the patient's experience and MR-Medicine prototype utilities:

- The consultation process is easy to follow and understand for patients, as is indicated by the visual elements in the space.
- The medical records are integrated and visualized with the 3D manikin for hosting all the health data.
- The telepresence is enhanced with VR and AR, especially for VR scenarios where patients can feel the strong presence of the physicians.

The evaluation proves that the design solutions used for the prototypes should improve the patient experience from three aspects: 1) telemedicine process, 2) medical records, and 3) telepresence. The evaluation results can be biased as no patient participants are recruited for the experiment.

6. Conclusion

6.1 Goals

MR-Medicine explored possible futuristic design solutions to improve the patient experience of using telemedicine applications. By experimenting through iterations of prototypes, it aims to explore how to integrate mixed reality technology and user experience design process into telemedicine video consultation, the patient experience can be improved through the process, the medical records, and telepresence.

6.2 Contributions

MR-Medicine has the potential to benefit patients and physicians, especially in the dermatology specialty. Industrial standards, best practices, and gaps in telemedicine, mixed reality, and user experience design are learned with the literature review. Three types of prototypes are created and iterated to incorporate the research findings from the literature review and explore improvements to the consultation process and patient experience. The 3D manikin, as a key feature, is implemented throughout all prototypes. Evaluations of the prototypes generate findings that can be used for future development of telemedicine platforms (VR, AR mobile, and desktop).

6.3 Limitations and Lessons Learned

MR-Medicine only focuses on the partial process of the remote healthcare consultation, using dermatology as a case study. It does not extend to the field of telehealth which includes remote healthcare education.

The prototypes focus on the proof of concept instead of the fully functional realization of telemedicine applications. Low fidelity and non-functional prototypes are developed for measuring the design concepts. As a lesson learned, during the prototype making and iterating process, it is crucial to focus on the essential flows and convey the ideas clearly as the viewers or users may be distracted by elements that are not the focus of the research exploration.

This project did not receive a review from the experts. It is based on a literature review and design experiments to explore possible telemedicine solutions. Regarding the evaluation of research outcomes, user testing was originally planned, and approval on the Research Ethics was received. However, participants were not recruited due to limited access to patients and physicians. A descriptive design evaluation was conducted; and as a result, could be affected by bias without more expert validation.

6.4 Future Work

Considering the fast advancement rate of technologies, telemedicine the study result may be applied to future telemedicine development in the Metaverse, especially with the research outcomes in the VR prototype.

For further development, experts shall be invited to participate in the design process to provide professional insight and validate the research outcomes. Patient participants can also be recruited to test the prototypes and provide feedback. With the participants, a user-centred design methodology can be used to replace the research through design methodology.

As the study currently focuses on dermatology as a use case, future work can be expanded to other specialties and even general doctors. Although this research is based on western medicine, it also has the potential to be expanded to other areas like holistic medicine.

The 3D manikins aim to represent the patients. They are originally designed to be customizable. Due to time constraints, they remain a pair of generic male and female models. For future development, patients should be able to customize the 3D models to reflect their appearance. 3D manikins may also be used for demonstrating inner the arts of the human body, including muscles and organs.

6.5 Final Thoughts

MR-Medicine achieves the goal of exploring potential design solutions for improving the telemedicine consultation experience and produces three prototypes as experiments. However, more studies and research can be done in the field with medical professionals and real patients to construct a more comprehensive design system. As technology advances, the integration of mixed reality and healthcare is a promising path that is worth researching. For any researcher who is interested in taking on the subject of telemedicine and mixed reality, please do not hesitate to do so as the research outcomes will have a positive long-term impact on the healthcare field.

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