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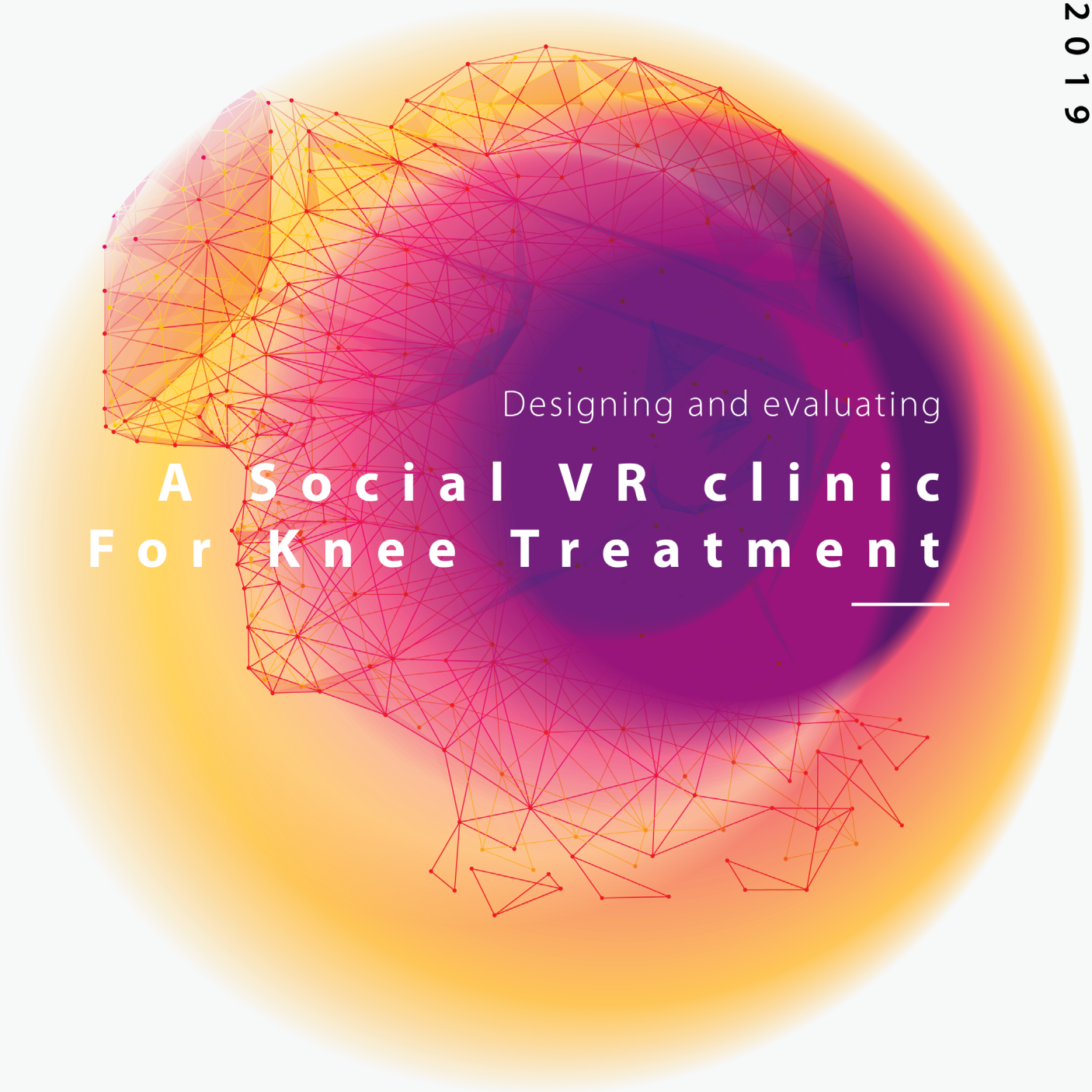

Designing and evaluating

A Social VR clinic For Knee Treatment

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DESIGNING AND EVALUATING

A SOCIAL VR CLINIC FOR KNEE REPLACEMENT SURGERY

Master Graduation Thesis by
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ABSTRACT

Knee osteoarthritis, the most common form of arthritis, which results in stiffness, pain, and impaired movement, is a major cause of disability in elderly populations around the globe. In the course of treating this disease, patients have to endure enormous pains travel to hospitals to meet medical professionals. The motivation behind this project is to support those patients with limited physical mobility to travel fewer times to the hospital but still, communicate well with doctors and nurses. The goal is to build a VR clinic that simulates the real consultation room and facilities in the hospital.

An ethnographic study was conducted at a local hospital in Delft to map the patient treatment journey from the first consultation meeting to the last meetings after surgery. The patient education part of the patient journey was chosen as the focus of this thesis since it involves most of the patient-nurse communications compared to other parts of the journey. Based on the results of the ethnographic study, a social VR clinic was designed and implemented to assist the nurse in explaining the treatment process, and to show the anatomy models and the surgery room to the patient.

The main contribution of this thesis is the design and evaluation of a social VR clinic, based on the use case of knee pain treatment. Future research can expand the consultation to other diseaseses, explore the impact of using more realistic avatars on the VR clinal experience. Other perspectives can be probed into to describe user portraits on their attitude of having VR consultations.

Contents

1

C H A P T E

INTRODUCTION

Virtual reality (VR) provides interactive and immersive experiences within simulated virtual environments that are similar to or completely different from the real world [34]. Virtual environments (VEs) are generated based on “real-time interactive graphics with three-dimensional models, when combined with a display technology, give the users immersion and direct manipulation in the model world” [15]. As early as the mid of 1960s, Ivan Sutherland demonstrated the potential of VR by creating a head-mounted display (HMD), which provided stereoscopic visual images and mechanical tracking that allow users to experience a "mathematical wonderland" [49]. As described by Sutherland [55], VR is a medium that makes the “mathematical wonderland” look real, sound real, feel real and respond realistically to the user’s actions. Nowadays, the goal of virtual reality experience remains largely the same. The virtual environments, immersion, sensory feedback and interactivity are considered as the four key elements in VR experience.

Recently, the wide availability of HMDs for consumers makes VR systems a feasible alternative to other types of technology-mediated communication systems such as telephone and video conferencing. With VR technology, people are able to "meet" in a shared, immersive VE and interact with the virtual representations of each other. This is where the idea of "social VR" originates from: VEs with multiple users are denoted as collaborative or social VR [20]. The virtual representations in social VR can render a user’s movement onto an avatar (e.g., Facebook Spaces). Alternatively, one can use a 2D real-time recorded user video as the virtual view of that user, or in the near future, use a highly detailed photo-realistic point cloud video [18]. Compared with telephone and video conferencing, [16, 59], social VR systems have high potential to allow several physically separated users to communicate in a VE, resembling face-to-face communication.

VR in healthcare has long been envisioned as a promising technology that can potentially approximate or even optimize the face-to-face communication between patients and medical professionals (e.g., doctors and nurses) [22, 35]. One of the pioneer VR applications in healthcare started in 1990s, with the main purpose of visualizing complex medical data for medical professionals to prepare for the surgery [48]. So far, many VR healthcare applications have been developed for medical training/education [44], psychological consultation [45] and remote (psycho)therapy [4].

For the medical training/education VR applications, the idea is to represent a patient with high fidelity, realistic body parts. In this way, medical professionals can explore the patient body by observing around, behind, or even inside [44]. For clinical psychologists, the goal of VR is to provide an human-computer interaction paradigm in which patients are no longer simply external observers of images on a computer screen but are active participating within a computer-generated three-

dimensional virtual world. Within the virtual world, the patient has the possibility of learning to manage a problematic situation related to his or her disturbance [45]. For remote therapy, VR enables the exchange of visual and auditory information through eye contacting, facial expressions, gestures of the virtual representations of the users. Remote therapy in VR is intended for patients with physical disability, occupational or social constraints, or residency in under-served areas. [4].

According to a national survey (2006-2017) in US [42], the time people spent travel to healthcare service was the longest than to other professional services like legal services, personal care, vehicle repair or even government activities like obtaining a permit/license. The time spent traveling and waiting for healthcare services was over 50% of the time spent actually receiving care. Beside the time cost, healthcare traveling can be painful for the patients who has disability or suffer from chronic disease.

The motivation behind this thesis is to support patients with limited physical mobility to travel fewer times to hospital, but still communicate well with doctors and nurses. Patients with knee osteoarthritis are the target group of this thesis. The goal is to build a VR clinic that simulates the real consultation room and facilities in the hospital, in which, patients can interact with the doctors/nurses with visualized information, such as preparation procedures, 3D anatomy models and a tour in the surgery room. Three main research questions are addressed:

RQ1: Is the consultation experience in VR clinic comparable to the experience in real life face-to-face (F2F) consultation?

RQ2: Compared to the F2F consultation, what aspects are missing in the VR clinic?

RQ3: Compared to the F2F consultation, what are the added values of the VR clinic?

The main contribution of this thesis is the design and evaluation of a social VR clinic, based on the use case of knee pain treatment. An ethnographic study was conducted at a local hospital in Delft to map the patient treatment journey from the first consultation meeting to the last meetings after surgery. The patient education part of the patient journey was chosen as the focus of this thesis, since it involves most of the patient-nurse communications compared to other parts of the journey. Based on the results of the ethnographic study, a social VR clinic was designed and

implemented to assist the nurse in explaining the treatment process, and to show the anatomy models and the surgery room to the patient.

To answer the three research questions, a within-subject evaluation study (N=12) was conducted to compare the patient education experience in two conditions: **(1) face-to-face (F2F)**, and **(2) the social VR clinic (social VR).** Participants' feedback was collected through a social VR questionnaire [30], the Prospective and Retrospective Memory QFuestionnaire (PRMQ)[9], a questionnaire to quantify how much information they had memorized in the consultation, and a semi-structured interview after they had done the two conditions. The test conditions were randomized and video-audio recorded. The results show that the consultation experience in social VR clinic is similar to that in the F2F condition, where participants

have access to the same information as they had in the F2F condition. So, social VR has the potential to reduce the traveling time of the patients, but still provides them sfficient patient education. In terms of quality of interaction, participants had richer and more sensory experience in the F2F condition than in the social VR condition. Participants appreciated the added values of social VR in terms of the visualization of the treatment process and the explanation of the medical jargons, the interactive 3D anatomy knee models, and the "walk-in" experience in the 3D virtual surgery room.

The thesis is structure as follows(Figure 0):

- **Chapter 1** describes the context and the motivation of the research.
- **Chapter 2** discusses the related work in the filed of VR medical applications, social VR, and the communication between patients and medial professionals.
- **Chapter 3** presents a series of ethnographic research in a local hospital Renier de Graaf in Delft, the Netherlands. The results show a complete treatment journey of knee osteoarthritis patients in that hospital, and suggest a list of requirements for designing a VR clinic, focusing on the patient education part of the treatment journey.
- **Chapter 4** describes a series of design decisions based on the results of the research, and specifies the consultation experience in the virtual clinic through the scenario.
- **Chapter 5** is dedicated to the design and implementation of the VR clinic. The links between the design requirements and design implementations are discussed.
- **Chapter 6** presents the methods and results of the within-subject user study.
- **Chapter 7** discusses the limitations of the thesis, including the setup of the experiment, the limited number of participants, and the profile of the participants. It also has a reflection on the lesson learned in the process.
- **Chapter 8** summarizes the thesis, and envisions future research directions and use cases for social VR.

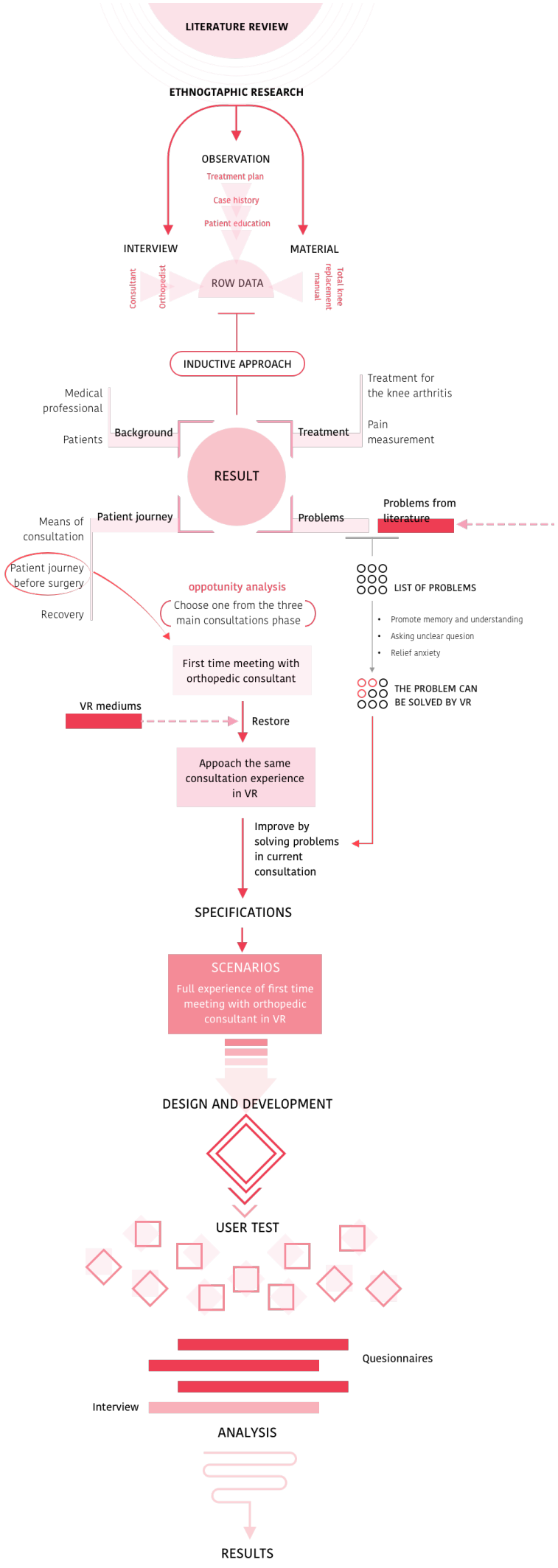


Figure 0. Structure of the thesis

CHAPTER

RELATED WORK

This section presents related work in the field of VR in healthcare, social VR, and the communication between patients and medical professionals.

2.1 - VR Applications in Healthcare

Over the past decade, the technological advances and cost reduction promote a steady growth in applying VR in healthcare. Moline [37] provides an overview on the use of the VR in healthcare, taking into account of a wide range of healthcare contexts and stakeholders (e.g., doctors, patients, healthcare workers, hospital managers). Moline's survey exhibits that VR can be applied for scenario simulations, immersion experiences, 2D/3D model interactions, massive data visualization, and real-time 2D/3D virtual objects creation. Moline [37] summarized the applications of VR in healthcare into seven categories, namely (1) surgical procedures, (2) medical therapy, (3) patient education, (4) medical education and training, (5) visualization of massive medical databases, (6) skill enhancement and rehabilitation, and (7) architectural design for health-care facilities (Figure 1). Explanations for each category are given as follows:

1. **Surgical procedure.** In terms of telepresence remote surgery, VR can enhance the surgeons' performance by helping them plan the surgery through real body simulation.

2. **Medical therapy.** VR is used in treating psychological conditions by providing appropriate environment for physical exercise and/or relaxation, and providing a means for patients to describe their experiences from within altered states.

3. **Patient education.** Use interactive game and virtual elements to help patients enhance their health knowledge and skills, their motivation to learn about health and self-care behavior.

4. **Medical education and training.** Interactive 3D models in VR help student to better understand the basic anatomy, which provide "a didactic and experiential educational tool to give a tour of the intended subject". The models are also used for medical conference, enabling international participants to sharing the medical knowledge in VR.

5. **Visualization of massive medical databases.** For visualizing the massive medical database, VR can help professionals by symbolically represent data as visual objects in a VE, allowing them to investigate and interact with the data in 3D.

6. **Skill enhancement and rehabilitation.** Applications of virtual environ-

ments and related technologies for skill enhancement and rehabilitation include those that provide training in the use of equipment, those that allow the exploration of virtual space, those that augment physical abilities, and those that teach skills.

7. **Architectural design for healthcare facilities.** Using VR to test the architectural designs for healthcare facilities.

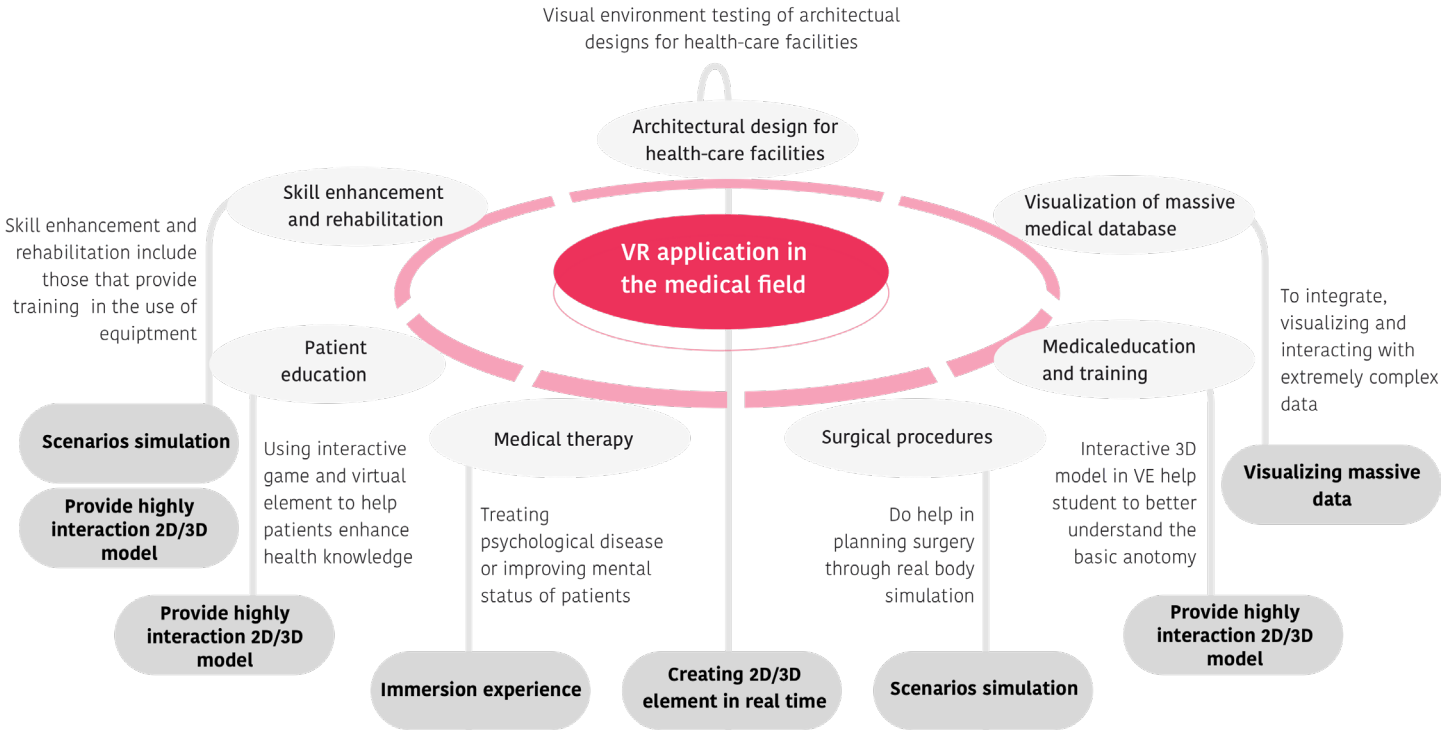


Figure 1. Applications of VR in healthcare

2.2 Social VR

Considering the amount of marketable VR software and content currently under development, VR is gradually changing from an isolated private experience to a social medium [13].

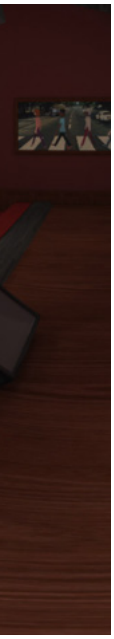
In this thesis, social VR is the type of VR system that the designed VR clinic is based on. Social VR invites multiple users to meet and interact in the same VE [30]. It is elaborately defined as a web-based social interaction paradigm, mediated by immersive technologies and taking place in pre-designed three-dimensional virtual worlds where individuals, represented by avatars or photo-realistic representations, may engage in real-time interpersonal conversation and shared activities [14].

The interest for social VR systems dates back to the late 90s [7, 8, 17, 33, 58]. Recently, commercial VR platforms, such as Sansar, AltspaceVR, and Facebook Spaces all seek to include social VR features in their systems [20, 28, 46, 50, 51, 57]. For instance, AltSpaceVR began to develop social VR content in 2013 by building a virtual community enables thousands of users to get together monthly in their virtual space [13](Figure 2). Later in 2017, Facebook Spaces was introduced, which is a VR application version of Facebook launched for Oculus Rift and Touch. These web-based, immersive virtual worlds enable users to virtually interact with one another under the mediation of a virtual body.

Figure 2. AltSpaceVR

Apart from the commercial social VR solutions, academic research has also investigated into social VR technologies and use cases. OrtsEscolano et al. [40] demonstrated a virtual teleportation system named Holoportation (Figure 3), with real-

Figure 3. *Holoportation*



-time high-quality 3D reconstructions of the entire space, including people, furniture and objects, using a set of high-end depth cameras. The 3D models can also be transmitted in real-time to remote users, enabling low-latency communication between two or more remote users, almost as if they were copresented in the same physical space. The system received highly positive feedback from users in terms of realistic spatial and social copresence, highly realistic self and partners' representation, natural full body interactions and freedom to choose a point of view. Gunkel et al. [18] have developed a web-based social VR platform for the concurrent consumption of videos by remote users. In that platform, the shared VR scenario is represented as a 360 degree static image, and the users are captured by using a single RGB-D camera. So, the user representations are photo-realistic. Cavallo et al. [6] created collaborative VR/AR space, where users are able to collaborate and interact remotely in a 3D environment and play with different types of content that is visualized in real time by all the participating users. Li et al. [30] proposed an experimental protocol and a questionnaire for measuring experiences in social VR. Based on the photo sharing use case, they conducted a controlled within-subject experiment to validate the social VR questionnaire, and to compare quality of interaction, social meaning and presence/immersion in three conditions, namely face-to-face, Skype and social VR. Using interviews,

audio analysis, and the social VR questionnaire, they concluded that the construct of the questionnaire is valid with high internal reliability. The questionnaire can be generalized to other use cases.

The application of social VR in this thesis focuses on facilitating the communication between patients and doctors, through visualizing the information in a 3D virtual clinic environment. Research on the influence of user representation realism or the types of user representations are out of the scope of the thesis. In this thesis, the representations of the patients and doctors are in the form of human-like avatars, with only upper body and hands visible. The social VR questionnaire developed by Li et al. [30] is adapted to measure the consultation experience in the user study.'

2.3 Communication between Patients and Medical Professionals

To design a virtual clinic for facilitating communication between patients and physicians, it is important to know how the ideal communication should be like and what are elements influencing it.

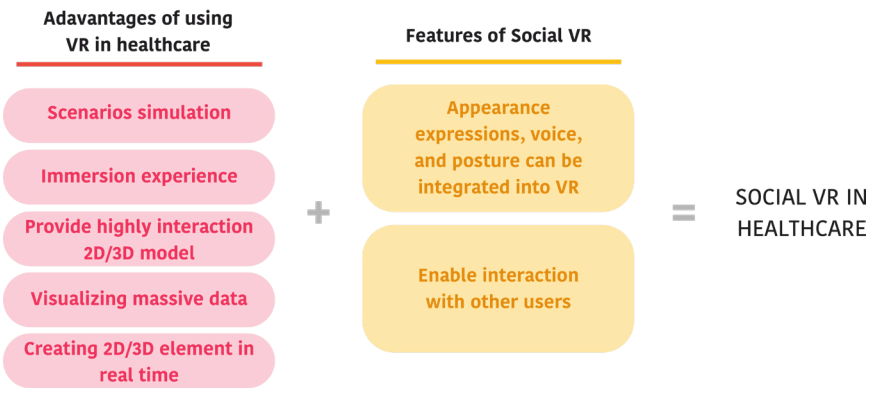


Figure 4:Inspiration from the literature: How social VR can support healthcare

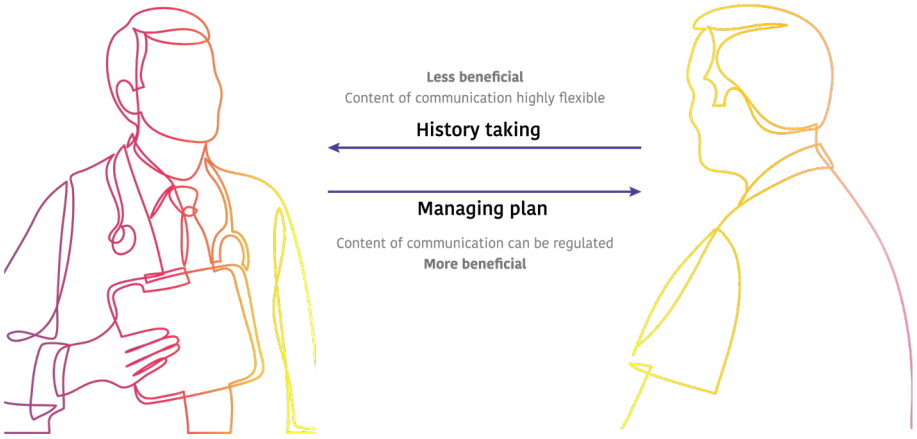


Figure 5:Two types of patient-physician communication

The study by Naidu [38] shows that the quality of patient-physician communication significantly influences treatment satisfaction and health outcomes. However, the significance of communication has not been fully considered by the physicians. As claimed in the previous research, 54% of patient problems and 45% of patient concerns are neither elicited by the physician nor disclosed by the patient [53]. Patients and physicians do not agree with the central issue in 50% of the visit and patients are not satisfied with the information provided by the physician [52]. Problems of patient-physician communication commonly exist, which need more attention [19].

Element of effective discussion. The requirements for good communication are different depending on the stage of the patient-physician conversation, Stewart et al. [53] classified it into two types (Figure 5: (1) history taking which information mainly flow from the patients to the physicians, and (2) the management of plan, in which physicians are the main source of information.

Stewart et al. [53] further concluded that six main elements are affecting the efficiency of patient-physician communication. They are listed as follows:

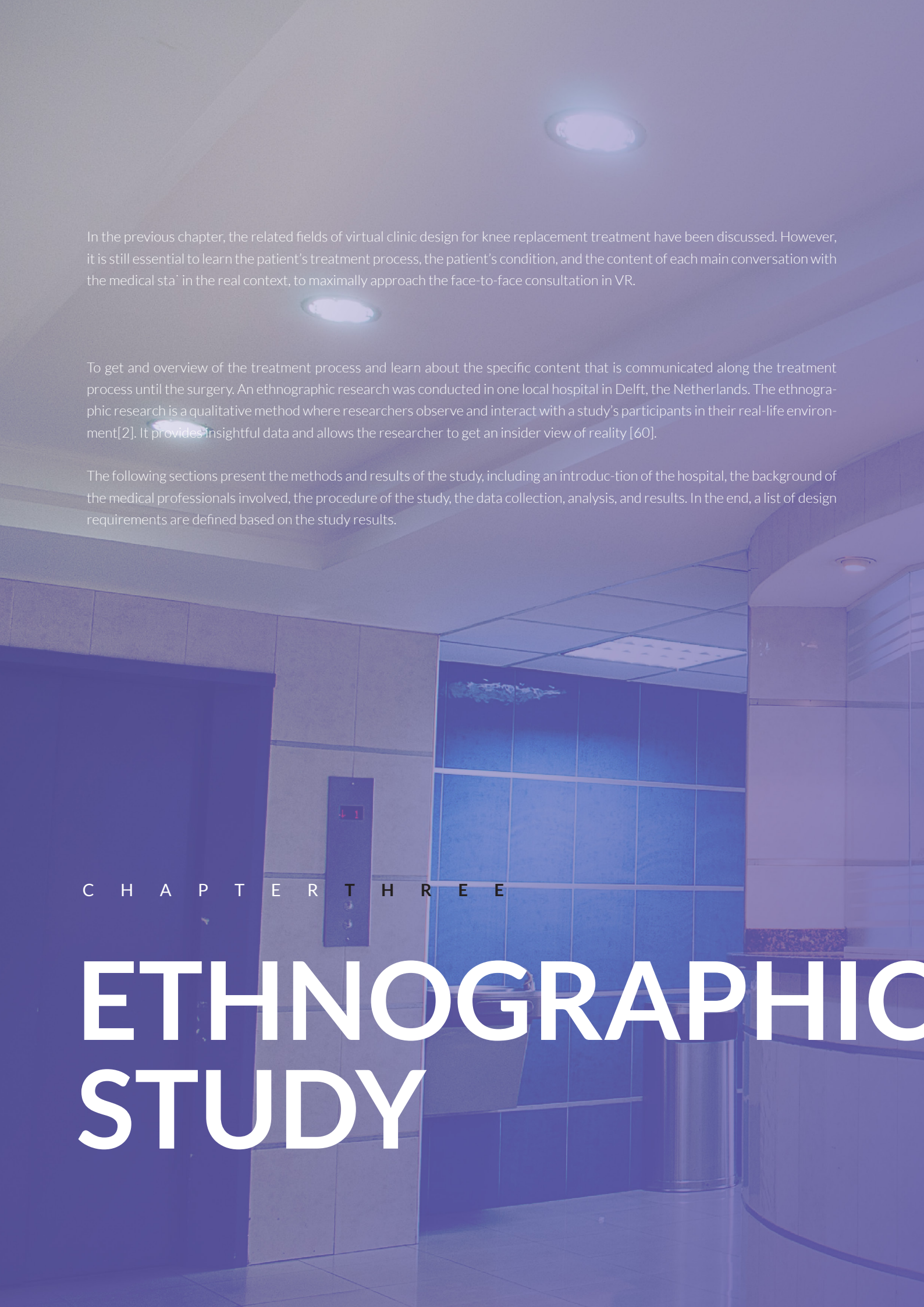
- Patient is encouraged to ask more problem
- Patient is successful in at obtaining information
- Patient is provided with information packages of materials
- Physician gives clear information along with emotional support

- Physician is willing to share decision making
- Physician and patient agree about the nature of problem and the need of follow-up

The importance of providing clear information in a way that patients can understand was especially emphasized by Riccardi and Kurtz [43]. At the end of the conversation, the physician and patient should "find common ground" where both sides agree with each other.

Patient education. Patient education, as an essential part of patient-physician communication, is defined as "helping patients become better informed about their condition, medical procedures, and choices they have regarding treatment." [24]. The resource of medical knowledge is extensive nowadays: from medical professionals, friends, relatives, magazines, internet. . .[12]. The educated patients turn out to be more engaged in the health care process, more compliant to the treatment plan [39], they have lower re-admission rate [21] and are more satisfied with the medical service and their physicians [11].

Although previous studies have provided a general picture of efficient patient-physician communication. It is still unclear that which elements are more vital in the communication of knee arthritis surgery. Therefore, an ethnographic study was conducted to understand the specific factors that influence the communication (see Section 3).



In the previous chapter, the related fields of virtual clinic design for knee replacement treatment have been discussed. However, it is still essential to learn the patient's treatment process, the patient's condition, and the content of each main conversation with the medical sta˙ in the real context, to maximally approach the face-to-face consultation in VR.

To get and overview of the treatment process and learn about the specific content that is communicated along the treatment process until the surgery. An ethnographic research was conducted in one local hospital in Delft, the Netherlands. The ethnographic research is a qualitative method where researchers observe and interact with a study's participants in their real-life environment[2]. It provides insightful data and allows the researcher to get an insider view of reality [60].

The following sections present the methods and results of the study, including an introduc-tion of the hospital, the background of the medical professionals involved, the procedure of the study, the data collection, analysis, and results. In the end, a list of design requirements are defined based on the study results.

C H A P T E R T H R E E

ETHNOGRAPHIC STUDY


3

3.1 Methods

The methods part presents the location (the Reinier de Graaf hospital), the subjects (the orthopedic surgeon and the consultant), the research methodology (semi-structured interviews and observations) and the procedure of the study.

3.1.1 The hospital and the medical professionals

The ethnographic research took place in The Reinier de Graaf hospital(Figure 6), who has been providing care to the residents of Delft and the surrounding area for almost eight centuries. It has 34 different departments, more than 2,600 employees, including more than 200 medical specialists and nearly 800 nurses. Approximately 450,000 people can rely on this hospital for care. The orthopedic department is one of the essential departments in the hospital, which deals with disorders of bones, muscles, tendons, ligaments and joints. Knee osteoarthritis, as a typical joint disease in the knee, will be treated in the orthopedic department.

Three medical staff participated in the study, including two orthopedic surgeons and an orthopedic consultant. Both doctors have more than ten years of work experience and are the main doctors of the joints and bones in the hospital and have extensive experience in the treatment of knee arthritis. In addition to surgery for patients, they also see patients in the outpatient regularly every week, discuss treatment plans with the patient, or check patient's recovery status after surgery. The orthopedic consultant(nurse) works closely with two orthopedics, she provides supervision of patients before and after their stay in the hospital. She is the person that patient will contact most frequently if they have questions about the treatment, surgery, or aftercare concerning the total knee treatment.

Figure 6:The Reinier de Graaf hospital in Delft, the Netherlands.This figure is fromthe website of the hospital: https://reinierdegraaf.nl/

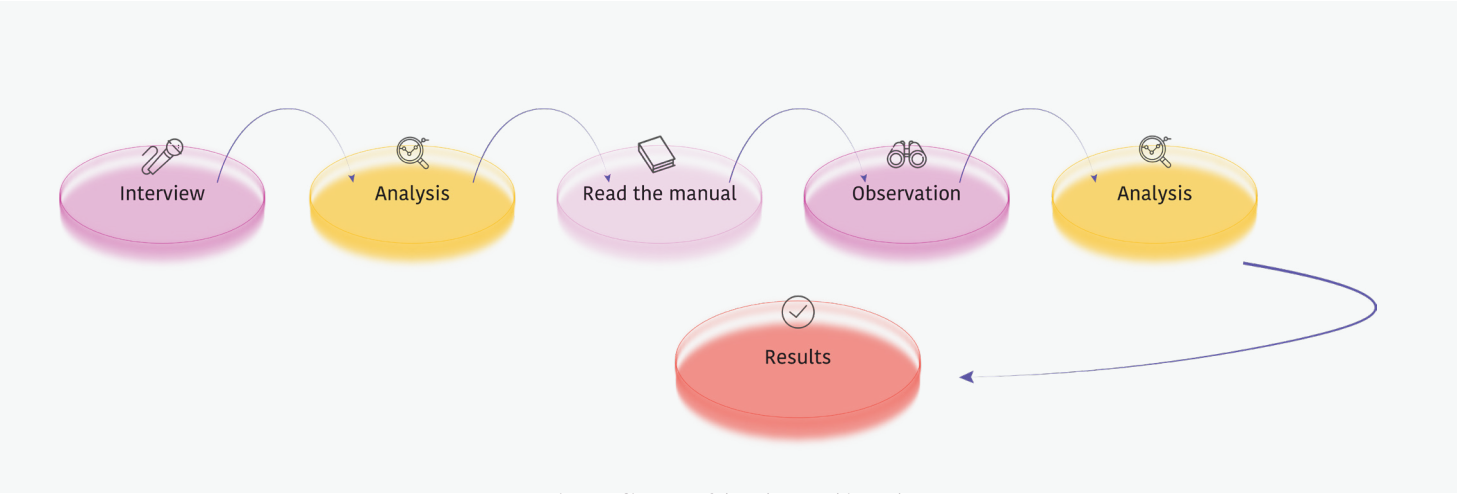


Figure 7:Six parts of the ethnographic study

3.1.2 Process

There are three methods of data collection in ethnography: observation, interviewing, and archival research [2]. In this theis, we mainly used the first two methods: Interviewing medical professionals and observe medical consultations.

The study is composed of six parts starting from interviewing the doctor and consultant (nurse) in their outpatient offices(Figure 7). The researcher conducted semi-structured interviews [3] separately with two orthopedic surgeons and one consultant. They are the medical professionals interacting frequently with the patients. Each interview lasted approximately one hour with prepared interview questions. To trigger the interviewees to tell comprehensive stories, the researcher prepared a booklet to present the interview questions visually. The conversations between the researcher and interviewees were recorded and later on transcribed. An educational manual that patients will receive for the outpatient was translated into English and analyzed thoroughly. The manual lists the information about the preparation of total knee replacement surgery.

To have a more in-depth understanding of the consultation, three observation sessions were conducted during the patient consultation. The patient and the medical professionals were asked to communication naturally in Dutch. During the observation, the researcher sat at the back of the clinical room, observing, note taking and voice-recording the conversations without interruption. The voice recordings were later on translated into English. An qualitative analysis using inductive approach was applied to analysis the result from the field study. The findings was sum up into seven categorizes.

Interview: Interview are verbal interchanges where one person, the interviewer, attempts to elicit information from another person. Semi-structured interview, as one of the three interview types, has some degree of the predetermined order but still ensure flexibility in the way of issues are addressed by the informant [32]. A booklet is prepared to guide the interview. The medical professionals are asked to explain what they were writing while completing the booklet by text or visuals. By involving creative acts of making in the research, the interviewee can reflect on and express their experiences, feelings, and attitudes in forms and formats that provide in-depth information for the researchers [47]. The interview begins with the introduction. First, the researcher will introduce the background of the project, as well as the purpose of the interview. Then the doctors/nurses will be asked to give a brief introduction on their specialty, responsibilities, and work arrangements. After confirming that the doctor's/nurse's expertise is in line with the research topic, the researcher will hand in the booklet to the interviewee. The manual contains several aspects: the general patient profile, treatments, patient journey, and the content of their conversation with the patients. And the problems in the treatment process and their communication with the patients. The doctor/nurse explains what he/she has written while filling out the booklet(Figure 8,Figure 9)

Figure 8: Interview with doctor

Figure 9: Interview with orthopedic consultant

Consultation session observation: Observation is defined as a process enabling researchers to learn about the activities of the people under study in the natural setting through observing and participating in those activities [3, 23].

The purpose of using participating observation is to especially look into the conversations between the patient and the medical professionals, the context, and the content been communicated. The obser-

vation sessions were performed three times, covering all the three most essential consultations in the patient journey before the operation, namely: developing a treatment plan, patient education, and status check(Figure 10).

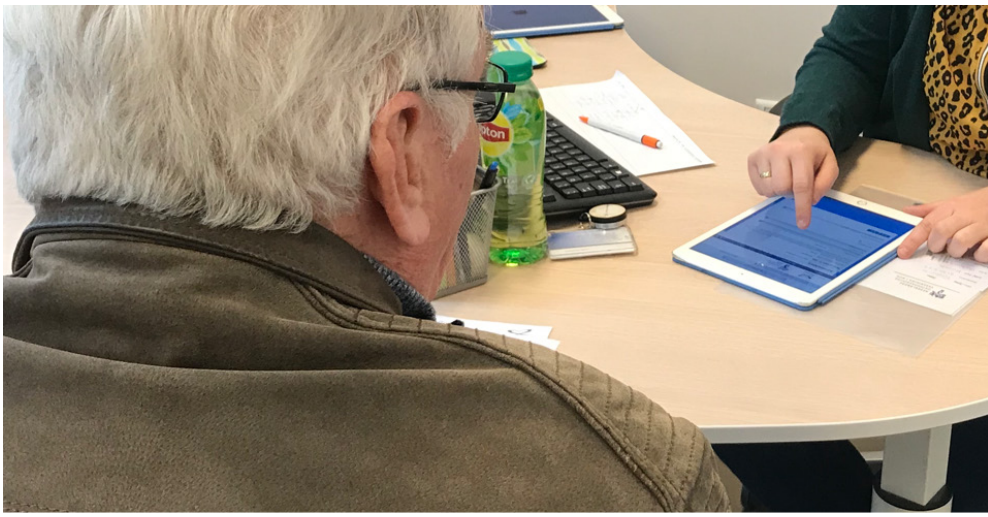


Figure 10: Observation

While conducting the observation, the researcher sat at the end of the office, observed and recorded the whole process of communication. The time taken for each session varies according to the patient's condition and the purpose of the conversation. To ensure that the conversation happened in the most natural situation, some of the consultation use Dutch instead of English.

3.2 Data collection

There are three main sources of data collected in the ethnographic study, namely interviews, observations, and printed materials (e.g., a patient manual).

- **Interview.** When interviewing medical professional, they were asked to fill in a booklet which was used to guide the entire interview process. Therefore, what the interviewee wrote on the booklet is one of the information source obtained from the interview. The booklets were later on electronically archived.

- **Participant observation.** All the three interviews were recorded and put into transcript combining with the visual information collected from the booklet afterward. Data from participant observation was mainly derived from dialogue recordings and records of behavior. During the observation, the researcher sat at the end of the office without disturbing the communication between doctors/nurse and patients, ensured the naturalness of the consultation process. For the conversation in Dutch, Two native Dutch-speakers were invited to translate all those recordings into English scripts sentence by sentence. After all the transcripts were compared, the different parts were double-checked and unified.

- **Printed materials.** In the treatment process, all the patients who decide to take the surgery will receive an operation instruction, which has more than 30 pages of text information all written in Dutch. This manual was also translated and confirmed by the native dutch speaker.

All of the above materials were organized into a uniform format and were read by the researchers repeatedly before the analysis

Figure 11: Prosthesis used in the consultation

3.3 Data Analysis

An inductive approach was applied to analyze the research data. Induction is a reasoning method by which a general principle would be inferred via observing specific cases [61]. This approach is widely adopted in the research field, a large number of authors reporting qualitative analysis data in journal articles that can be labeled as "general inductive approach." Unlike other methods such as grounded theory(e.g., [54]), discourse analysis [41] and narrative analysis(e.g.,[31])., the inductive approach provides a more straightforward and direct set of procedure to analysis vast amount of raw data without technical barriers [36]

In this research, the inductive approach of analysis qualitative data ()was adopted to condense extensive raw text data into summary format and derive clear findings Two researchers are invited to analyzing the data through the procedure below:

1 **Data cleaning** All the recordings were translated in English by native speakers, transcripted and formed into dialog format.

2 **Reading the documents** All the documents were printed and carefully read by the researcher for several times.

3 **Coding the text and creating the categories** The insightful text will be highlighted and labeled with lower categories, which were created from summarizing meaning or actual phrases used in specific text segments. Higher categories were derived later on based on the research goal after all the documents were coded.

4 **Uncoded text** The text that cannot be assigned to any category and is not relevant to

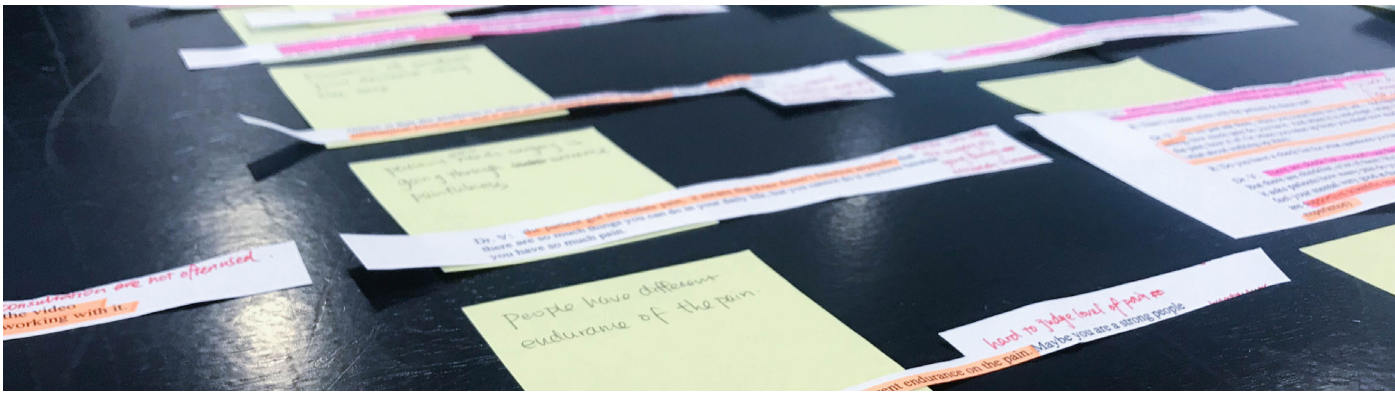


Figure 12: inductive approach of analysis qualitative

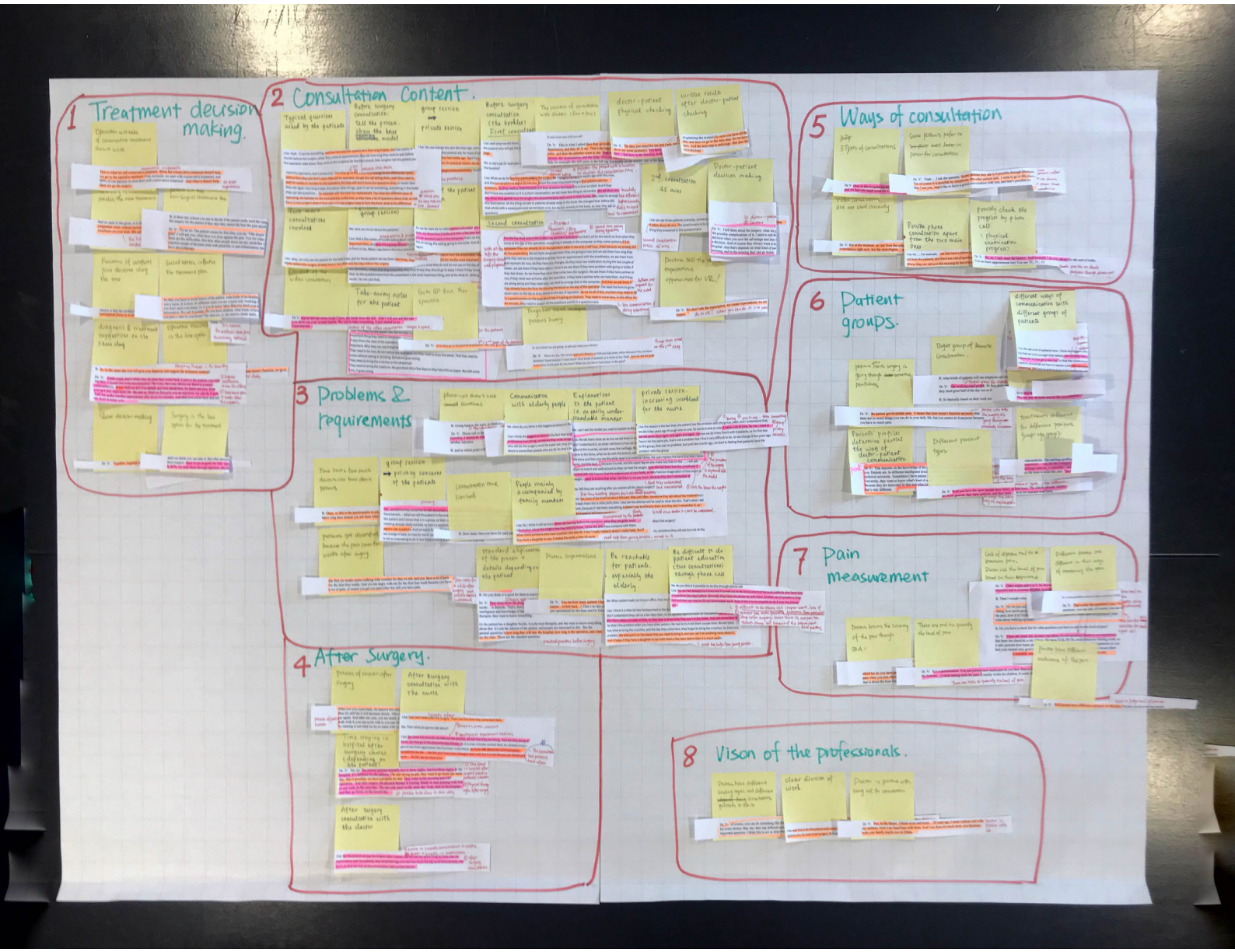


Figure 13: Results of the enthnographic study

3.4 Result

The code texts were first sorted into eight categories(Figure 13) by two researchers and the names of each category was given: (1) treatment decision making, (2) consultation content, (3)problems and requirements, (4) after surgery, (5) ways of consultation, (6) patient groups, (7) pain measurement and (8) vision of the professionals.

Then, the two researchers conducted a second round of categorization. Category (1), (2) and (4) were combined as a new category, and named as "consultation before and after surgery", because they were all about the consultations in different phases of the treatment process. Category (5) and (6) were combined as a new category as "customized consultation", because different patient groups tend to use different ways of consultation. For instance, the elderly needs more repetitions and

explanations than younger patients. Category (3), (7) and (8) were combined as a new category named as "problems, requirements and opportunities". The following subsections are going to describe the three new categories and the representative quotes from the three medical professionals (two doctors and one nurse), who are labelled as M1-M3. Before explaining the three categories, Section 3.4.1 clarifies the backgrounds of the medical professionals involved in the treatment process.

The general practice (GP) is the first-person who the patient meets in the treatment process. The GP will send a reference letter to the specialist if the patient needs further inspection or treatment.

Orthopedist (Orthopedic specialist or doctor) receives the letter from the GP, and will carefully examine the patient and suggest a treatment plan. The doctor who meets the patient at the outpatient clinic is not necessarily the doctor who does the surgery. It might be that another orthopedist performs the surgery. In that case, the other orthopedist will meet the patient before the operation.

The orthopedic consultant will meet the patients if the patients decide to take the surgery. He/She will provide the patient education and help the patient to prepare for the surgery.

The anesthetist will also meet the patient if they are going to take the surgery. The anesthetist will acquire all the patient information to prepare the ward of the operation.

Physiotherapists will relieve pain for patients through physical therapy and help patients with rehabilitation.

Figure 14: Medical professionals involved in the knee replacement surgery

3.4.1 Medical professionals

We list all the medical professionals(Figure 14) involved in the treatment process. The three medical professionals participated in the interviews are two orthopedic doctors (later referred as "doctors") and one orthopedic consultant (later referred as "nurse).

3.4.2 Consultations before and after the surgery

Typically, for patients who need to have total knee replacement surgery, there are three consultations between the patient and the medical professionals. All patients start with the first consultation with the doctor, for examination and making decisions about the treatment. When the patient needs to have surgery, a second and third consultations will be scheduled with the nurse.

The first consultation.

During the first consultation, the doctor needs to see the patient face-to-face, does the physical checking and has the patient go through some medical examinations (e.g., X-ray). **M2** mentioned the main content for the first consultation.

> *"The patient comes to me with a letter written by his/her GP. I do three things: asking about the history, doing a physical examination and having the patient examined by the X-ray."*

In this consultation, the doctor explains the procedure and risks of the surgery, and shares the decision making about the treatment with the patient.

> *"I tell them about the surgery. What are we going to do? How long does it take? What possible complications of it? I need them to know the risks. So, the patients can make a good decision when they know both advantages and risks. We made decisions together (M1)."*

Most of the patient (80-85%) starts the treatment with conservative methods or in other words, non-surgical treatment, such as medications and injections. Going for surgery is the last option. Only when the conservative methods do not help, the doctor will suggest the surgery. As mentioned by M2,

> *"Here in the hospital, we only operated 15-20% of the patients. For the other 80-85%, we treat them through injections, physiotherapy and medications."*

Similarly, M3 also pointed out,

"Normally, we start with conservative treatment. When it doesn't help, we go for the surgery."

Furthermore, the professionals also mentioned some factors that influence the decision on treatment methods, such as the history of the pain and treatments the patient had before and the profile of the patient. Is the patient new, or has he/she suffered from this pain for years already? What type of job does he/she have (e.g., heavy physical workers or mostly sitting office workers)? How is the patient's endurance for pain? A quote from M3,

"You need to understand the social context and the history of the patients. Do they have some other diseases, like diabetes, hypertension? What are their professions? If they sit in front of the computer, then they probably do not need to use their knees that much. If they have heavier labor work, then they need their knees more. This type of information we call it social context. Do you have children? What type of house do you live in? Do you have stairs in your house?These kind of questions are also about social context of the patients."

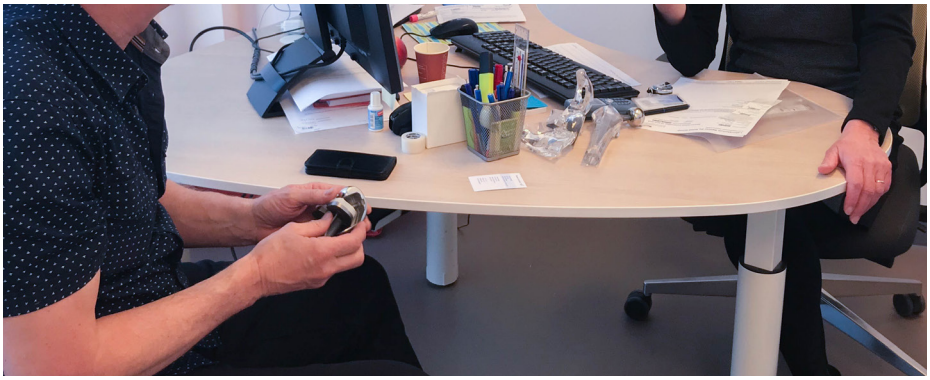


Figure 15: The second consultation

The second and third consultations.

When the patient needs surgery, then they schedule with the nurse the second consultation 6-7 weeks before and surgery, and the third consultation a few days before the surgery. The second consultation is a 20-minute Q&A patient education session with the nurse, where the process for preparing for the surgery is explained by the nurse and in a printed booklet. The anatomy model of the knee and a model of the prosthesis are shown to the patient to help him/her better understand the surgery. Patients are encouraged to ask questions during this consultation

"We show them [the patients] the models, and talk about the surgery. I always make sure the patients feel the weight of the prosthesis. The most important thing is that the patients ask questions. They need to read

the booklet and raise questions. If they do not have many questions, we will point out a few important things for them to remember (M3)."

The second consultation involves a lot of conversations and physical interactions (e.g., showing the anatomy model).

The third consultation takes about 45 minutes, which is the last consultation happening a few days before the surgery. This consultation to finally confirm the details of the surgery and to ask the patient to fill in a comprehensive questionnaire about their physical and mental conditions. As M3 told us,

"This questionnaire is for the staff working in the wards, we need to make sure when the patient comes at the day of the surgery, everything is recorded in the computer. The surgery and the ward are prepared. We ask everything in the questionnaire: their physical, mental conditions, whether they have partners or people to take care of them, their home environment. The patient fills in the questionnaire on an iPad. We also make sure they've already got the form for drawing blood."

After the surgery.

After the surgery, depending on the condition of the patients, they can either stay in the hospital for a few more days or go home on the same day. M1 explained,

"Normally, the patients stay two or three nights in the hospital. It is di˙erent for every participant. Some strong people want to go home at the same day. That is possible. We have a program for that. Right after the surgery, the physiotherapists are coming. They can start training the patients and they can start walking on the same day of the surgery."

Two weeks after the surgery, the patient is requested to meet the nurse, to check how the recovery is going.

3.4.3 Customized consultations

Although most patients are in their 70s or older, there is a growing number of younger patients in their 40s-50s who had the surgery. Those younger patients are usually actively working, so their time is relatively limited compared to the retired patients. The communication with di˙erent age groups is different, like mentioned by M3,

"We normally have patients with the age around 70, but now we have a growing category with people in their 40s-50s. So, the communication becomes very di˙erent. For people who are older than 80, we need a lot of e˙ort to explain and write down things. For people with dementia, we

need to communicate with the persons who accompany them to the hospital."

Doctor M2 also pointed out that patients' profiles partially determine the way of communi-cation.

> *"That [The communication] depends on the knowledge or intelligence level of the patients. Some patients really experienced difficulties in understanding my explanations. Once I had a patient who is a full professor. He asked much more details, like the exact material of the prosthesis."*

The hospital has a solution to provide consultation through telephone and video conferenc--ing. The target patient group for these types of consultation are the patients who have

Figure 16: Patients at the waiting area

> *"much more severe symptoms"(M1) or "the patients who are still working"(M3). So, they can save some time and effort choosing the video consultation."*

3.4.4 Problems, requirements and opportunities.

The main problems mentioned in the interviews are about the communications between the patients and the medical professionals. Communication with the elderly is difficult, especially the ones who have diseases like dementia.

> *"I think the biggest problem we are facing now is the communication with the elderly. Most of the patients who need to have surgery are already 80 or even 90. They have problems to understand me. Even if they write down things, they do it wrongly (M3)."*

The medical professionals also have limited time to explain everything in details when the patients have difficulties, but they try to do the patient education in a easily understandable manner, avoiding using difficult medical jargon's. M3 told us about the patient education,

"We tell them about the surgery in an easy way. If we need to use medical terms, we explain them well to make sure they understand them. We show them the knee model and the prosthesis that needs to be placed on their knee. We tell them how the surgeon is going to operate on their knee, their muscles around it, the cartilage and the bones."

The limited consultation time also stops the nurse to ask about the expectations of the patients,

> *"We have a questionnaire to ask about their [the patients'] expectations, but we don't use it because it takes long time to complete. Instead, we tell them what to expect (M3)."*

Another aspect that makes the communication difficult is that the patients have different endurance for pain. For patients who have higher endurance for pain, they might only need conservative treatment rather than the surgery. The doctors lack standard tools to measure the pain, which increases the difficulty in deciding on the treatment plan. M2 explained,

> *"Every doctor has experience. They ask the patients questions based on their own experience. For example, I usually ask 'How much pain do you have while sitting?', 'Do you wake up in the midnight because of pain, and how painful is it?', How much pain do you have when you raise up from your chair, and walking upstairs?' We do not have objective tools to measure the pain. Sometimes, it is difficult to decide on the treatment."*

Most of the elderly patients need their family to accompany them to the hospital. Not only the patients need to visit the hospital several times suffering from unbearable pain, it also takes a lot of effort from the family members who must accompany the patients. As M3 mentioned,

> *"The third consultation will provide a lot of information about the surgery, and we require the patients to remember them. I think above 80% of the patients are accompanied by someone to the hospital. When this "someone" is also 80 years old, it does not help at all. If their kids accompany, it makes things easier."*

The doctors/nurses tried to do remote patient education through telephone and video conferencing. These solutions can help with minor questions, but it is difficult to explain and visualize things.

> *"We have tried [the telephone and video consultations], but it turned out to be not so practical, because we have a lot to explain. The patients and their family have a lot to ask. We also need them to fill in questionnaires, a lot of paper work involved (M3)."*

The medical professionals complained about their heavy workload. They need to do the consultation in a one-to-one session with every patient, due to the privacy concerns of the patients. M3 told us,

> *"It takes a lot of time. I need to tell the same story again and again. It is boring for me to repeat the same story 6 times a day. We had this consultation in groups before, but we found patients did not want to talk about their problems in front of other patients, and they were reluctant to ask questions as well. So, we changed it back to private sessions."*

Another aspect of the workload is that the medical professionals also need to be reachable by the patients all the time.

> *"We need to be approachable on phone, especially for the elderly. They keep on forgetting important things even if we have told them and written down for them a few times (M3)."*

Besides asking for the problems, during the interviews, the medical professionals were asked about their opinions towards social VR consultation solutions. All of them are positive towards the social VR clinic,

Problems

- It is painful for the patients to travel several times to the hospital.
- Patients have different ability to learn medical knowledge (e.g., Communication with the elderly is difficult due to their decreased ability to comprehend.).
- Patients have different endurance for pain. The doctors lack tools to measure the pain.
- Older patients or patients with dementia need an accompanying person to help remember the important issues.
- Patients normally lack medical knowledge, which requires extra effort of the nurses to make the information understandable.
- The nurses experience difficulties in remembering/recording the content they have already explained to the patients.
- The consultation time is limited for the nurses to explain information in details.
- The workload is heavy for the medical professionals because of the one-to-one face-to-face consultation.

Figure 17: Problems from ethnogrphic study

> *"Yes, in the near future, I can see this [social VR clinic] is possible, like the evolution from telephone to video call (M2)."*

M3 also mentioned,

> *"If we can pre-record some explanations and visualizations in social VR, and let the VR nurse explains to the patients. This can save me a lot of time. I do not need to repeat the story again and again."*

To summarize, we identified a list of problems about the communication between the patients and the medical professionals, based on the ethnographic study results. They are devscribed as problems, but also can be seen as requirements and opportunities for improvement. The problems are listed in figure 17.

3.4.5 Patient journey

In the previous subsection, a list of problems are identified based on the interviews with the medical professionals. Here, an overview of the patient journey is illustrated as described as (1)-(7) in the following paragraphs(Figure 18). Step (1) of the journey is the first general consultation with the doctor. Step (2) and (3) describes two types of decisions of the treatment. Depending on the treatment plans, patients will either go for the conservative treatment or decide to have the surgery. If the latter treatment is selected, they need to schedule extra consultations with the nurse, which are explained in (4) and (5). The procedures that patients need to follow on the day of the surgery and after surgery are described in (6) and (7). (1)

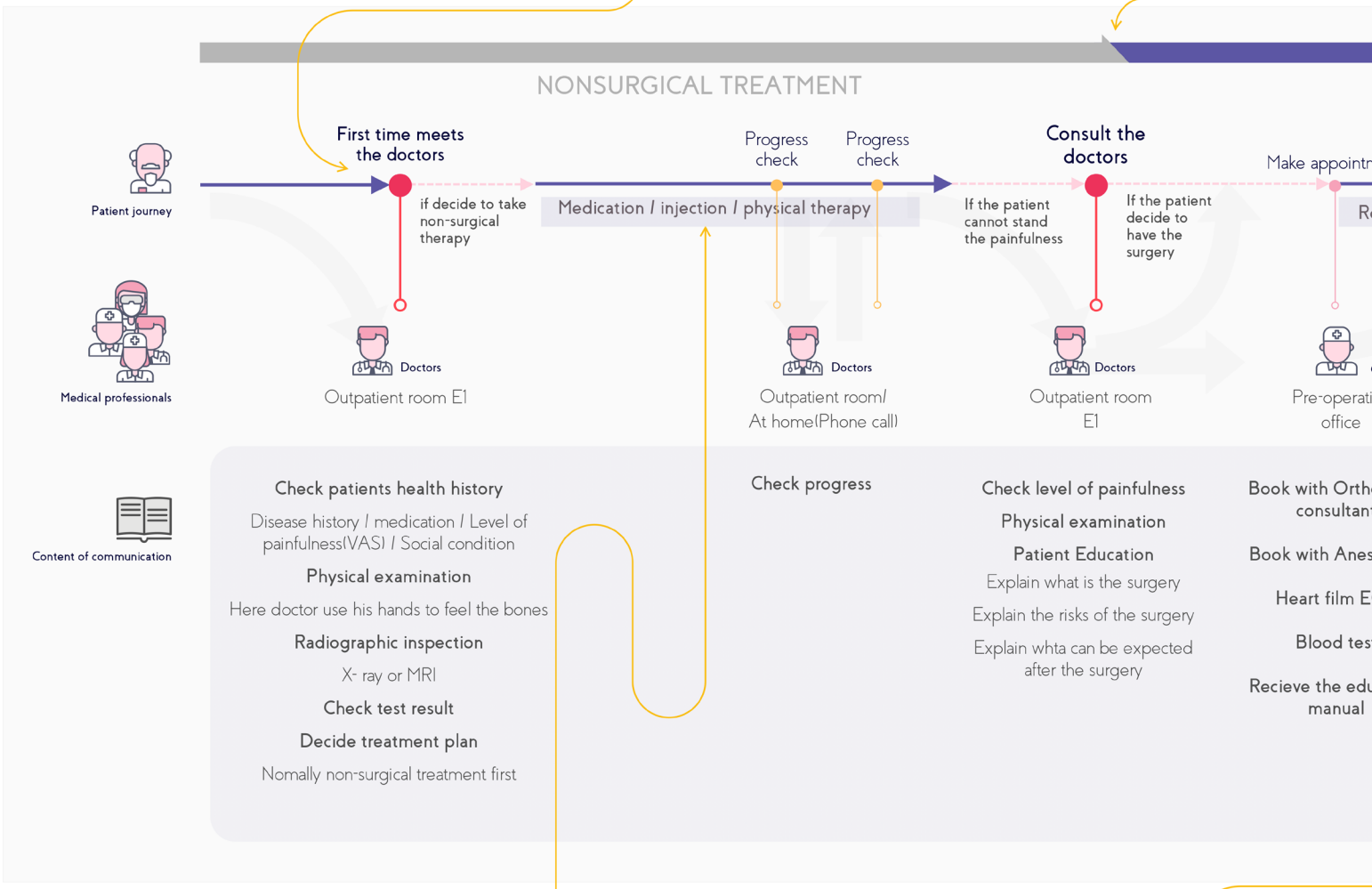
For full figure, see Appendix 9.1

1 The first consultation: Visit the orthopedist (doctor)

The patient who gets the reference letter from the general practice first meets the doctor in the hospital (i.e., the outpatient office). During the first visit, the orthopedist checks the patient's health history, and does physical examinations. Then, the patients go to the radiology department for radiographic inspection. The result is directly be sent to the doctor. With the result, the doctor discusses a treatment plan with the patient. It usually starts with non-surgical treatment (e.g., medication, physiotherapy or injection).

3 Decide to have surgery

If the non-surgical treatment goes well, the patient does not need to come to th hospital again. He/She only needs to have regular examinations with their gene practice. If the non-surgical treatment does not help, they meet the doctor agai about the possibility of having the knee replacement surgery. The doctor asks a the level of pain and does the physical examination again. The doctor also expla procedure and risks of the surgery. The patient and the doctor decide together necessary to have the surgery. Once the patient decides to have the surgery, th doctor gives him a booklet, including all the details about the surgery. The patie then referred to the pre-surgery oÿce, where he/she needs to make appointme the surgery, and for meeting the orthopedic consultant and the anesthetics.



2 Decide to have non-surgical treatment

The patient is requested to visit the hospital again or contact the doctor through telephone while taking the non-surgical treatment. During the new consultation, the doctor checks the progress of the treatment. Some patients prefer to do this through telephone since it saves traveling time.

4 The second consultation (patient education):

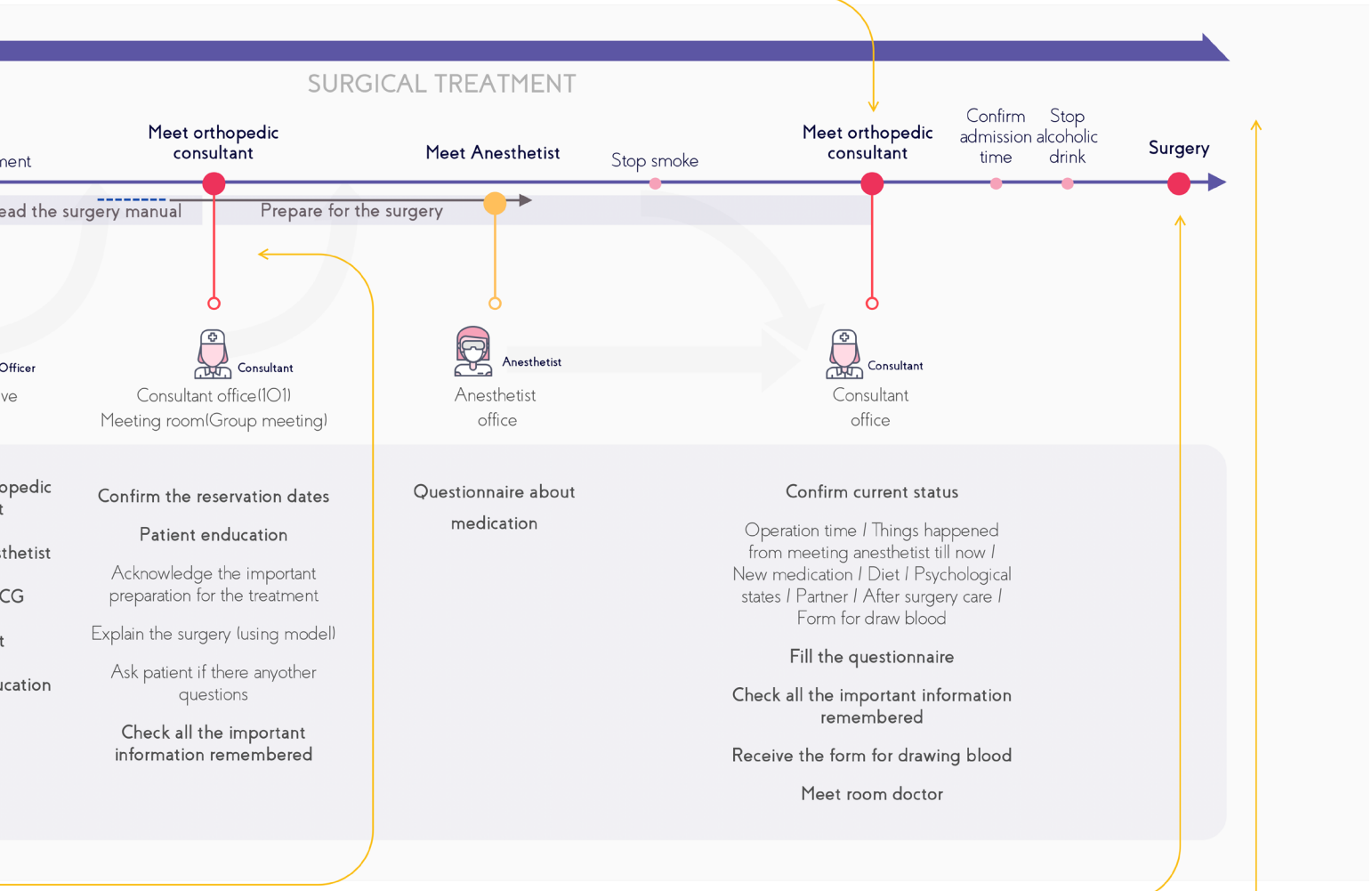
Meet orthopedic consultant (nurse) for the first time

The first-time patient meeting the nurse is 6 or 7 weeks before the surgery. Th sultation takes about 20 minutes. The nurse tells how to prepare for the surger shows the patient the prosthesis, explaining how the prosthesis will be installed nurse also lets the patient feel the weight of the prosthesis. Then, the patient is time to ask questions they have about the surgery, the booklet and so on. There nose culture at the end of the consultation, which inspects S.AUREUS: a bacter can cause infections around the new installed prosthesis. In the end, the nurse schedules a date for the surgery and arranges another consultation with the pa

Figure 18: Patien

5 The third consultation: Meet orthopedic consultant (nurse) for the second time

The patient meets the nurse again a few days before the surgery. The nurse asks about the patient's physical and mental conditions, and confirms the time of the surgery. The patient is requested to fill in a questionnaire, for the sta working in wards to prepare for the surgery. The patient also receives a form for drawing blood and a piece of take-away paper with all the important reminders written down. Two days before the surgery day, the patient receives the phone call from the hospital to confirm the exact admission time for the surgery.



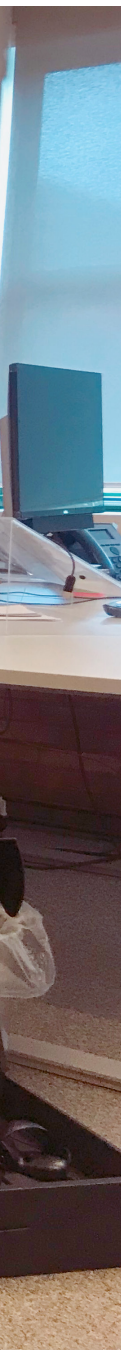
6 Day of Surgery

On the day of the surgery, the patient needs to arrive at the hospital half an hour earlier than the scheduled time. He/She needs to first draw blood in the lab. Afterwards, the patient goes to the recovery room to prepare for the surgery. Ideally, the patient can leave the hospital at the end of the surgery day, as long as he/she has stable condition and can do basic activities with the crutches. In most cases, the patient stays one or three nights in the hospital. He/she receives physiotherapy during and in the hospital.

7 After surgery

After the surgery, the patient normally feels pain on the knee, but it will decrease in a few weeks. The patient needs to visit the nurse two weeks after the surgery. The nurse checks the wound, asks how the patient feels and takes out the stitches. Six weeks after the surgery, the patient visits the doctor who did the surgery and performs all the inspections again as the first consultation. The patient normally feels much better three months after the surgery. They are able to walk, cycle and drive.

Figure 19: Develop with the oculus devices



THIS THESIS CHOOSES TO FOCUS ON THE PATIENT EDUCATION PART OF THE PATIENT JOURNEY. CHAPTER 4 WILL PRESENT THE DECISION MAKING ABOUT WHY WE CHOOSE TO FOCUS ON THE PATIENT EDUCATION, AND DESCRIBE HOW THE RESEARCH RESULTS ARE TRANSFORMED INTO DESIGN SPECIFICATIONS.


maybe if it is a video call, will it be more
doctors Postup
R: Going back to the topic, so there is a second visit for patient, it is through phone-call.
Dr. V: Phone call or they just come to the office again. Because if they need another injection, I cannot do it through phone call, so they need to come here again and I give them another injection
R: and in which point will the patient start to think about having the surgery
Dr. V: So first, is prescription of medicine and physiotherapy, the physiotherapist will help you with the training.
R: Patient need to come here for physiotherapy?
Dr. V: No they go to the physiotherapy clinic.
his is what we ll conservative treatment. When the conservative treatment doesn't help, e go to the ope tive treatment. First, normally we start with conservative treatment, and 0% of our patie ts we treat them with conservative treatment . And when it doesn't help, en we go the su gery.
what kinds of atients will use telephone
ient?
Reduce time
R: so it means telephone call.
Dr. V: Yes, indeed

This chapter explains the design and implementation of the VR clinic. The links between the design requirements and design implementations are discussed. Based on the results of the ethnographic research at the Reinier de Graaf hospital, the treatment process including three main consultations was identified. One of the consultations was chosen as the main use case to design VR clinic for. The following subsections will discuss the decisions made for designing and implementing the VR clinic.

CHAPTER FOUR

FROM RESEARCH TO DESIGN

4.1 Socail VR Opportunities

The previous chapter identifies some typical problems, and requirements for improvement in the face to face consultation, based on the results obtained from the results from the ethnographic study, as well as the literature about doctor-patient communication.

The problems and requirements are listed in Figure 20.

Communication problem found from ethnographic research

- It is painful for the patients to travel several times to the hospital.
- Patients have different ability to learn medical knowledge (e.g., Communication with the elderly is difficult due to their decreased ability to comprehend.).
- Patients have different endurance for pain. The doctors lack tools to measure the pain.
- Older patients or patients with dementia need an accompanying person to help remember the important issues.
- Patients are often lack of medical knowledge, which requires extra effort of the nurses to make the information understandable.
- The nurses experience difficulties in remembering/ recording the content they have already explained to the patients.
- The consultation time is limited for the nurses to explain information in details.
- The workload is heavy for the medical professionals because of the one-to-one face-to-face consultation

Communication problem found from literature review

- Information transferring between doctors and patients is not effective because of the misunderstanding and lack of communication.
- Patients and doctors have different levels of knowledge, resulting in different opinions about the severity of the illness and different expectations about the treatment plans.
- Patients are passive in conversation, and often feel uncertain about treatment decisions even after the consultation.
- The consultation environment is often felt as dull and detached, which may make the patients anxious and talk less about their disease.

Figure 20: Summary of the problems

Social VR has the potential to solve some of these problems because of the immersive experience it provides to the users. For example, it can save the traveling time of patient. Patients can stay at home, but still get sufficient patient education from the medical staff. It can also play the pre-recorded and visualized education materials. So, the medical staff do not need to repeat these again and again, which help reduce their workload. By visualizing the information in social VR, we expect patients to better understand and more easily memorize the abstract medical knowledge. We also expect that patients will be more active participating in the conversation, and possibly ask more questions triggered by the virtual 2D/3D visualizations.

4.2 Three main consultations

The osteoarthritis patients, especially those who need operation, are suffering unbearable pain when they are walking. Since the main feature of social VR is to bring people from different locations together, it is beneficial for the patients if the amount of times they spent traveling to hospital is reduced before the surgery.In the osteoarthritis treatment process, patients need to visit the hospital several times in person. Their hospital visits include three main consultations(Figure 21): the first consultation with the doctor, and the second and third consultations with the nurse. The first consultation with the doctor usually involves medical check-ups (e.g., blood tests, medicine injections, and/or X-ray inspection). The second consultation is mainly on patient education, which happens 6-7 weeks before the surgery. The nurse will explain the surgery process, and show the patient how the prosthesis will be installed. The third consultation happens a few days before the surgery, during which the physical and mental status of the patient is checked through face-to-face conversation and a questionnaire. The patient is also requested to meet

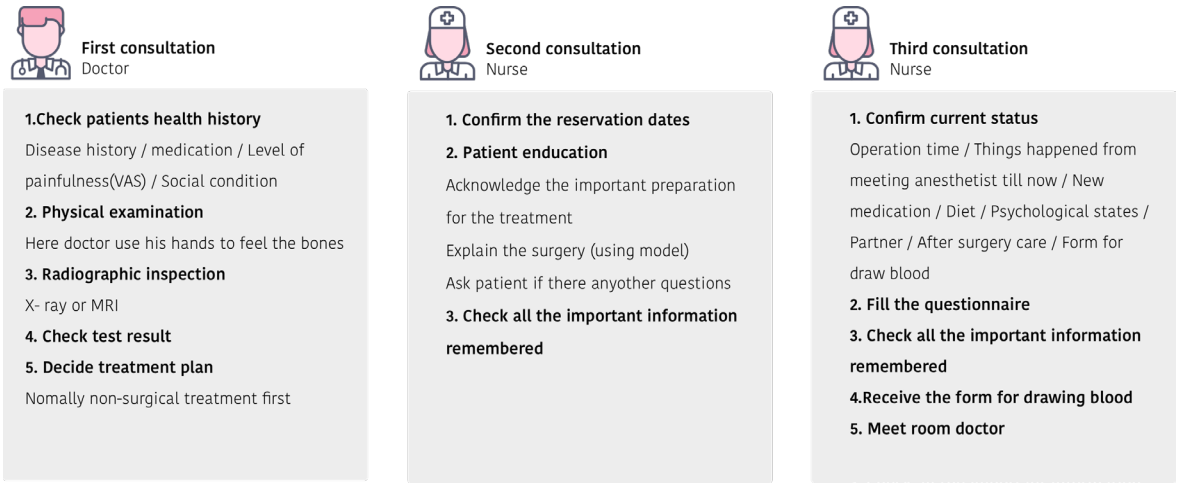


Figure 21: Content of the three main consultations

the surgery room doctor in person.

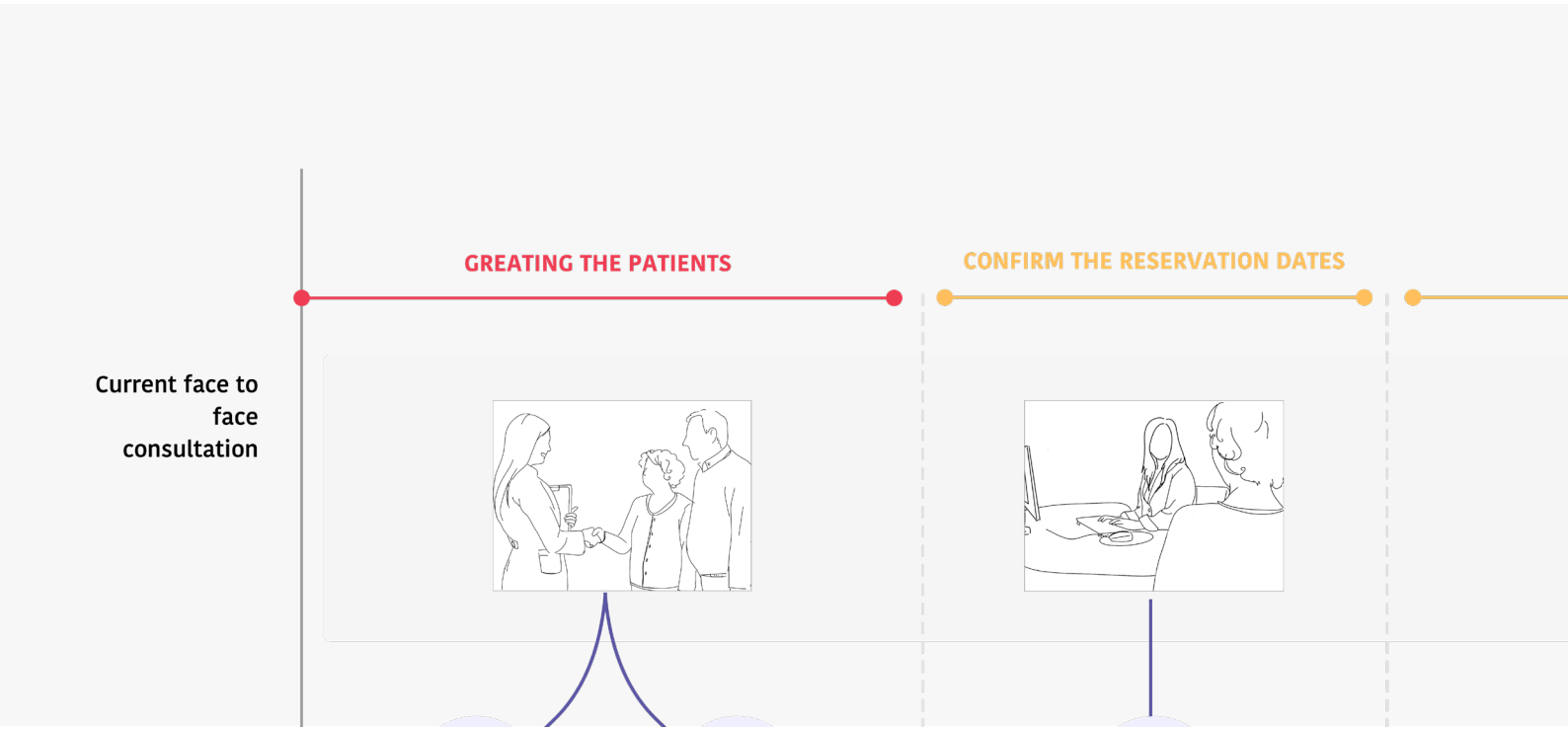
So far, due to the technological limitations, not all the consultations can be implemented in VR. Most medical check-ups need professional equipment. As the doctor and nurse commented in the interview, at the moment, the blood tests usually can only be done at the hospital. It is also not possible to have medicine injection and X-ray inspection in VR. So, the first consultation is excluded for the VR clinic desgin in this thesis.

In addition, for the short duration of this thesis, the implementation of the third consultation is less preferred in this thesis. During the third consultation, the patient will receive a physical form for blood drawing that is necessary on the day of surgery, and he/she will spend most of the time filling in the questionnaire for a final medical check. The verbal and non-verbal communications between the nurse and the patient is limited. It is possible to do the third consultation in VR, but due to the limited interactions, it is less interesting for this thesis compared to the second consultation. Furthermore, the nurse and the surgery room doctor prefer to see the patient face-to-face to understand his/her physical and mental status in the third consultation. Unless the quality of human representation in VR reaches a certain level, it is difficult for the nurse to do the checking through VR. Therefore, this thesis selected the second consultation as the target use case.

4.3 Current workflow of the second consultation

The second consultation is the patient meeting the consultant (nurse), which happens about 6-7 weeks before the surgery. The patient is requested to come to the consultant office in person and most of them are accompanied by their partner, kids or relatives. The consultant welcomes the patient at the waiting zone of the hospital and walks them to the consultation office.

The conversation starts from (1) confirming the important dates. The consultant confirms with the patient about the dates for meeting the anesthetist, the third consultation, and the admission date for the surgery. Following this, the consultant explains in details to the patient how he/she should prepare for surgery, which is called (2) patient education. While explaining, the consultant highlights the key points that need extra attention. For example, some particular medicines need to be taken before the surgery on specific date. Home facilities need to be prepared for the after- surgery-care. To better explain the surgery process, a realistic prosthesis model is shown to the patient, to give him/her a clearer idea about the surgery. The consultant explains the surgery process using the prosthesis model, and then asks



the patient to hold the model to feel the weight. Some patients like to take photos of the prosthesis sharing with their family members. The consultant also explains the possible situations the patient can encounter in the surgery room, like the high temperature around the operation area. In the end of the consultation, the consultant again (3)checks if the important issues are remembered by the patient. The consultant repeats the take-away messages and asks the patient if he/she has any other questions. The figure below shows the detailed process and content of this consultation (Figure 22).

The information is provided through verbal descriptions, printed/digital manuals and a physical artificial knee model, which are the same as described in [28]. Due to the feeling of unfamiliarity of the clinic environment and the uncertainty about the treatment process, the patient can feel anxious about what might happen at the surgery. So, they tend to be hesitant talking about their conditions [12].

As observed in the consultation sessions, the consultant is active in providing the information, the patients are reactive and passive. Most patients want to be more active participants in their treatment. The orthopedic consultant always asks patient if they have any questions while the consultation, however, after receiving a large amount of the new information it is hard for the patient to come up with questions immediately, but that doesn't mean the patient understands everything.

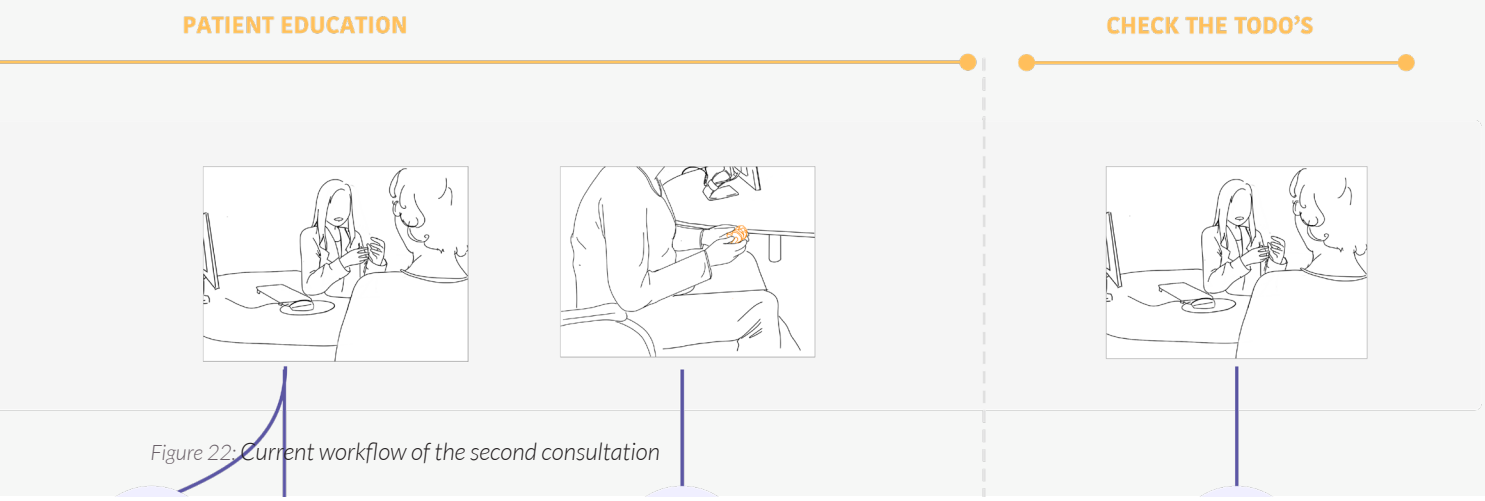


Figure 22: Current workflow of the second consultation

4.4 Design the Social VR Clinic

Social VR could help patients reduce the painfulness of travelling to hospital through moving the consultation into virtual clinic. Therefore, the virtual consultation experience should very be similar to face-to-face consultation.

While entering the virtual clinic, the patient should receive welcome. They will meet the consultation in the office-like virtual environment, with patient and nurse sitting at each side of the table. There should be a calendar to help with confirming the reservation date. The calendar should be editable so the appointment can be assigned to another time if necessary. The consultant will talk through all the important issue patient need to pay attention to, just like how it happens in the real meeting. While talking about the surgery, the doctor will explain the surgical process and environment the knee prosthesis model should be available for patients to hold in hand. The consultation will end with the nurse reconfirming the important to do's and assure the all the unclear questions are answered.

In the following paragraphs will elaborate on the details of the design three aspects: visual information, immersive experience, and flexibility of the 3D model.

4.4.1 Design for visualizing verbal information

"We have to explain a lot. We have to explain it multiple times because they can't remember."

In the research, it has been brought up several times that the patients have difficulty in understanding the medical knowledge as well as remembering them. That is not an occasional issue in outpatient service, research demonstrates that forty to eighty percent of medical information provided by healthcare professionals is forgotten immediately [37], and more than half of the information is remembered incorrectly [1]. The comprehension and ability to recall the medical knowledge is actually close related, shown in Ley's model on the interactions between patient-related factors and therapy adherence(Figure 23). From the graph we can infer that the degree of understanding of the information affects the patient's memory ability, together ultimately influence their adherence.

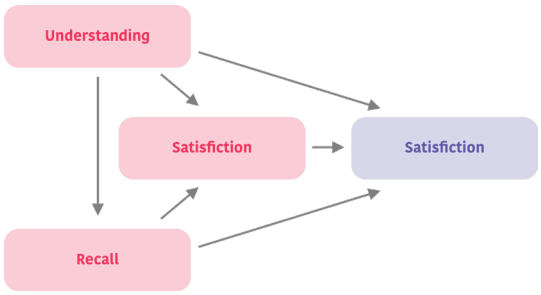


Figure 23: Ley's model on the interactions between patient-related factors and therapy adherence

Three important factors have been shown to affect the patient's memory ability, First is the medical terminology which is more related to the clinician's wording. Second, which is the related to the educational level of the patient, which cannot be changed by the design. And, third, the mode of the information (e.g. spoken, written versus visualization) [30]. It turns out that the combination of spoken and visual information is much more successful that simple verbal information in given medical advice [26, 58]

In our case of meeting orthopedic consultant, most important information comes along in the patient education part, where consultant explain the surgery preparation and final to-do's check.

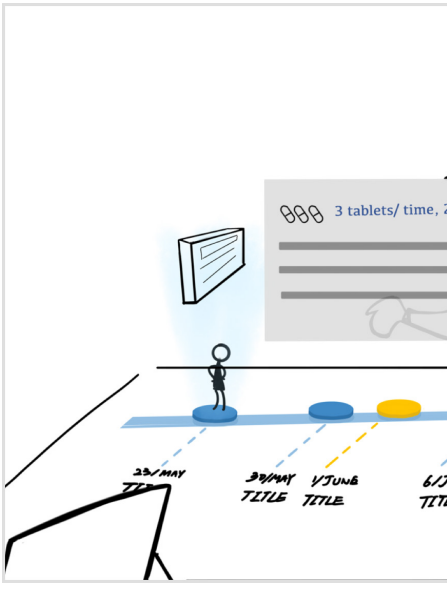


Figure 24: Visualization prep

1. *Visualization preparation process*

The preparation process can be visualized in 3D process model, the information of a specific phase will be neatly presented through pressing one of the highlight points on the process model in the VE(Figure 24).

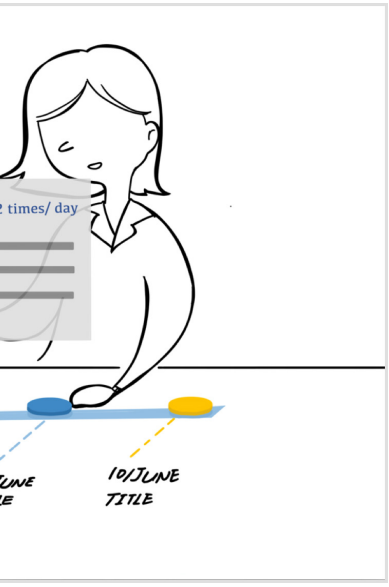
2. *Visualization to do list*

In the last phase of patient education, all the most important issue will be re-emphasis one again. To help patient better-remembering this information, all the to do's will be presented in a 2D list view interface. The patient will need cross out all the items one by one to confirm they have remembered(Figure 25).

4.4.2 Design for immersive experience

In the hospital Reinier de Graaf, the orthopedic consultant will briefly explain the procedure of the operation during the patient education consultation. In addition to the form of oral presentation used in the investigated hospital, other forms are also used in many other hospitals, for example using videotapes to explain the surgical environment and procedures [27].

In the VR environment, taking the advantages of the virtual properties, the operating room and the proximate surgical process can be largely restored through modeling, and a virtual doctor with vivid motions can be added to simulate the operation(Figure21).



paration process

Figure 25: Visualization to do list

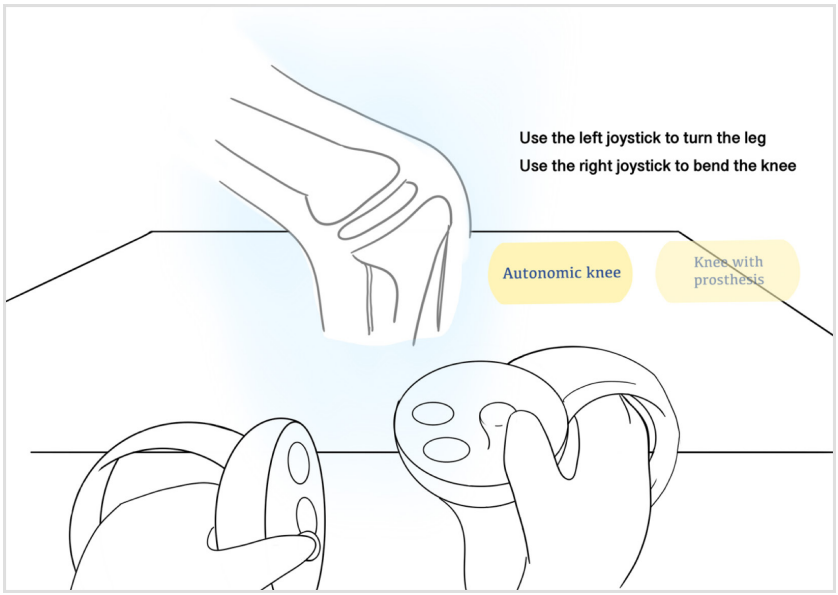


Figure 26: 3D interactive prosthesis model

`Research shows the immersive experience provided by virtual reality can enhance knowledge and information transformation through simulation of the real world and encourage the participation of the players [10]. Therefore, by entering the operating room in person before the surgery can improve the patient's understanding of the surgical procedure, but also promote the patient's active involvement in the consultation process [5]

In the designing of the virtual clinic, a virtual model of the real operating room is added to the scene(Figure 27); the patient can follow the nurse go around the operating room. The nurse can introduce the surgical procedure and other issues in this simulated environment.

4.4.3 Design to provide abundant information through flexible 3D model

"can you hold it and let me take a picture?"

When explaining how the knee prosthesis will be installed on the knee, a real prosthesis is used to elaborate on the process. The knee prosthesis consists of three

Figure 27: 3D operation room

separate parts, including femur component, tibia component, and artificial cartilage.

During the surgery, the doctor cuts the front of the knee, then the joint capsule is opened, the doctor will shape the end of the femur in preparation for the sizing of the femoral component.In the same way, the top of the tibia will be shaped for the proper sizing of the tibial component, next the trial unites are put in place, then the skin is closed and connected.

However, this abstract installation process cannot be fully demonstrated by these separated prosthesis components(Figure 26). Therefore, in the face-to-face consultation, the nurse will hold the three parts together to show patients the process of installation. Due to the flexibility of VR manipulation, in the virtual clinic have both the artificial joint and the anatomical knee

4.5 Specifications

The design specification is a summary of the design requirements above to guarantee a convenient consultation experience which maximally approach face to face consultation

1. **The design should enable multiple users to come together and interact in the virtual environment through the means of audio and virtual cues.**

2. **The system should greet the patients while launching the app.**

3. **The design should involve editable calendar to show patient's reservation date/time.**

4. The design should provide artificial knee model which patient can hold in hand virtually.

5. The prosthesis model should be flexibly shows the artificial joint model and how it is install on the knee.

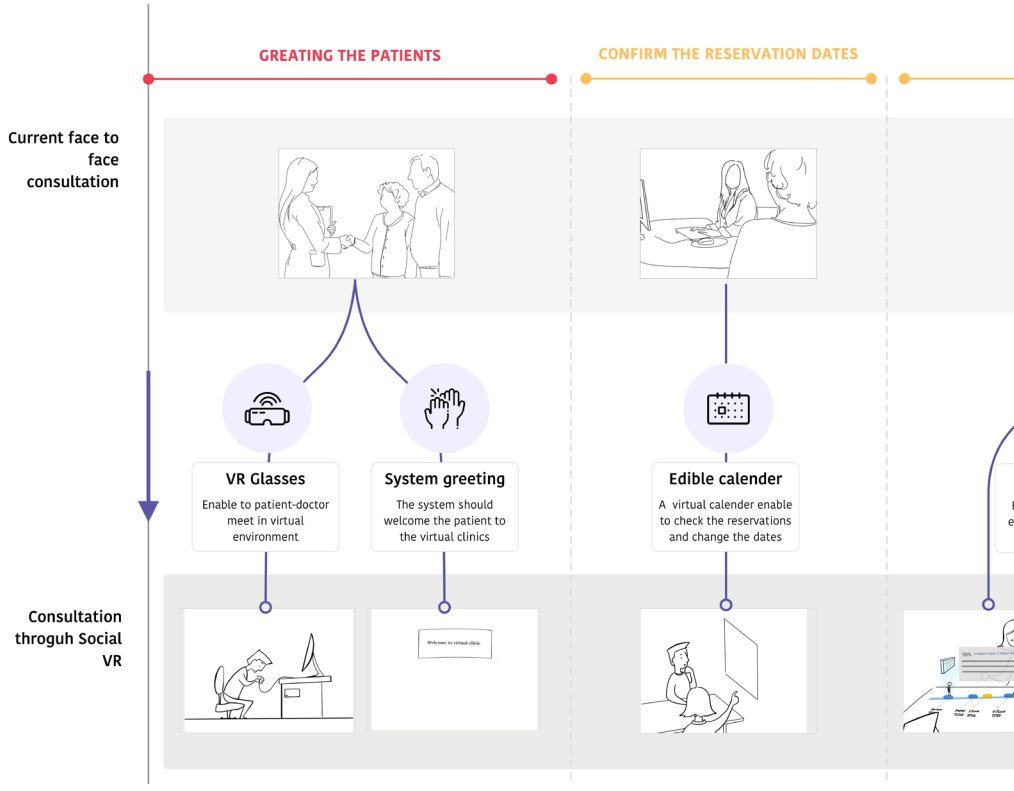
6. The design should embed interactive visualized preparation timeline to show patients the key points for preparing the surgery along the process.

7. The design should be able to demonstrate an simulated the operation room where the patient can walk inside to help the patient familiar with the surgery setting.

8. The design should provide relaxant environments for the communication to release the anxiety of the patients.

4.6 Scenarios

The scenario, created based on the design specifications, describes patient experiences in the virtual clinic(Figure 28).



Today is Tuesday, 17 of Jun, 6 weeks before the total knee replacement surgery. As been organized by the pre-operative office, Dan will meet his orthopedic consultant Laura for the first time. Dan put on the HMD and enter the Virtual clinic app. The system greets Dan and asks him to input his name and ID number **(2. The system should greet the patients while launching the app).**

After completed, Dan enters the virtual clinics, Laura is already in the room waiting for him. **(1. The design should enable multiple users to come together and interact in the virtual environment through the means of audio and virtual cues).**

The conversation starts by confirming the information. Laura presses the first button, a calendar appears. On the calendar, the date for next time consultation, and surgery are highlighted. By clicking another date on the calendar, the date for the appointment can be changed. **(3. The design should involve editable calendar to show patient's reservation date/time)** A 3D surgery preparation timeline appears, floating on the table after confirming the time of the appointments. This model demonstrates the preparation process Dan will go through, with all the important dates highlighted. **(6. The design should em-bed interactive visualized process model to show patients key points for preparing the surgery along the process).**

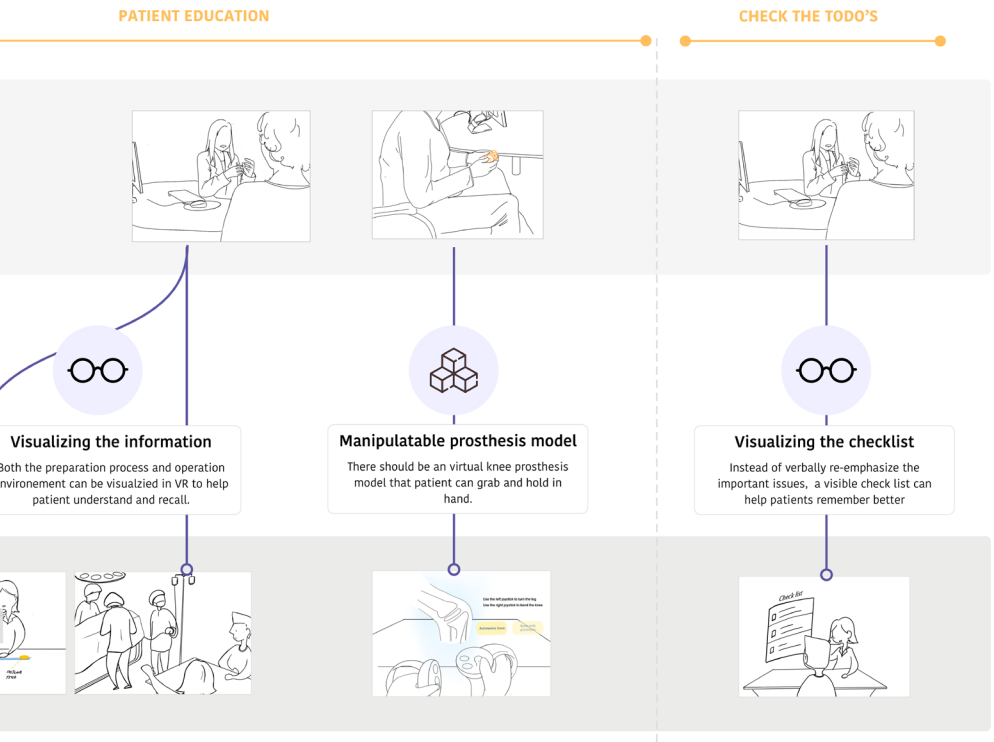


Figure 28: Scenario

Laura presses the highlight point; the important thing Dan needs to prepare or needs to pay attention to will appears on the top of the process.

While talking about the admission date. Laura asks Dan if he wants to see the operation room, Dan agrees. Then next to the office the operation room gradually appears where Dan sees the operating table, patients and all the medical professionals. Laura walked Dan around the operation room ,explains that functions of the medical professionals, then guides him back to the office. **(7. The design should be able to demonstrate an simulated the operation room where the patient can walk inside to help the patient familiar with the surgery setting)**.

While talking about the surgery, there is a model of artificial joint floated on the table, Laura talks about the three different parts of the prosthesis. Then a anatomical knee with prosthesis installed appears in front of Dan**(5. The prosthesis model should be flexibly shows the artificial joint model and how it is install on the knee).** Dan can drag it near him, he can turn the model, bend the straight the knee with joystick.**(4. The design should provide artificial knee model which patient can hold in hand virtually).**

In the last phase, Laura checks if Dan understands and remembers all the important thing by showing a checklist. Each list item with a title of important issue need attention. Dan confirms that he remembered the information by pressing "OK**(8. The design should provide checklists the important to-do's after the consultation).**

After all the items are confirmed, Laura asked again if he has any question. Dan said everything is clear for him. Laura reminds Dan that he can call her during the working hours if he has questions. After thanks Laura for here patient explanation, Dan exit the virtual room and take off the VR glasses.

4.7 Reflection on design

The design of the virtual clinic aiming to promote communication efficiency while reducing the pain of visiting the hospital for those knee arthritis patient. Specifically, the design intended to improve patients' comprehension and recall for the medical information, facilitate patients' active communication, and release the nervousness before the surgery. Corresponding to the problems list, the problems that are to be solved in the design are highlighted in blue.

In the previous chapter, the related fields of virtual clinic design for knee replacement treatment have been discussed. However, it is still essential to learn the patient's treatment process, the patient's condition, and the content of each main conversation with the medical staff in the real context, to maximally approach the face-to-face consultation in VR.

To get and overview of the treatment process and learn about the specific content that is communicated along the treatment process until the surgery. An ethnographic research was conducted in one local hospital in Delft, the Netherlands. The ethnographic research is a qualitative method where researchers observe and interact with a study's participants in their real-life environment[2]. It provides insightful data and allows the researcher to get an insider view of reality [60].

The following sections present the methods and results of the study, including an introduction of the hospital, the background of the medical professionals involved, the procedure of the study, the data collection, analysis, and results. In the end, a list of design requirements are defined based on the study results.

C H A P T E R F I V E

IMPLEMENTATIO

ON

5.1 Scope of Implementation

Due to the limited time of the project, only the patient education part of in the consultation (which is the part between confirming the operation time and re-confirming the key takeaways) will be realized and tested in this project.

The selected part(Figure 29) is essential in this consultation containing concentrated medical information exchange. The demonstration of the patient education part has to meet the design requirements of articles 1, 4, 5, 6, and 7.

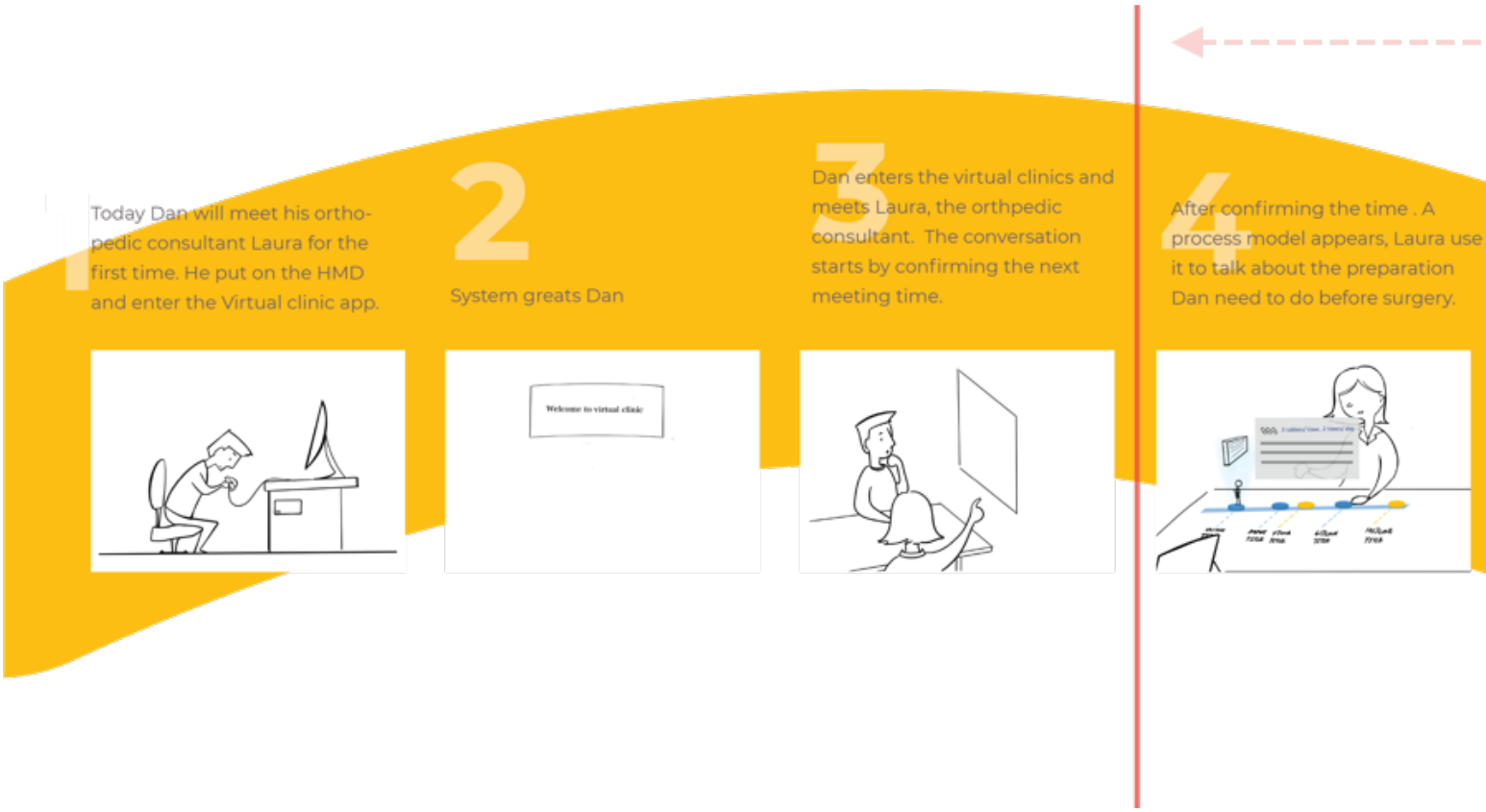
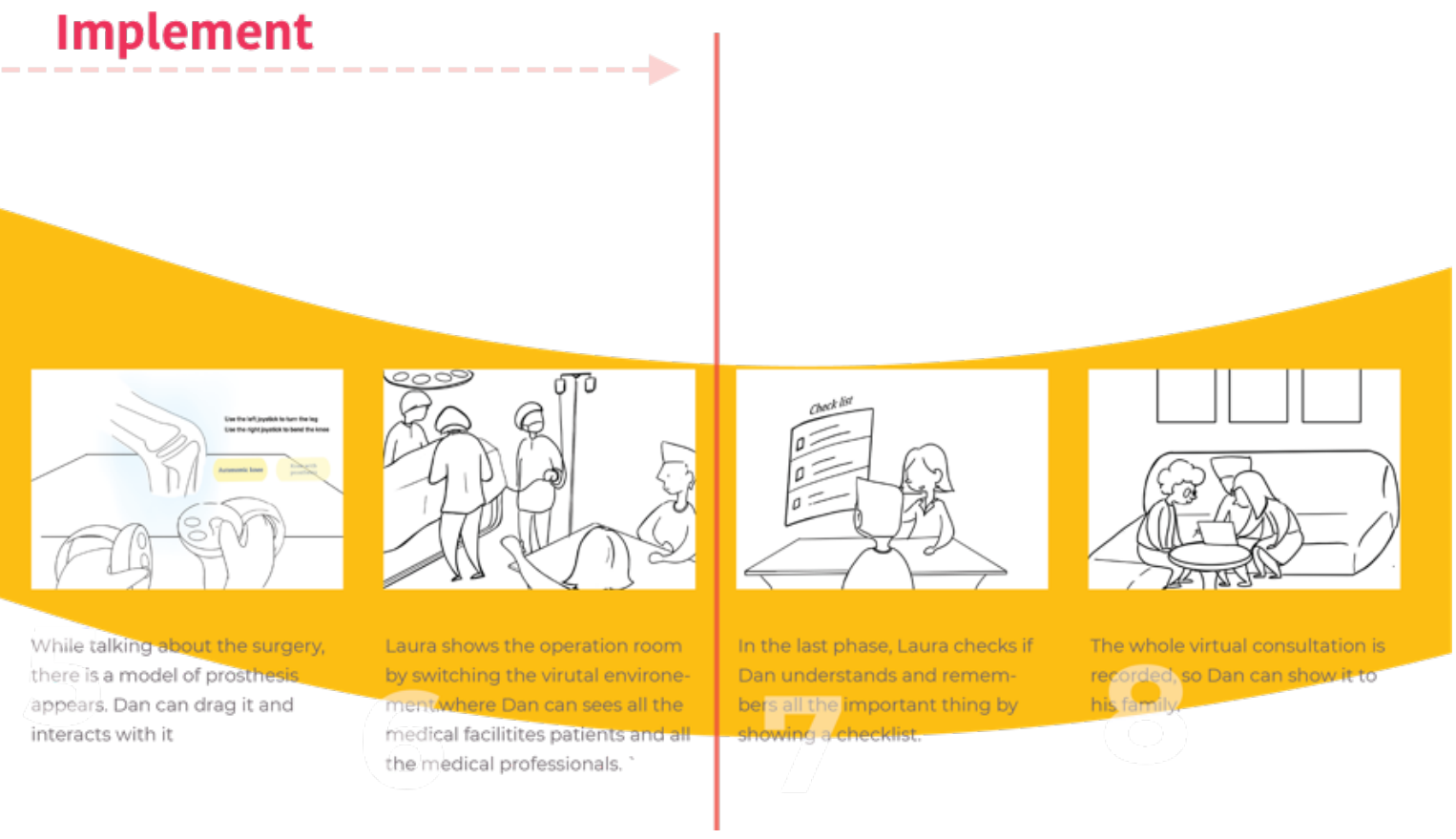


Figure 29:

5.2 Software and hardware

The social vr clinic prototype is developed in Unity3D. It is a preferred development tool for the majority of XR creators, compatible with most leading VR devices, with built-in support for numerous platform-specific features. Oculus Integration for Unity is also applied. It is package with some useful pre-built functions, including interfaces for controlling VR camera behavior, first-person control prefab, unified input API (Application Programming Interface) for controllers, debugging tools, and so on.



Implementation scope

5.3 Virtual Objects

The virtual objects involved in the clinic scenario are a virtual timeline, an walk-in surgery room, and the 3D knee and prosthesis models

5.3.1 The virtual timeline

The virtual timeline is designed to demonstrate the important dates, types of medications and usages, and the duration of each medication(Figure 30). The virtual timeline has mainly two elements:

1. *Time line.*

The timeline is marked with nodes to highlight the important messages, such as important dates, name of the medicines and so on.

2. *Floating panel.*

The floating panel gives details about the medicines, duration of the usages, precautions and side effects.

When the nurse is explaining the surgery preparation process, the corresponding node on the virtual timeline will flash, indicating the position of current content in the preparation process. The floating panel above the flashing node displaying the name of the medicines and their usages.

To well display the information, the timeline is tiled in the x-y plane, while the floating panel is oriented perpendicular to the x-y plane toward the patient. The virtual timeline does not involve interactions with patients and nurses in this prototype. Instead, the researcher will control the switching of nodes at the backstage.

5.3.2 Surgery room

To ensure that the patient concentrates on what is being explained during the conversation, the surgery room only appears when the nurse is explaining the surgery process(Figure 31). The virtual surgery room appears next to the virtual clinic office. The patient can use the Oculus controller to "walk" into the surgery room following the nurse. The virtual surgery room has the same equipment, the same number of medical staff, and the same lighting as the real one. However, for this prototype, due to modeling limitations, the researchers chose a relatively realistic surgery room, but is not exactly the same as the real one. The patient and the nurse can "walk" in the virtual surgery room, but they cannot move or interact with the medical staff or facilities there.

Figure 30: Developed virtual process model

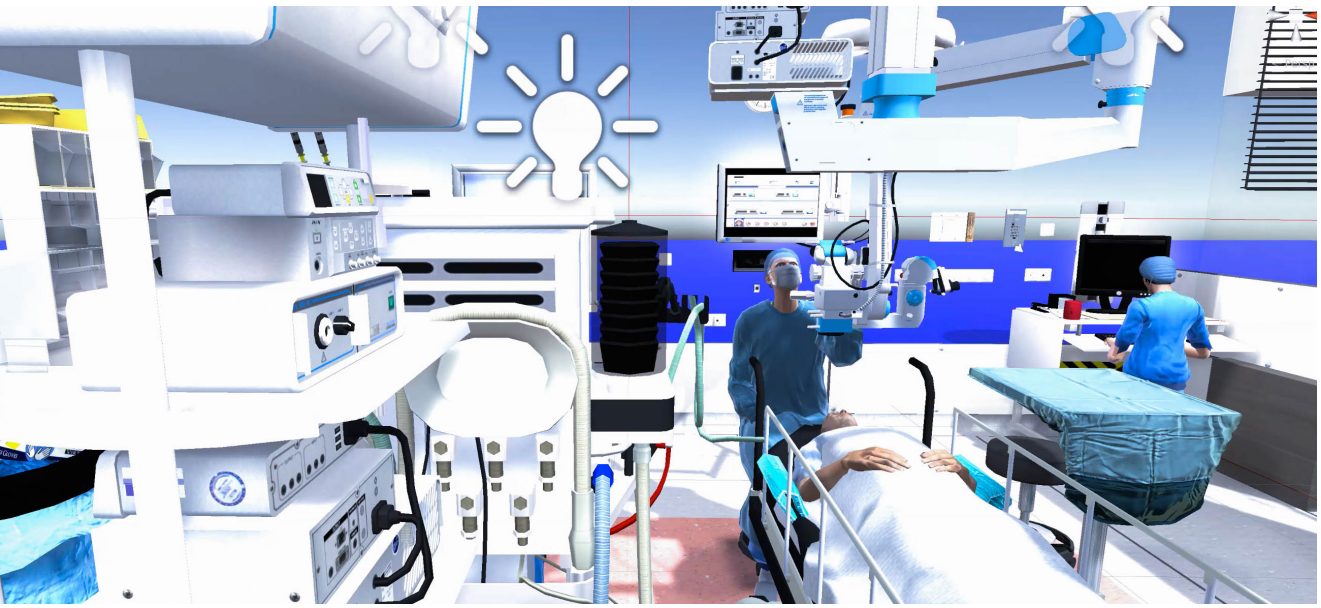


Figure 31: Developed virtual operation room

5.3.3 3D Knee and Prosthesis Models

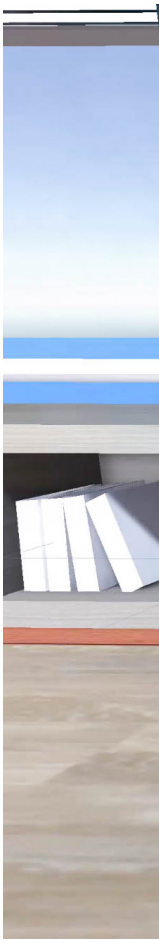
When describing the prosthesis installation process, the same as the face-to-face consultation, the nurse first shows the patient the artificial knee prosthesis model: how the three separate parts are combined and installed on the knee(Figure 33). The patient can play an animation of the prosthesis model in social VR clinic, to see how the joint is separated and come together again. This animation aims to assist the patient in understanding the structure of the knee prosthesis.

The anatomical knee model will appear after the prosthesis. By clicking the virtual button right next to the model, the patient can switch between the knee model and the knee model with an installed artificial joint.

1. *Virtual button interaction.*
The patient switches the knee model and the knee model with the prosthesis by clicking the virtual button.

2. *Physical interaction.*
The patient or doctor can grab the knee model and have a detailed observation.

3. *Animation control.*
The patient can bend and straighten the knee through the controller.



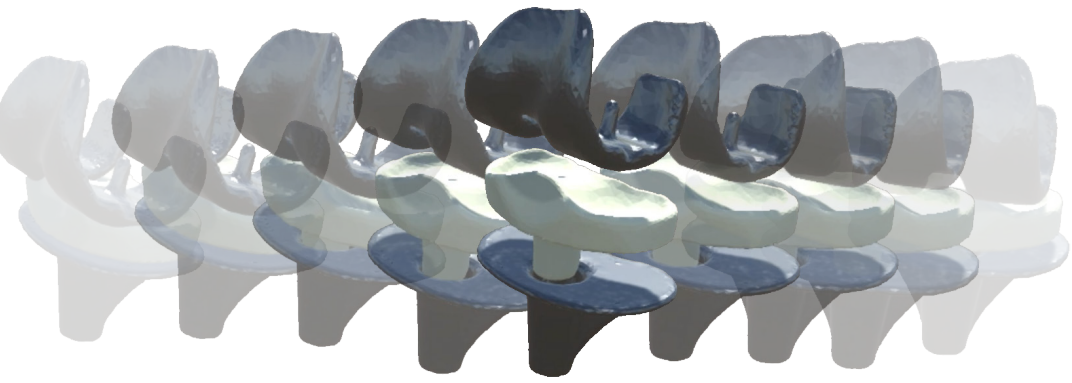


Figure 33: Developed knee model with the prosthesis installed


6

To answer the research questions, a comparison experiment was conducted in both face to face and designed virtual clinic consultation. In the experiment, the participants took the role of patients, experienced the patient-education consultation in two different conditions: through face to face and Social VR consultation. The researchers acted the nurse, gave each participant the same medical information in both conditions as the actual consultation.

C H A P T E R S I X

EXPERIMENT

The goal of the experiment is to understand how the designed virtual clinic using social VR can closely approximate the current face to face clinical surrounding patient education consultationfor total knee replacement surgery. Specifically, the experiment aiming to answer three mainresearch questions three main research questions:

RQ1: Is the consultation experience in VR clinic comparable to the experience in real life face-to-face(F2F) consultation?

RQ2: Compared to the F2F consultation, what aspects are missing in the VR clinic?

RQ3: Compared to the F2F consultation, what are the added values of the VR clinic?

To answer the research questions, a comparison experiment was conducted in both face to face and designed virtual clinic consultation. In the experiment, the participants took the role of patients, experienced the patient-education consultation in two different conditions: through face to face and Social VR consultation. The researchers acted the nurse, gave each participant the same medical information in both conditions as the actual consultation.

They answered the information acquisition questionnaire and the patient education experience questionnaire after experiencing each condition. At the end of the test, each participant was given an interview session and memory ability test.

6.1 Method

A within-subject experiment is designed with two test conditions: face-to-face consultation and social VR clinic. To counterbalance, half of the participants started with the face-to-face condition, the other half started with the social VR condition.

6.1.1 Participants

All the participants were students from different majors at TU Delft, recruited through the University's internal Facebook group. While screening, the gender was balanced. Participants were all between the ages of 20 and 30, with four participants of twenty-three and twenty-five-year-old respectively and two in their twenty-fourth and twenty-seven respectively. Two of the participants reflected that they have never used a VR device before, three of them have used cardboard, and others have minimal experience in using Oculus. None of the participants has proficient expertise in interacting with advanced VR devices. Each participant was rewarded of 10 euro voucher after the experiment.

6.1.2 Apparatus

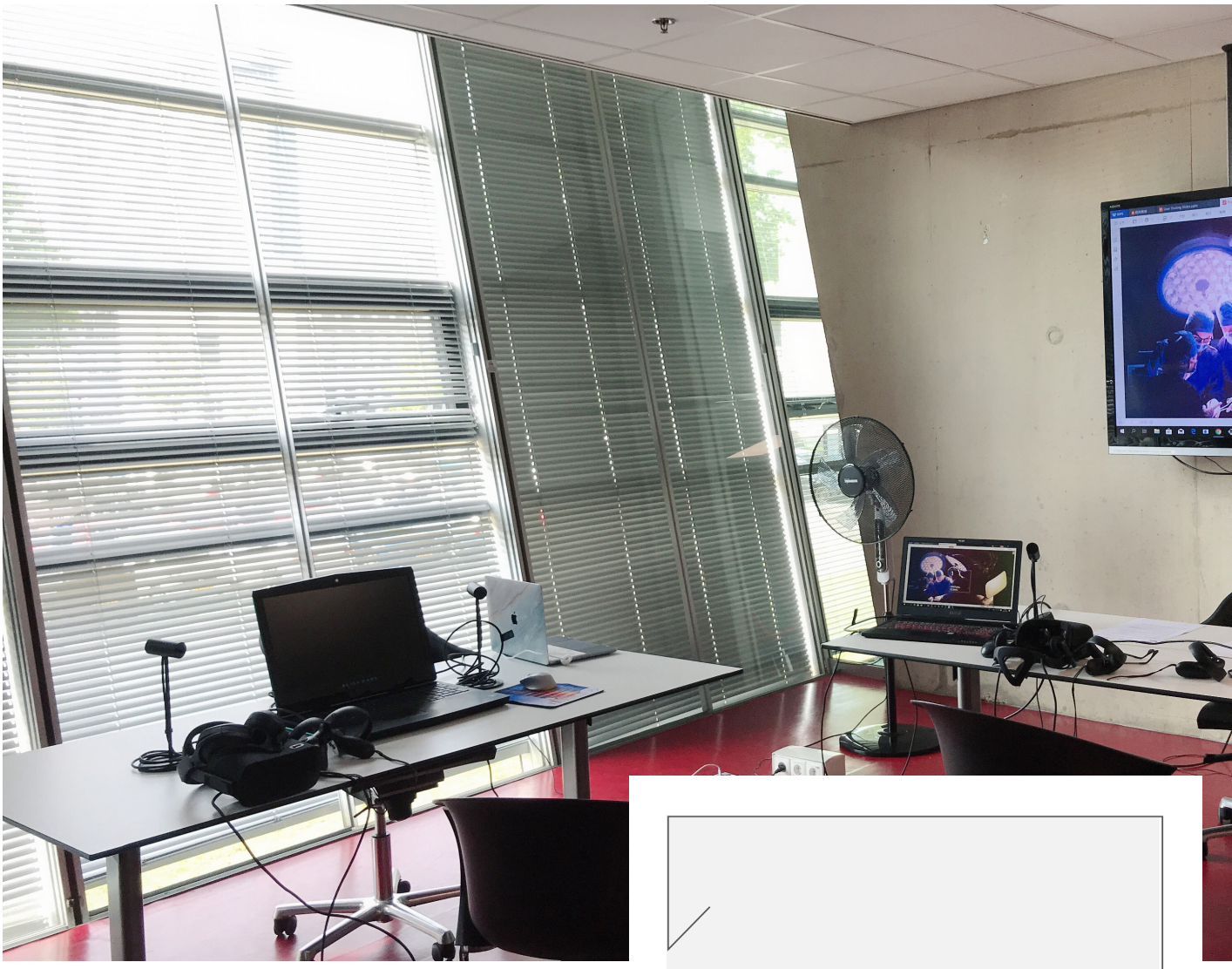
1. Equipment and materials

The equipment and materials included two window work-station equipped with an i7 CPU, two oculus rift devices, a 70-inch Sharp screen for displaying video to participants, and a knee prosthesis model. Both workstations were installed with the same version of Oculus software. The experimental app of the virtual clinic is set in the system in advance. Both Oculus Rifts were set up again at the testing location with the default height of the player set to 1.67m. Both VR equipment uses Oculus Touch as the controller. The controllers were installed with fully charger battery before the test.

The knee prosthesis is 3D printed using the digital model of real knee prosthesis(Figure 34). The femoral and tibial component is painted silver using the metallic spry, to mimic the artificial knee used in the actual consultation maximally.

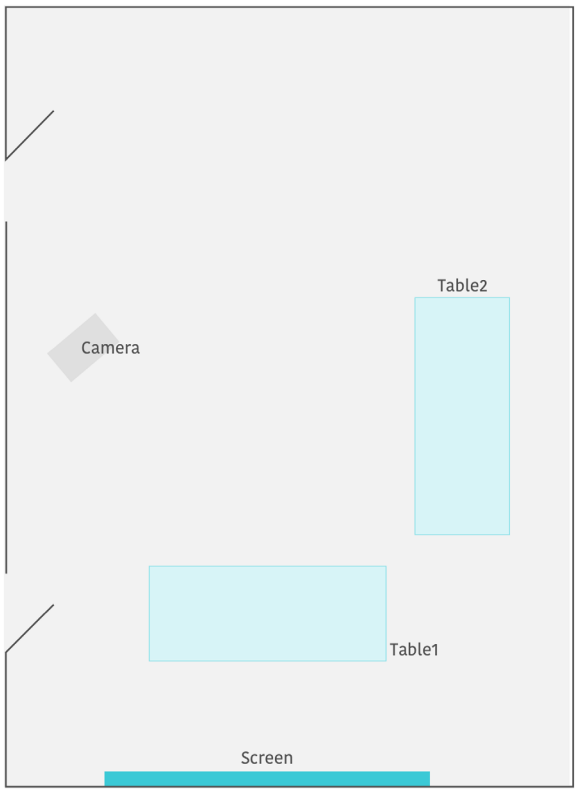
Figure 34: 3D printed artificial knee joint

Figure 35: A sketch of the participants



Environment setup

The experiment was conducted at a 5.3mX7m conference room in the TU Delft University Library, and the room layout was as follows(Figure 37). The two tables face the two adjacent sides of the room, one of which placed against the screen. The position where the camera is placed can cover the whole setting: two tables, researchers, participants, and the TV screens, all in one



scene.

In the face-to-face condition, the location of the researchers and participants is as follows. They sit on either side of table 1 near the screen and the participants back to the screen. The computer which has its desk-top projected on the screen has pre-loaded video of the operation room ready to play.

In the virtual clinic scenario, the researcher and the participant sat on two separated tables with back towards each other, and the sensors of the VR device is placed facing the player.

Figure 36: Experiment set up

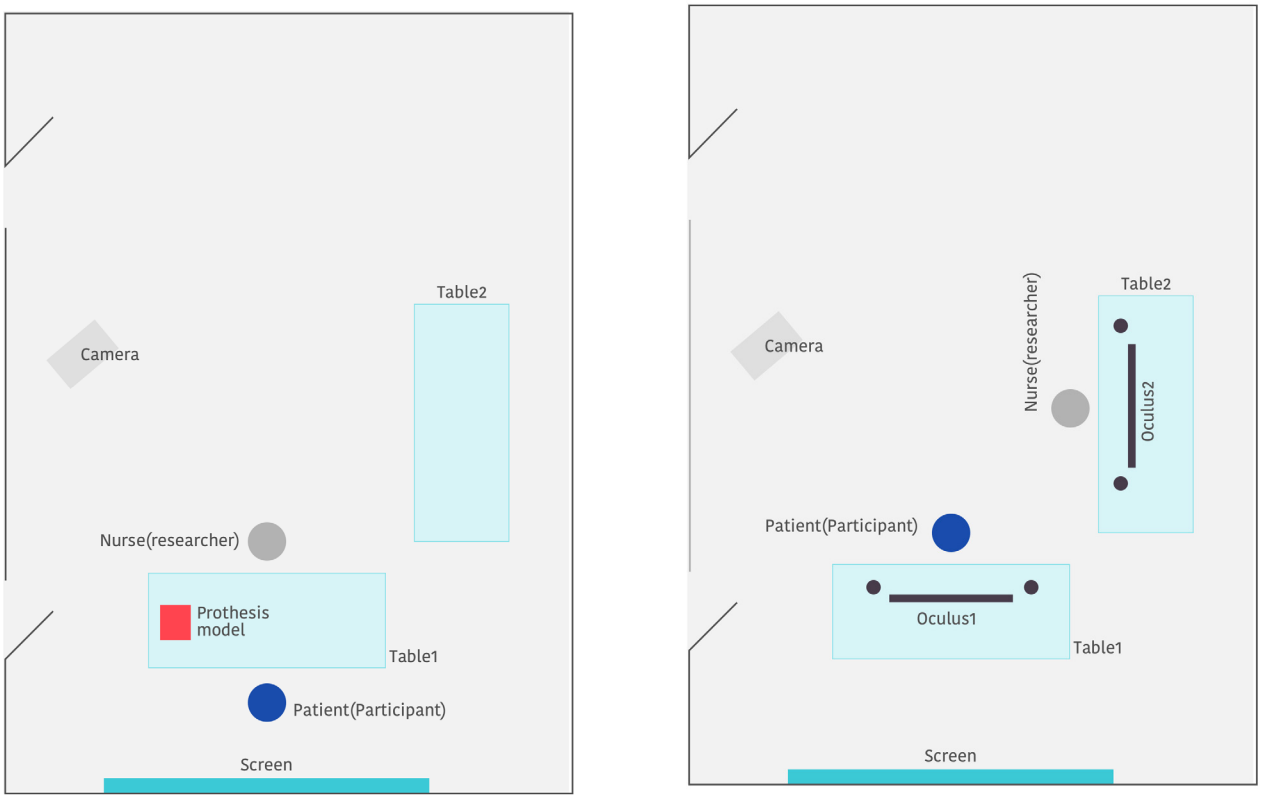


Figure 37: Set-up for three conditions: On the left is the original setting of the room, the middle one shows how participant and researcher sit in the face - to - face condition. The right one illustrates the environment of Social VR condition.

6.1.3 Questionnaires

The research questions are answered by the results of the quantitative questionnaires and qualitative interview. There are three questionnaires used in the test:

1. *Social VR questionnaire*

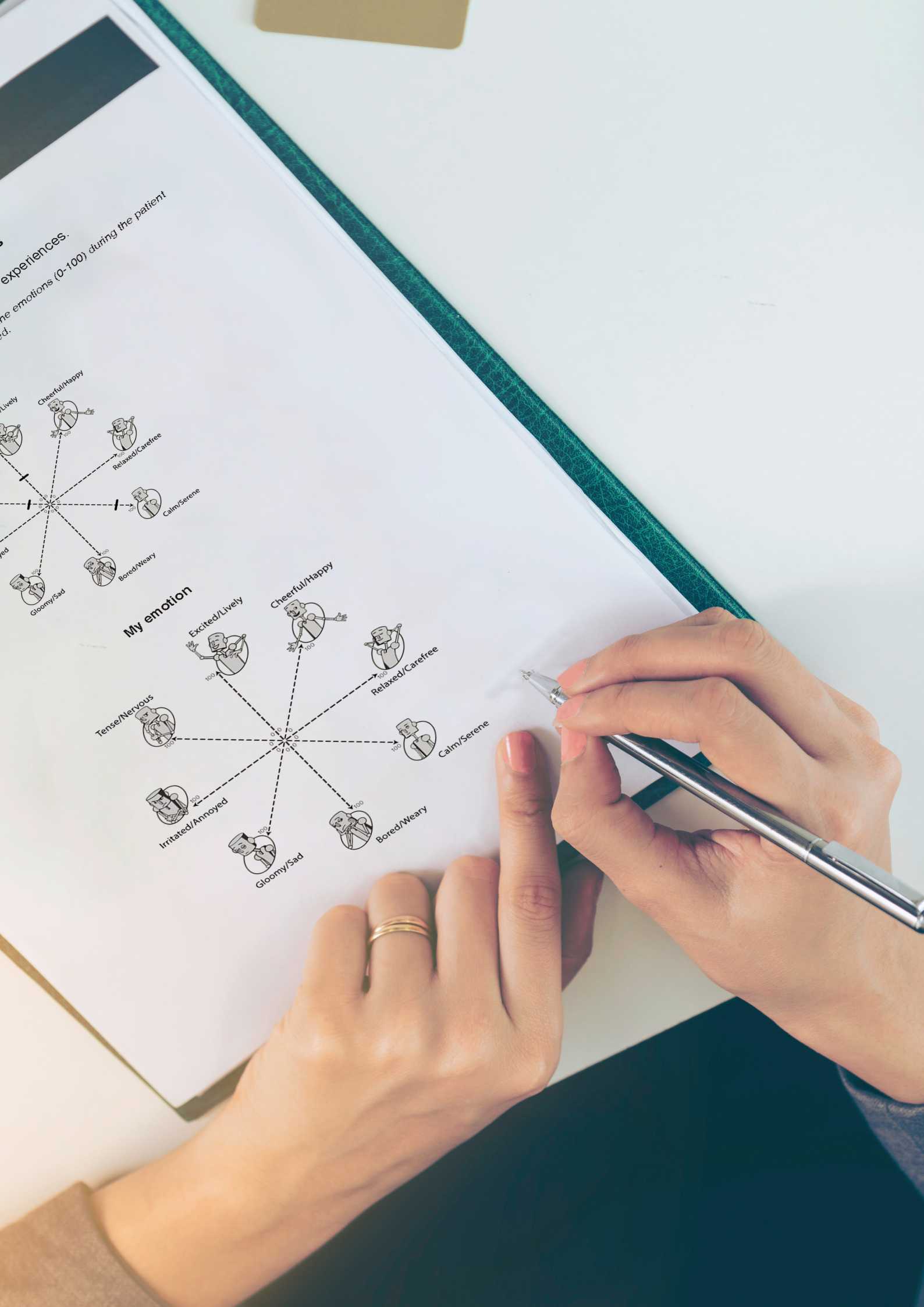
Social VR questionnaire which was mainly derived from the social VR questionnaire [31]. The query aiming to understand the difference between face to face and VR consultation in terms of the patient experience, it needs to be filled after each condition.

2. *The information acquisition questionnaire*

The information acquisition questionnaire is designed to investigate if the same information is conveyed in both conditions and if the hardness of remembering the medical information is the same in both cases. Therefore, in this questionnaire, we extracted some information from the consultation and formed them into question, we asked the patient whether they remembered this information, and the specific content of this information. Considering the sequence of the tested conditions will affect the result of this test, we balanced the test sequence for both cases. This questionnaire also need to be answered after each condition.

3. *The Prospective and Retrospective Memory Questionnaire (PRMQ)*

To ensure the preciseness of the information acquisition questionnaire. It is also essential to make sure that the participants have general memory capability. Therefore, at the end of the experiment, the participant would complete a memory capability questionnaire, namely The Prospective and Retrospective Memory Questionnaire (PRMQ) [9].


experiences.
ne emotions (0-100) during the patient
d.
Cheerful/Happy
Relaxed/Carefree
Calm/Serene
Bored/Weary
Gloomy/Sad
My emotion
Excited/Lively
Cheerful/Happy
Relaxed/Carefree
Tense/Nervous
Calm/Serene
Irritated/Annoyed
Bored/Weary
Gloomy/Sad

6.1.4 Procedures

Before the experiment, all the questionnaires and consent forms were printed, the participants were reminded with the time and location of the experiment one day before it took place. There were three parts in each experiment, namely: Introduction, testing and interview.

1. *Introduction*

The facilitator introduced the background of the project, the goals, and procedure of the experiment to the participant (Figure 38). After the participant understood the content of the project, he (she) was be asked to sign the experiment consent form. Then the camera and recording device were turned on.

The facilitator would asked about his(her) VR experience and their knowledge about knee arthritis. Then the context of the experiment was introduced:

"You (participant) are a patient with severe knee osteoarthritis. You decided to take the total knee replacement surgery to get rid of the pain completely. The operation will take place six weeks from now. For this consultation, you will meet the orthopedic consultant, she will tell you about the pre-operative preparation process and the surgery procedure."

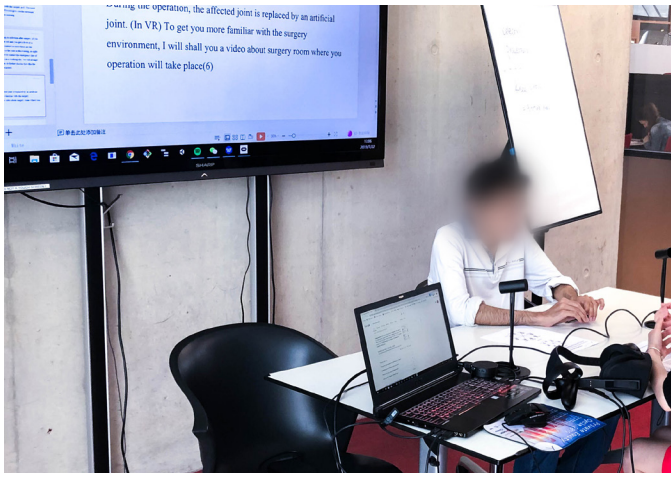


Figure 38: Experiment introduction

Figure 39: Experiment face to face condi

2. *Testing*

The two tests conditions were counter balanced. The experiment started with either the face-to-face condition or the social VR condition.

- Face-to-face condition:

In the face-to-face condition,

the facilitator acted the nurse, the conversation started from confirmed the next meeting time and operation time with the patient(Figure 39).

“So next time we meet will be on 26th of August, on that day the room doctor will perform the last research, he will investigate your skin on possible wounds, we cannot operate on the wounded leg. If you have an infectious disease, we will not be able to undergo surgery until it is completely cured. It is crucial that you keep watch of this. In case one of the mentioned does happen, go to your GP and ask for a cure so that the operation can occur.”

The nurse then began explaining the preparation process, the medicine he(she) needed to take along the time line, that included the painkillers, the anti-inflammatory drugs, the stomach protector, the antibacterial, and more.

"As a standard, you will get Celecoxib for two weeks; it is a pain killer and an anti-inflammatory drug. This medicine can prevent grouping of calcium in the joint, but it has a side effect on your stomach, so you will also get a stomach protector with it. If you stop with Celecoxib, then you should stop using the stomach protector, too. It is also important to take 500 milligram paracetamol four times a day. . . "

After that, the facilitator would talk about the preparation for the home facilities and personal health before the operation, for instance, raising the toilet and bed, starting to practice walking with crutches.

"After the operation, getting up from a chair, bed, or toilet can be diffcult. You are recommended to get a toilet seat so that you raise the low toilet, make sure the seat is secure. You can raise your bed by placing an extra mattress on it — all those things you can buy them at home care store. Try to keep yourself as fit as possible. . . "

After the preparation instruction, the facilitator showed the environment and process of the operation through the video. The participant turned to the screen, and then the movie was played. While watching the video, the patient was briefed on the different functions of the medical professionals in the surgery room.

After the video, the facilitator took out the 3D printed artificial knee joint, explained the material of its different components and its installation process.

tion

“This is the artificial knee that will be installed on your knee. During the

surgery, the doctor cuts the front of the knee. Then the joint capsule is opened, the doctor will shape the end of femur in preparation for the sizing of femoral component. In the same way the top of the tibia will be shaped for proper sizing the tibial component, next, the trial units are put in place. Then the skin is closed and connected . . . ”

Throughout the conversation, the nurse continuously asked the patient if they understood, if they had any question.

After face to face session, the participants filled in the questionnaire about the information acquisition and the questionnaire for consultation experience.

- Training session

Before the social VR session start, there was training session teaching the participant how to interact in the VE through Oculus touch (Figure 40). There were mainly three interactions used in the virtual clinic:

Move in the scene: There are two ways to move in the VE, physically move in the scene or using the touch controller. Physically moving will be sensed by the sensors and synchronized in the virtual environment. Similarly, move the left joystick can also move the virtual character.

Figure 40: Training session

Grab the virtual object: The grabbing function enable the player to grab an object and get it closer to the player. By pressing down index and hand trigger, meanwhile having the thumb touching the joystick, a virtual object can be grabbedand bring closer to the player. By releasing the triggers, the player can drop the object in his hand.

Click a virtual button: Clicking function is pre-defined in the Oculus setting. When a button is clickable in the VR, the pointer will appear on the right touch, hold the pointer towards the button then press A, the button is clicked.

This interaction will be practiced through the training app, in which the participant

Figure 40: Experiment Social VR condition

stand in the front of a pile of grabbable cubes. Next to the cube is the testing UI, with a clickable on it.

- Social VR condition

After the participant was familiar with the VR interactions, he (She) would enter the virtual clinic. The facilitator also joined the environment, faced the participant at the other side of the table in the room.

The content of the consultation was exactly the same as the face to face condition. However, in VR, the designed virtual objects were added to facilitate the conver--sation: The preparation process model appeared on the table while explaining how to prepare for the surgery. When talking about the surgery process, the facilitator would guide the patient around the virtual operation room, then leaded him(her) back to the office. An artificial joint model would float above the table, showing its structure through the animation of splitting then combining the three prosthesis components. The prosthesis then changed to an anatomical knee model, which the participant could grab and hold it near to him(her). By clicking the UI buttons next to the model, the anatomical knee could switch to the knee with the prosthesis installed.

3. Interview

After the experiment in VR, the participant filled in the same questionnaires as the face to face condition. After experience the two conditions, the participant was invited to talk about the strength and weakness of having medical consultation in the

virtual clinic, in terms of three aspect: the preparation process, surgery environment and the artificial joint model.

At the end of the experiment, there was a last questionnaire needed to be completed to investigate on the memory capability of the participant.

Figure 40: While testing the social VR condition: on the left was the nurse (researcher) explaining the process. On the right was the patient (particioants) listening to the nurse.

6.2 Data collection

The experimental data was collected mainly through questionnaires and interviews. The data collected through the questionnaires include: The information that participants learned and remembered during the consultation; Their memory ability. And the overall experience in face to face meeting and social VR meeting. For a detailed explanation for the questionnaires, see chapter 6.1. The interview was conducted at the end of each experiment. Participants will explain the advantages and disadvantages of VR for the three main contents of the outpatient consultation: surgical preparation, the introduction of the surgical environment, and the introduction of the surgical procedure. And share their other views on VR consultation. The data of the interview was derived from the transcripts converted from the audios and video recordings.

6.3 Result

In this section, we will discuss the results obtained through questionnaires and interviews. The participants here were labeled as PF1-PF6 (face to face condition first) and PS1-PS6 (Social VR condition first). At the end of this section, we will further discuss the interconnection between these seven parts, as well as the three potential perspectives for creating user portrait in the context of a Social VR clinic. Before discussing the results of the experiment, in Section 6.3.1, we will first elucidate the background information about the participants in terms of their overall VR game experience and their understanding of knee arthritis.

6.3.1 Participants' understanding of VR devices and knee disease

Basically, all the participants know what is Virtual Reality and have tried VR devices before. But their experience in using VR device is very limited. Most of them have never used a VR device. Some of them reflect that they have used VR devices for once or twice, in the exhibitions(PS4), or for VR related theoretical research(PF5). Two participants have used cardboard VR glasses before for the projects(PF3, PS3, PS5). None of them has extensive experience in using interactive (non-cardboard) VR device.

All patients are more or less aware of knee arthritis. This medical term is familiar to patients. But their understanding of the disease is limited to the cause: that it is a degenerative disease commonly appears among the elderly. Some participants know that knee replacement surgery is the surgical treatment of this disease. Except for one participant(PS6) who was doing a project around knee replacement,

all the others are not familiar treatment process of the total knee replacement. One of the participants(PS6) said that he had accompanied his grandparent to visit the outpatient clinic for knee replacement surgery once. But she did not participate in the entire treatment process, all the others are not familiar treatment process of the total knee replacement.

6.3.2 Questionnaires

1. *The prospective and retrospective memory questionnaire (PRMQ)*

The result of the prospective and retrospective memory questionnaire shows that nearly all the participants have average memory ability. Only two of participants have abnormal results, which might be caused by the different metrics for frequency and the different understanding of the questionnaire. However, since all the tests were graduate students from TU Delft, who receive higher education, there should be no pathological defect in their memory capability.

2. *Information acquisition questionnaire*

Figure 41 shows the medical knowledge transmission effect in both conditions. The results are arranged in groups. The icon represents the gender of the participants, and the circles stand for the answers from the corresponding participant. If the circle filled purple, indicating that the participant received the tested information, within which the dark purple and light purple describe different levels of memory. Dark purple means that the knowledge was remembered and light purple indicates the information was heard but wasn't fully memorized. Comparing the two consultations, face-to-face and SocialVR, their purple regions are nearly equal, portending that the same medical knowledge is conveyed in both meetings. Since the tester listened to the same content twice, the condition tested later usually get higher results than the first. Only two of the subjects who first performed the VR test indicated that they missed some of the information that appeared in the questionnaire. One of the two testers scored a lower memory ability score in the PRMQ test. As a result, the two consultations have the same effect in terms of acquiring medical information.

3. *Social VR questionnaire*

A social VR questionnaire [30] was filled in by participants in both experimental conditions (F2F and Social VR), to measure three aspects of their experiences, namely Quality of Interaction (QoI), Social Meaning (SM) and Presence/Immersion (PI). According to the descriptions of Li et al. [30], the QoI assesses the quality of communication (e.g., feeling understood, having engaging conversations), mutual sensing of emotions, and naturalness between (virtually represented) users. SM

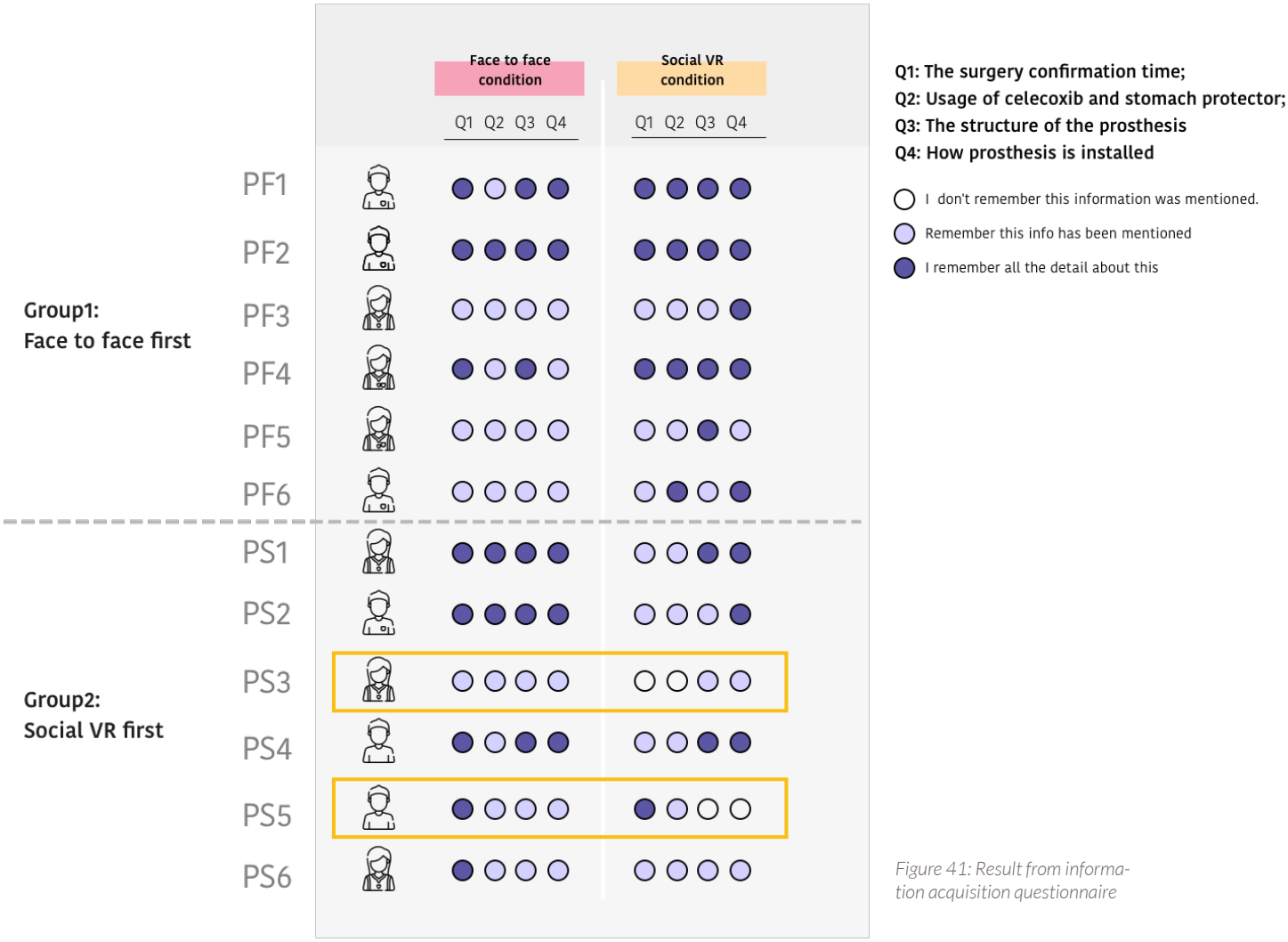


Figure 41: Result from information acquisition questionnaire

is defined as the experience of "being together", both mentally and physically. PI is described as a subjective and psychological state characterized by perceiving oneself to be involved in and interacting within a virtual environment. A complete social VR questionnaire can be found in Appendix 3.

Since the third factor PI is not relevant for F2F condition. So, we focus on the comparison of the first two factors (QoI and SM) in the two experimental conditions. As shown in Figure 42, in terms of QoI, the median of the sum of scores is slightly higher in the F2F condition (Median=4.1, IQR=11.25) than that in social VR condition (Median=36.5, IQR=5.25). However, the IQRs of the two boxplots are overlapped, which indicate no true differences in QoI in the two conditions. To confirm, a Friedman rank sum test was performed. For QoI, no significant differen-

ces were found between the two conditions ($\chi^2(1) = 0.33$, $p = 0.56$).

Similar results are obtained for the SM factor (Figure 43). The median of the sum of scores are slightly different, with F2F (Median=37.5, IQR=6.5) versus social VR (Median=38, IQR=8.75). A Friedman rank sum test showed that, for SM, there are no significant differences between the two conditions ($\chi^2(1)=1.33$, $p=0.25$).

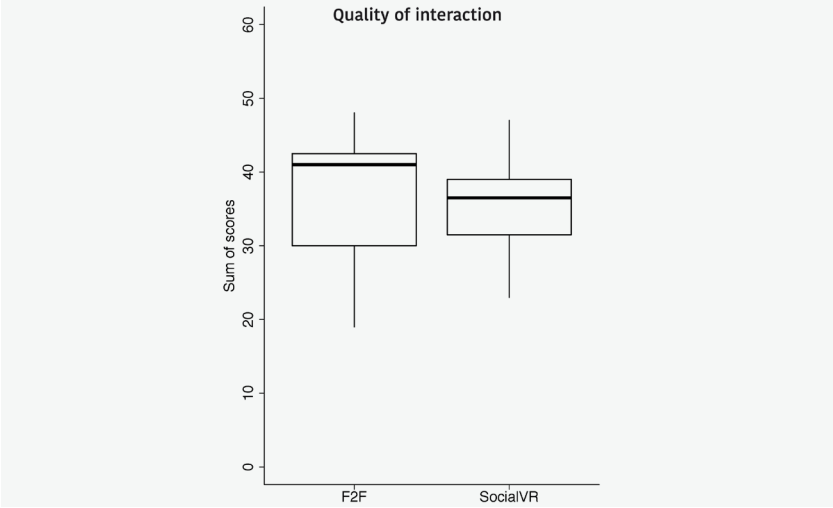


Figure 42 Boxplots: Sum of scores of QoI in the F2F and social VR conditions. The thick horizontal lines are the medians, the boxes are interquartile ranges (IQR) and the whiskers extend to lower quartile minus 1.5 × IQR to upper quartile plus 1.5 × IQR. Values outside of this range are shown individually.

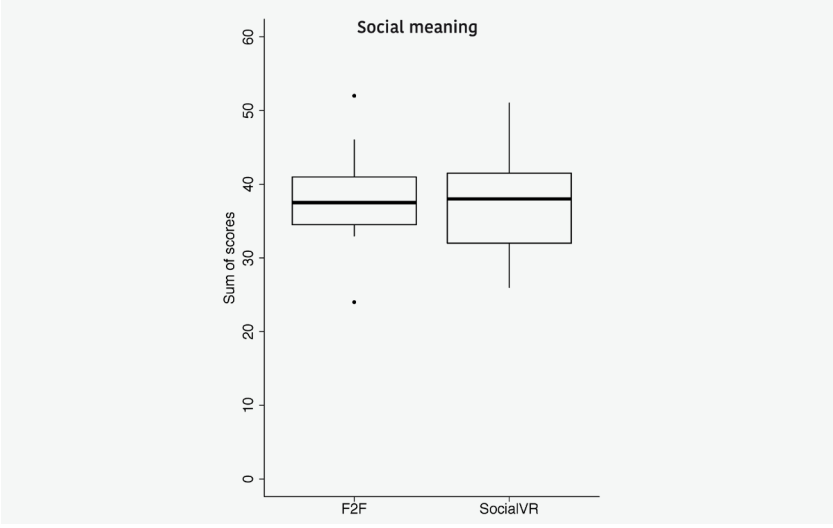
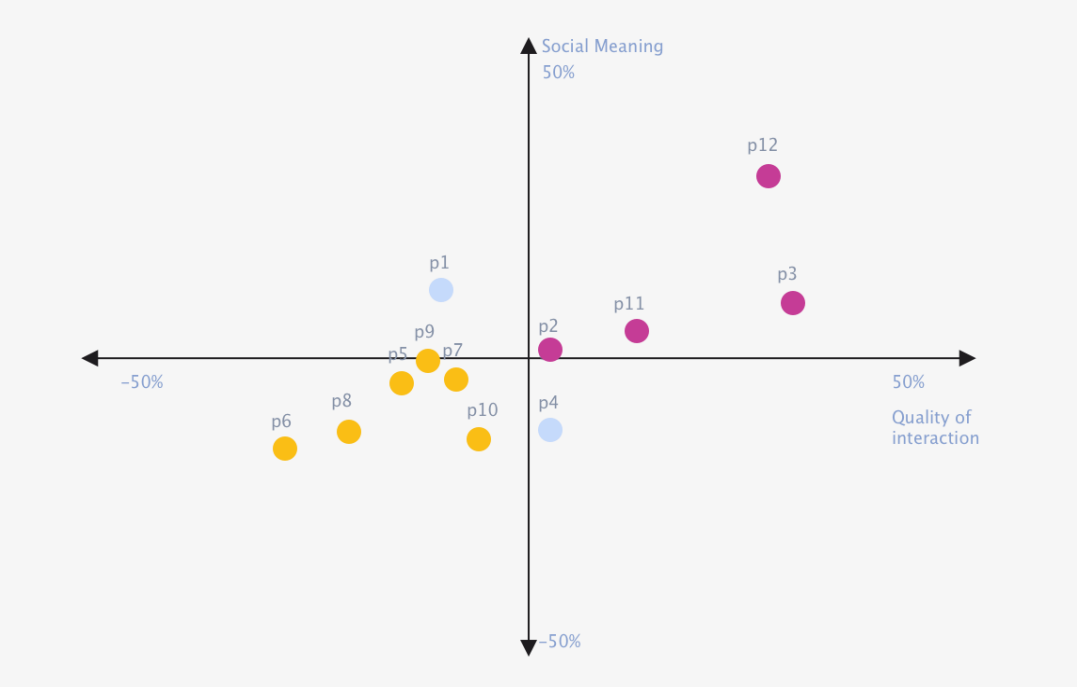


Figure 43 Boxplots: Sum of scores of SM in the F2F and social VR conditions

Figure 1 Boxplots: Sum of scores of QoI

In conclusion, no differences in QoI and SM were found comparing the F2F and social VR conditions. However, if we take a close look at individual participants, we found there is a deviation between participants. Some participants (P5, P6, P7, P8, P9, P10) showed preference towards F2F consultation, while P2, P3, P11 and P12 preferred the social VR consultation. They reported differently both in the social VR questionnaire and in the semi-structured interviews. This kind of individual preference is worth further investigating.



Prefer Social VR consultation

- Participant #2 — F2F / Social VR
- Participant #3 — F2F / Social VR
- Participant #11 — F2F / Social VR
- Participant #12 — F2F / Social VR

Prefer F2F consultation

- Participant #5 — Social VR / F2F
- Participant #9 — Social VR / F2F
- Participant #6 — Social VR / F2F
- Participant #10 — F2F / Social VR
- Participant #7 — Social VR / F2F
- Participant #8 — Social VR / F2F

Partially prefer social VR Consultation

- Participant #1 — F2F / Social VR
- Participant #4 — Social VR / F2F

Figure 44: Summary of results from the Social VR questionnaire

6.3.3 Interviews

All the evaluations from the interview are categorized by content: the preparation process introduction, the surgical environment introduction, the surgical procedure introduction, the expression of the avatar nurse, and others. Each code was colored into either green(Social VR positive) or red(Social VR negative) according to its attitude towards VR consultation.

In the second phase, the participant based classification was disrupted and clustered into six categorize based on the essence of the content(Figure 45), namely: **(1) Information, (2)Emotion,(3)Concentration, (4)The realism of the models, (5)Interaction in VR, and (6)Active communication .**

The following subsections will elaborate on six categories together with the representative quote of the participants.(For the full figure, see Appendix 9.2)

1. Convey information

The information in VR can be presented more diversely and flexibly in Social VR clinic, which helps the patients to comprehend the treatment process readily. For example, VR can provide a knee prosthesis model that assists in explaining the surgical procedure. It can flexibly show the structure of the prosthesis, its installation on the leg, how it bends and straightens together with the leg, etc.*"The information in VR is more abundant. It presents the structure of the whole leg and the installation of the prosthesis" (PF5).* This feature is ideal for most patients. However, some of the participants believe that this approach adds complexity to the conversation and is less straightforward than the F2F consultation*"it is still a complicated structure. Although I had the options to see the leg with or without the artificial joint, it is still too complicated" (PS4).*

The information presented in the VR office is more informative. From the perspective of information organization, the visual process model helps the patient to memorize the complicated surgical preparation process in a graphical way*"Compared to the verbal message, the visualization gives a clearer indication of what medicine I need to do during a period of time" (PF6).* By visualizing the conversation in 3D format, the layering of the information is improved through clear graphic rhythm*"The three-dimensional process with motions are impressive" (PF3).*

The combination of multiple types of information: the text, graphics, models, animations, and voice, promote the communication efficiency between nurse and patient*"The listening and reading was fine. Because the key points, the highlights were mentioned in the process model. And you were giving other details, so it was nice" (PF4).* Especially for explaining the surgery process, it has been mentioned by several participants, that the prosthesis on the

extension leg model is more comprehensive, comparing to physical model used in the face-to-face condition *"I also like the knee model, seeing how it works, it is nice. I think it is nice to see the animation and see how this works"(PS1).* Some participants believe that showing the installation process through animation can further advance the experience.

However, not all participants have shown preference to the combination of various form of information. For these people, it is considered challenging to deal with multi-tasks and multi-type of information at the same time. For instance, in the experiment, they reflected that it is difficult to listen to the nurses while reading the medication information on the floating panel *"I can't listen while also read the text on the floated interface at the same time" (PF2);* And it is difficult to navigate the virtual avatar through the controller while visiting the virtual operating room. *"Moreover, in the VR environment, I need to walk, I need to control my character, and meantime I need to follow you, so many factors were distracting me, and as a consequence, I cannot focus on the detail." (PS3).* Compared to other participants, they need more focus and simpler messages.

Some participants considered that the same experience could be achieved in real--life consultation as the virtual one, by providing surgical preparation visuals, the extended leg model with the prosthesis, as well as video of the operation room *"When there was information given by the nurse, I think if we have the same thing in real life, like a chart like that, then it could also be the same" (PS5); "For example, if the model is also movable for the physical one, like it moves up in the VR, if so then it wouldn't make any difference"(PF4).* This feedback, from another perspective, supports that virtual consultation is comparable to the face to face consultation, even in the current situation. The virtual clinic can be even more advantageous, given the cost of producing the new model and filming the video for the real-life situation.

2. Emotions

The patient feels nervous during the consultation, results from the intensive dialogue, and fear of an unknown surgery. This anxiety can be reduced by game-like interactions such as manipulating the prosthetic model and visiting a virtual operating room *"When you can walk inside, it is much like visiting someone's home. You can move this and that which release your nervousness" (PF3).* Meanwhile, diversified information and immersive experience can increase the patient's understanding of the surgical environment and process, thus release the patient's nervousness *"The part of the operating room, in VR, really tells me what will happen at the time, which released my fear of the operation" (PS6).*

Under this situation, emotional support from the nurse become very important. *"Especially for surgery, if a patient is sitting there, then he might also have some fears. Like if I feel pain, I probably have some expression on my face. I think it's essential." (PS4)* In the VR environment, the face-to--face dialogue, the question and answer can help to improve the emotional communication between the patient and the nurse to a certain extent, but this may not be

INFORMATION

Impressive information

3D inforamtion help to remember

Firstly, the three-dimensional process with motions are impressive, would be even better if it has more visuals.(#3)

The information was more diverse if shown in the VR, and the process is presented in segments.(#12)

Organized information help to remember

Easier to remember the schedule with graphical timeline

Compared to the verbal message, the visualization gives a clearer indication of what medicine I need to do during a period of time.(#12)

The starting part will is better to be in VR because it has an **intuitive timeline(#2)**

The timeline shows what I needed to do four weeks ago, three weeks ago, two weeks ago, that was very nice. So I can manage my time, and I can see what I have to do on that specific day. (#7)

Re-organization of the information is clear

The main advantages is that the layout on the table, it is pretty clear that what you are talking about, in the regular visit it is so hard for me to keep track of the scientific names, sometimes I don't remember which name and when to take what. (#1)

I like so much the patient journey, because I can understand every step in the process, and it is very interactive, so I am very like it.(#4)

Multitype information help to remember

Easier to remember the medicine name because of the the written message

The starting part will is better to be in VR because it has an **intuitive timeline (#2)**

Cannot do multi-task at same time

I don't focus much on the facial expression of the nurse during the VR experience. I don't know if I can still understand everything if I look at the nurse.(#8)

The model contains multiple information which popped up at different places, meanwhile, I also need to listen to you.(#6)

Moreover, in the VR environment, I need to walk, I need to control my character, and meantime I need to follow you, so many factors were distracting me, and as a consequence, I cannot focusing on the detail. (#6)

I can't listen while also read the text on the floated interface **at the same time.(#2)**

Good combination of listening and reading

The listening and reading was fine. Because the key points, the highlights were mentioned in the process model. And you were giving other details, so it was nice.(#10)

I can do both listening and watching at the same time, just like in a lecture(#3)

VR show how the artificial joint installed and work with knee

And even the model, I could see how it would be with other things which was an advantage. Emotionally with the nurse(#9)

For the knee model, it was definitely better than watching this(the physical one) Because it was an extended model. So I don't know if we have the same thing, like an extended form in real-life consultation.(#10)

For the model of the knee, I think it is much better from the VR because with the physical model(the artificial joint). I know there is a shape, but if I see it for the first, I would have no idea how it is fit on the knee. If I don't know what femur is and what is tibia, then I don't know how it is fitted. (#1)

I also like the knee model, seeing how it works, it is nice. I think it is nice to see the animation and see how this works. (#4)

But in VR you can also see the tissue around it .(#2)

I think it's important to show how will the artificial knee be installed on the leg. (It is hard to imagine this in face to face condition if) I don't know what the structure of my leg is. (#3)

There is the entire knee model, and in the case of face-to-face, there is only this prosthesis itself, so I don't know how he installed it.(#5)

Easy to be understood by the elderly

Some people like my grandmother, she doesn't understand anything, you show her the artificial knee like this(physical), she can't understand(#4)

Flexible in showing vasive information

VR is more flexible in showing information

The information in VR is more abundant. It presents the structure of the whole leg and the installation of the prosthesis.(#11)

The advantages in VR is that it is more flexible, it can present more details(#12)

3D model provides vasive information

The part of the operating room, in VR, really tells me what will happen at the time. (#12)

The model and operating room are better in VR because they are three-dimensional so they convey more information.(#5)

Model in VR too complicated

I think have the physical thing in my hand is better than seeing it in VR, because it is still a complicated structure. Although I had the options to see the leg with or without the artificial joint, it is still too complicated. (#7)

EMOTION

Emotional connection

Feel like a dialogue

it is only when you are facing someone it feels more like dialogue; it is the advantage here. (#3)

Help to build connection with the nurse

I prefer having someone guides you around the scene so that I can feel the connection with the nurse. Just like you are in an unfamiliar environment, you will be more relaxed when someone is guiding you.(#12)

Less emotional conection with nurse

I didn't have any emotional communication with the nurse in that environment. When my family member when through surgery which I experienced before, I got really nervous, and under that condition, you will ask a lot of questions.(#12)

But it was not very..., there were no emotions. I'm not sure. Like, especially for surgery, if a patient is sitting there, then he might also have some fears. Like if I feel pain, I probably have some expression on my face. I think it's essential. (#7)

But I feel when someone is going through an operation, the emotional support is very, very important. And that is kind of missing. (#9)

However, in the VR, I am not able to follow your emotions.It is maybe necessary to have facial expression. Although you are not looking at me all the time, you stare at me at lease for some times; it feels better. In VR, there is no eye contact.(#1)

Help to build connection with the nurse

I could get the whole tour of the entire thing. And I think that will make me more connected. Emotionally with the nurse.(#9)

It is good to have a real doctor with me

Then I think, like, obviously, I didn't know what questions to ask. But if I had to ask them questions, even in between, I think it's it is nice that it's not a recorded video, which I'm watching through me.(#9)

Release nervouness

Less constrains in VR

I think in this VR situation, I will feel more relaxed, but I am also easily distracted because the doctor can't see me. I think if he can hint on the key content, like highlight the especially important thing. (#3)

Virtual doctor makes me feel at ease

I think that seeing a virtual doctor makes me feel at ease. Because it is a virtual avatar, my doctor probably, or I feel they don't know how I am, as long as I am not facing him in the flesh. (#3)

Walking in the operation space relax the nervousness

When you can walk inside, it is much like visiting someone's home. You can move this and that which release your nervousness;(#3)

Number of the participant

Positive comments about Social VR consultation

Negative comments about Social VR consultation

Weak indication about the process

it doesn't give me a strong indication about the process, the information it provides was soon forgotten. The model contains multiple information which popped up at different places. (#6)

Easier to remember in face to face condition

Both face to face and VR, there a lot of information for me to remember, but face to face was, comparatively easier for me to get that information.(#9)

Replaceable

Can be replaced by written inforamtion on paper

I think VR experience for not necessarily in this particular case if all these things are generally handed out in written. The first part is generally handed out in writing. So any patient will definitely read it by taking medicine.(#8)

I also feel about the information thing. When there was information given by the nurse, I think if we have the same thing in real life, like a chart like that, then it could also be the same.(#10)

Another thing is that, if in the face to face condition if you have something visual, like the same patient journey but in the paper, it also helps(#4)

Can be replaced by same model with the extented leg model

For example, if the model is also movable for the physical one, like it moves up in the VR, if so then it wouldn't make any difference. (#10)

Figure 45 Results from the interview, Part 1

REALISM OF THE MODEL

Prefer physical prosthesismodel

Prefer to have physical model in the hand

But if the physical model also has the leg structure, I would prefer the physical one. It is better to have something you can feel in your hand with weight and materials.(#3)

In the last part, the knee model, I like to touch things that are going to be installed in my body.(#6)

Model in VR too complicated

I think have the physical thing in my hand is better than seeing it in VR, because it is still a complicated structure. Although I had the options to see the leg with or without the artificial joint, it is still too complicated. (#7)

Nice simulation of real life consultation

But I think having such model in VR was a very nice simulation of the real experience because I can move things in real and you can also move the pointer in the VR which really got it close to having such in a real experience.(#10)

Realism of nurse

The nurse looks real

I might ask some questions at the beginning to test whether it is a real person opposite. If he can solve some of my problems, then I don't think the avatar presentation matters. The nurse in the scene is quite real.(#11)

The nurse looks unreal

The advantages in VR is that it is more flexible, it can present more details(#12)

Although I am talking to a fake nurse, she still has less realism; only her upper body can be seen in the VR environment.(#6)

The talking and the lipping are not in sync. Because when I see you, the way you speak, syncs with how you are lip-sync those words, and that then it is natural for me.And also the nurse wasn't a full body, there were your hands and the body, which was very unnatural for me. (#10)

Operation room feeling unreal

I was moving around the operation room, and I felt that I was almost into something. And I would have nudged it in the real space, but I don't feel like that. Yeah. So I can point out the moments that will tell me that it's not real for me.(#10)

Interaction in VR

Easy to interaction

Easy interaction

I don't think the interaction using the controllers is difficult, but it might because I have some experience with it before.(#11)

I don't think there is much interaction involved, it's still very well mastered. (#12)

The VR interaction method is still relatively easy, even if there is a problem in the first time, there should be no problem later(#5)

Difficult to manipulate

It is difficult to manipulate the structure in VR. Then you do it with the physical one in your in front of you.(#8)

Training session is important

During the training, I wouldn't need to try it one more time, because I could get it at once. It was fun and easy to do.(#10)

Active communication

More freedom to look at the details

VR is better indeed it gives me the feeling that I am walking thought the room(#6)

But definitely, it was very immersive because going around the room, looking at the nurse from every angle. Yeah, yeah, that is a very immersive thing to do(#10)

there may be some details that I want to look at that were not captured by the video. But if I am in the virtual operation room, I can look at what I care about, more carefully and freely.(#11)

I really like to see the tour because it was a complete whole to which I could go around and really see the whole place(#9)

For the operation room, the video is not as good as VR; it is better if I can go and see what is happening there.(#1)

More interaction in VR

Because in the VR, the interaction was a bit more than just looking at the video. So that's also a beneficient.(#7)

Provides immersive experience

the operation room was definitely more immersive and watching it because I was in there. But definitely, it was very immersive because going around the room, looking at the nurse from every angle. Yeah, yeah, that is a very immersive thing to do.(#10)

CONCENTRATION

Cannot do multi-task at same time

The model contains multiple information which popped up at different places, meanwhile, I also need to listen to you.(#6)

I didn't focus much on the facial expression of the nurse during the VR experience. I don't know if I can still understand everything if I look at the nurse.(#8)

Unreal nurse is distracting

Otherwise, I'm watching the nurse, and I'm trying to understand what I heard, and meanwhile reading the information. I was unable to grab information because I was much focused at looking at the nurse (#10)

VR Environment help me concentrate on

it makes me concentrate on the consultation itself since everything you see is important, is what you need to remembred. it helps me to get rid of other distractions(PF2).

Unfamiliar experience is distracting

Hard to concentrate because of the familiar VR environement and devices

People like me who had never experienced a VR consultation will be easily distracted by the environment.(#6)

Dizzy feeling makes me hard to concentrate

The dizzy feeling makes it difficult for me to concentrate on the information. I have gone through VR a few times, but not for a very long time (#9)

When I was moving the joystick and also the chair, at the moment, I think I got superimpose(dizzy).(#10)

Video tells where to focus

I think the video is much better because it tells you where to focus on, instead of (in VR), it lets you free to move around, and you don't know where to look at.(#8)

enough *"it is only when you are facing someone it feels more like dialogue; it is the advantage here"(PF3).*

Due to technical limitations of VR, the current VR device cannot fully imitating the detail change of human face; For example, there is no eye contact under the avatar figure, the facial expressions are also limited. From the patients' perspective, they may not receive psychological support: the compassion, understanding, or affirmation from the nurse. *"However, in the VR, I am not able to follow your emotions. It is maybe necessary to have facial expression. In the real-life situation, although you are not looking at me all the time, you stare at me at lease for some times; it feels better. In VR, there is no eye contact"(PF1).*

Nevertheless, not everyone requires strong emotional support. A few participants thought that it is enough to have a real nurse in the scene who can answer all the questions, the facial expressions and emotion communication are better to have not essential *"If he can solve some of my problems, then I don't think the avatar presentation matters. The nurse in the scene is quite real"(PF5).*

This lack of emotional connection cause by facial expression can be compensated by involving cooperative activities, such as asking patient walk around the operation room guided by the nurse *"I could get the whole tour of the entire thing. And I think that will make me more connected. Emotionally with the nurse" (PS6).*

3. Realism of the models

The realism of the model in the virtual environment is one of the essential factors for approaching real-life consultation. In the tested scenario, it is much depressed by the lack of physical properties in the virtual environment. In a face to face condition, the patient can hold the knee prosthesis that is used in operation, feel the material and the weight. However, in the virtual clinic, although using the same prosthesis model, the patient cannot perceive the same realism as real consultation, due to the missing sense of weight and touchtouch *"It is better to have something you can feel in your hand with weight and materials" (PF3).*

Similarly, while going around the virtual operating room, when they hit the wall or equipment in the scene, the impact is only visually reflected. Although the model of the operating room is in high-fidelity, it still immediately gives the patient a sense of "not in the real environment" *"I was moving around the operation room, and I felt that I was almost into something. And I would have nudged it in the real space, but I don't feel like that. Yeah. So I can point out the moments that will tell me that it's not real for me"(PF4).*

4. Interaction in VR

It is easy to grasp how to interact in VR using the oculus controller, approved by most of the participants *"I don't think the interaction using the controllers is difficult, but it might because I have some experience with it before" (PF5).*

Figure 46: Results from the interview, Part 2

Only one participant consider it was challenging to master; using the controller distract their concentration on the content of the consultation *"It is difficult to manipulate the structure in VR. Then you do it with the physical one in your in front of you (PS5)".*

Although it is generally agreed that interacting with the controllers is easy to master, for those players who have limited experience with VR, a training session, even the simplest one, is much helpful than oral explanation *"The training session is really helpful. During the training, I wouldn't need to try it one more time, because I could get it at once. It was fun and easy to do"(PF4).*

5. Active communication

In the VR clinic, patients have more freedom to interact with the virtual environment. It provides patients with more opportunities to participate in the consultation process actively. *"For the operation room, the video is not as good as VR; it is better if I can go and see what is happening there" (PF1).* For example, compared to the video, the patient is free to walk around the virtual operating room, observe what he wants to see in VR without being limited by what the video shows *"there may be some details that I want to look at that were not captured by the video. But if I am in the virtual operation room, I can look at what I care about, more carefully and freely" (PF5).*

While explaining the operation procedure, the patient can switch and move the model themselves. All these factors make the patient's position in communication more positive. However, not all patients appreciate this freedom. Some patients prefer to accept information passively. They think too much freedom leads to the loss of correct focus for the patient.

6. Concentration

Concentration is an interconnected group that is closely related to and influenced by the other five groups. The unfamiliar VR experience might result in the distraction. A user might feel dizzy in VR because of the dislocation between visual sense and physical sense: seeing yourself moving forward, even if your body is standing still. This symptom is especially notable in some players, which tremendously affect the VR experience. This discomfort can also come from the unfamiliar feeling of wearing bulky devices during communication, which distracts the patient from the consultation *"The dizzy feeling makes it difficult for me to concentrate on the information. I have gone through VR a few times, but not for a very long time" (PS6).*

Multi-information and multi-tasking are another cause of distraction. Some users turn out to be more inclined to deal with a single form of information. Therefore, listening while reading, or observing while controlling the avatar will obstacle this type of user from concentrating on the content of the conversation *"The model contains*

multiple information which popped up at different places, meanwhile, I also need to listen to you"(PS3).

Finally, the unrealism model will divert one's attention. Due to the limitation of VR technology, the character only has its upper body with hands in the scene, and its mouth shape cannot completely correspond to voice. These unnatural feelings can also occupy the user's attention *"I'm watching the nurse, and I'm trying to understand what I heard, and meanwhile reading the information. I was unable to grab information because I was much focused at looking at the nurse".*

However, for some of the participants, the immersing virtual environment reduces the interference of the real world. Since the user is completely immersed in the virtual environment, everything they see and hear is about the consultation *"It makes me concentrate on the consultation itself since everything you see is important, is what you need to remembered. it helps me to get rid of other distractions" (PF2).*

6.3.4 User profile

Through the interview, users' opinions toward the virtual clinic illustrated distinct trends in several topics, some of which are utterly contrary to each other. By sorting out the opposite comments, the researcher obtained four potential criteria for defining user portraits. Through the portraits, VR developers can determine the type of the target user based on the research, decide whether to use VR technology and how to implement based on user demands. The four criteria are:

1. *Acceptability of VR technology*

People vary in their capability of adapting virtual environment. In this case, participants with higher acceptance can quickly master controllers interactions. They

Figure 47: User pro
ceptability of VR tech

are able to adapt to the VR environment gradually without unbearable dizziness. However, a few people show a lower resilience to the virtual experience. They

Figure 50: User profiles of th

spend considerably longer time to remember who to interact with virtual objects, and the lasting and unbearable vertigo significantly a˙ect their ability to complete the tasks in VR.

2. The willingness of handling multi-tasks and multi-type information

Some users are more dept to handle multiple tasks at the same time, such as lis-te-

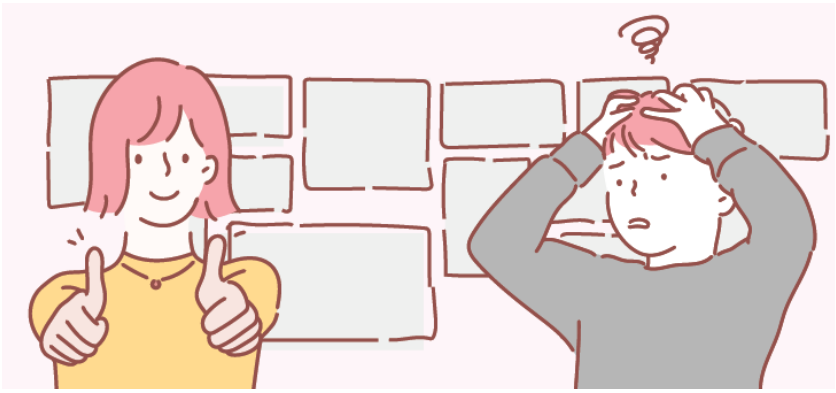


Figure 48: User profile_willingness of handling multi-task and multi-type information

ning while reading, observing while controlling the avatar, etc. They are good at defining their own way of processing information, consider it as an advantage of comprehensively understanding a particular issue. However, for the opposite group who prefer the single type of information, deem that simple knowledge is more accurate. Therefore, when the designing of the VR application, the diversity and complexity of the information and tasks should be considered based on the

he twelve participants

user type.

3. *Demands for emotional support*

In the experiment, we found that the people has diffierent demands for emotio-

Figure 49: User profile_ demands for emotional support

nal connection. Some people care more about the functionality of the communication. Therefore the design of the virtual environment should focus on promoting the effiectiveness of information transformation. On the contrary side, for those who have higher demands for emotional connections. It is indispensable for them to understand others' attitude through eye contact and facial expression. When designing for them, a high-fidelity model is needed, the countenance and eye movement of the players should be maximally captured and simulated.

Different user portraitures can greatly affect the user's experience in virtual reality. This phenomenon is also evident in the experiments by combining the results of the Social VR questionnaire with the interview. The result of social questionnaire indicates that participants PF2, PF3, PF5, and PF6 are more inclined to virtual clinics from both social meaning and interaction quality perspectives. Oppositely, the testers PS2, PS3, PS4, PS5, PS6, PF4 have more preference in face-to-face condition. By reviewing individual's feedback on the consultation experience, it reveals that testers who were pessimistic about virtual clinic consultations had relatively concentrated user portraits. They are more comfortable in addressing single type information, require higher emotional needs, and have lower adaptability to the VR technology. Their specific comments are shown in Figure 50.

In this section, we will discuss the limitations of this project; The potential directions for future study, as well as the answers to the initial research questions.

CHAPTER SEVEN

CONCLUSION

7

7.1 Limitation of the studies

1. Approach medical professionals

Due to the unique requirements of the test environment, the complexity of device set-up, as well as the time consumption of the experiment, this project did not successfully involve the medical professionals in participating the test. The evaluation lacks opinions from the professional field.

2. Study setup

To have better control over the testing procedure, the nurse and the participant entered the virtual environment at different positions in the same room during the social VR consultation during the experiement. The sound was echoed transferred through both physical room and headphone on the VR glasses with delay in between. Since the echo seriously affects the experiment outcome, system sound was turned off. Therefore, during virtual consultation, participant faced the nurse in the front but heard the voice from another angle in the real space. This inevitable technical limitation influenced the immersion of the virtual clinic.

3. Participants

Only 12 participants were invited to the experiment because of the limited time and resources. Each group contains six participants. According to paper from Guest, Bunce, and Johnson (2006)[18], at least 12 subjects should be involved to decern common views and experiences. In that case, to compare the information acquisition in both cases, ideally, there should be twelve more participants take part in the test to make it twelve for each group. Similarly, for the quantitative analysis, the data collected were insufficient for getting satisfactory conclusions. However, the sample size does reach the theoretical requirement of twelve for the qualitative analysis of the consultation experience.

The profile of the participants was restricted, all of which are graduate students from TU Delft University. Under strict regulation in the Netherlands. Experiments conducted with real patients need to be approved by the government. Furthermore, it is hard for the researchers to find twelve knee patients with the limited time and budget. The feedback from the students, although not completely accurate, still provides lots of insights for understanding the Social VR consultation.

7.2 Conclusion

In this project, literature in the related fields was reviewed, an ethnographic study was conducted to obtain a profound understanding of knee replacement surgery. Based on the result, the application of Social VR in medical consultation was explored. A virtual clinic for patient education was designed and developed, and an experiment was organized to compare the effiectiveness of the virtual consultation with face-to-face consultation. The quantitative and qualitative data were collected and analyzed. The results can answer the initial research questions of the project:

1. *The consultation experience in VR clinic is comparable to the real-life face-to-face consultation*

From the perspective of information acquisition, patients tend to obtain the same medical information in both conditions. From the perspective of experience, the results of the Social VR questionnaire reflected that neither quality of interaction nor social meaning reveals a significant difference between the two.

2. *The added values of VR clinics*

In essence, virtual consultations alleviate the pain of traveling to the hospital for patients with knee arthritis. In terms of the experience, the 3D information in the virtual environment can help to provide more diversified, flexible, and intuitive medical knowledge. By incorporating more interactions, patients can be actively involved in the consultation process.

3. *The missing qualities in VR clinics*

Not all users can quickly adapt to the virtual environment, this incompatibility may be reflected as dizziness, hard to concentrate, difficult to learn the interaction in VR, etc. All of the above may affect the effectiveness of the consultation. Due to the limitations of VR devices and technology, the avatars lack emotional expression, so patients cannot get sufficient emotional support in virtual environments.

7.3 Future studies

In this project, we used the knee replacement surgery as a case study to explore the application of Social VR in medical consultation. In future research, other medical consultations can be explored to define the difference in applying Social VR technology for different diseases.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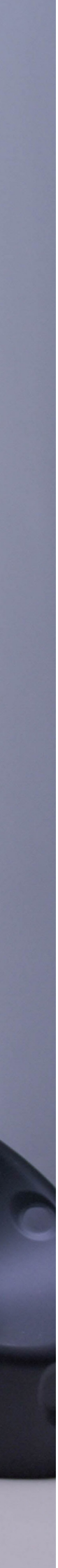
In the current design of the virtual clinic, both nurses and patients appeared as avatars. Some participants commented that the nurse looks unreal. Therefore it was difficult to establish an emotional connection with them. In future research, new modeling approaches, such as point cloud can be explored to develop high-quality 3D reconstructions of the users. Future studies can further explore the influences of characters resolutions under virtual medical consultation context.

Based on the result of the experiment, three potential bases of understanding the people's attitudes towards virtual consultation were discovered. In the future study, researchers can testify these principles and look into other possible criteria to create detailed user portraits. The outcome of this study will bring tremendous benefit for those VR software producers to design and develop proper Social VR applications that accurately target the key user group.



CHAPTER EIGHT

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CHAPTER NINE

APPENDIX

9.1 PATIENT JOURNEY

9.2 RESULTS FROM THE INTERAVEW

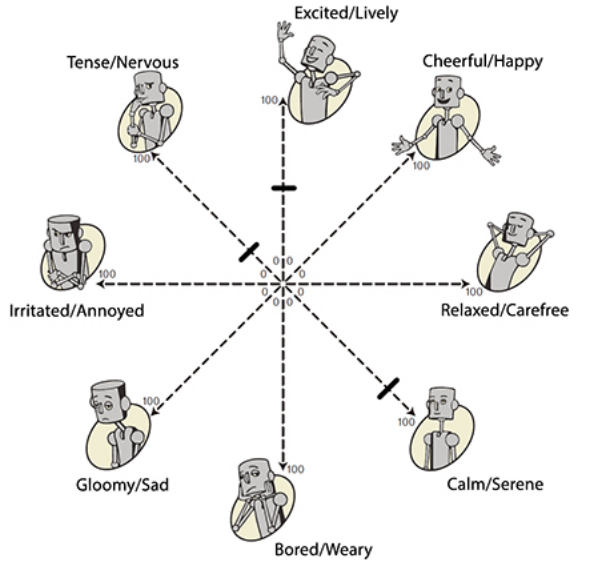
9.3 SOCIAL VR QUESTIONNAIRE

Your Patient Education Experiences

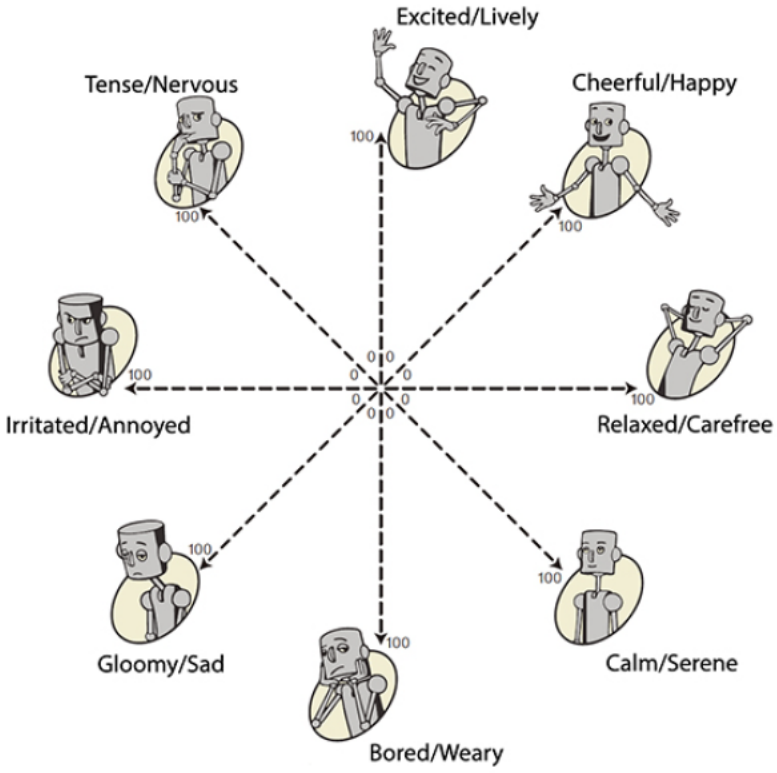
Please answer the questions, according to your patient education experiences.

1. Please indicate, on the chart below, your emotions and the intensity of the emotions (0-100) during the patient education. You only need to choose the emotion(s) you have experienced.

For example



My emotion



Please rate the degree to which you agree or disagree with each of the following statementes, where:

1 Strongly disagree *2 Disagree* *3 Neutral* *4 Agree* *5 Strongly agree*

	1	2	3	4	5
2. "I was able to feel the nurse's emotion during the patient education."	☐	☐	☐	☐	☐
3. "I was sure that the nurse often felt my emotion."	☐	☐	☐	☐	☐
4. "It was easy for me to contribute to the conversation."	☐	☐	☐	☐	☐
5. "The conversation seemed highly interactive."	☐	☐	☐	☐	☐
6. "I could readily tell when the nurse was listening to me."	☐	☐	☐	☐	☐
7. "I found it difficult to keep track of the conversation."	☐	☐	☐	☐	☐
8. "I felt completely absorbed in the conversation."	☐	☐	☐	☐	☐
9. "I could fully understand what the nurse was talking about."	☐	☐	☐	☐	☐
10. "I was sure that my nurse understood what I was talking about."	☐	☐	☐	☐	☐
11. "The experience of patient education seemed natural."	☐	☐	☐	☐	☐
12. "The actions used to interact with the nurse were natural."	☐	☐	☐	☐	☐

	1	2	3	4	5
13. "I often felt as if I was all alone during the patient education."	☐	☐	☐	☐	☐
14. "I think the nurse often felt alone during the patient education."	☐	☐	☐	☐	☐
15. "I often felt the nurse and I were sitting together in the same space."	☐	☐	☐	☐	☐
16. "I paid close attention to the nurse."	☐	☐	☐	☐	☐
17. "The nurse was easily distracted when other things were going on around us."	☐	☐	☐	☐	☐
18. "I felt that the patient education experience enhanced the closeness between me and the nurse."	☐	☐	☐	☐	☐
19. "Through the VR patient education, I managed to share my thoughts with the nurse."	☐	☐	☐	☐	☐
20. "I derived little satisfaction from patient education with the nurse."	☐	☐	☐	☐	☐
21. "The patient education experience with the nurse felt superficial."	☐	☐	☐	☐	☐
22. "I really enjoyed the time spent with the nurse."	☐	☐	☐	☐	☐
23. I feel emotionally closed to the nurse now.	☐	☐	☐	☐	☐

	1	2	3	4	5
*24. "I had a sense of being in the same space with the nurse."	☐	☐	☐	☐	☐
*25. "Somehow I felt that the same space was surrounding me and the nurse."	☐	☐	☐	☐	☐
*26. "I had a sense of interacting with the nurse in the same space, rather than doing it through a system."	☐	☐	☐	☐	☐
*27. "My patient education experience seemed as if it was a face-to-face sharing."	☐	☐	☐	☐	☐
28. "I did not notice what was happening around me during the patient education. "	☐	☐	☐	☐	☐
29. "I felt detached from the world around me during the patient education."	☐	☐	☐	☐	☐
30. "At the time, I was totally focusing on the patient education."	☐	☐	☐	☐	☐
31. "Everyday thoughts and concerns were still very much on my mind."	☐	☐	☐	☐	☐
32. "It felt like the VR patient education took shorter time than it really was."	☐	☐	☐	☐	☐
33. "During the patient ducation, time appeared to go by very slowly."	☐	☐	☐	☐	☐

* ***Not applicable for face-to-face condition***