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Roadmap for AI in a Humane ICU

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Strategic Product Design

Executive Summary

ICU is the place with the most advanced monitoring and support machines in a hospital. But surrounded by all these machines, ICU patients are also like machines instead of humans. Scientific advances have been proved to greatly improve the cure rate. Meanwhile, patients' well-being has been gradually treated as important as curing the disease itself. With the trend of human-centered intensive care, new services are required to better satisfy patients' needs.

Artificial intelligence can be a strong force to improve the quality of care in ICU. Apart from taking advantage of the existing monitoring data and EHR data to improve the cure rate, A.I. also has great potential to promote social support for ICU patients.

The purpose of this project is to design a roadmap for A.I. to provide social support for ICU patients, in order to improve the patient wellbeing and contribute to a humane ICU.

The design solution is an application called Cricare that includes nine services: 1. Orientation; 2. Autocomplete; 3. Voice Simulator; 4. Music Creator; 5. Environment adjuster; 6. Chatbot; 7. Virtual Psychologist; 8. Peer support; 9. Goal setter.

A questionnaire evaluation with nurses was conducted to test the desirability, importance, and effect on providing social support and effect on patient wellbeing. The results show Cricare is the potential to contribute to a humane ICU. After feasibility evaluation, a primary roadmap was created to develop Cricare.

TU Delft
Delft University of Technology

Critical Alarms Lab

Erasmus MC

Content

Chapter 1 Introduction

This chapter aims to introduce the project background, problem definition, assignment, and design approach. This section is where the project begins.

1.1 | Project brief

This project is a joint work of ICU in the Erasmus Medical Centre (Erasmus MC) and TU Delft Critical Alarms Lab (CAL). Every year, more than four thousand patients are treated in the ICU of Erasmus MC (Erasmus MC, 2020).

ICU is a highly stressful environment for patients who are treated in life-threatening situations. Stressors can be lack of natural light, disruption of sleep-wake patterns, absence of clocks, lack of contact with family and friends, and the several clinical procedures that cause patients to experience different types of physical and psychological discomfort (Dias, Resende, & Diniz, 2015). Also, ICU is a physically and emotionally challenging environment for the interprofessional teams, comprising physicians or intensivists, clinical pharmacists, respiratory therapists, dieticians, bedside nurses, clinical psychologists, and clinicians-in-training (Ervin, Kahn, Cohen, & Weingart, 2018). Besides, the families of patients are suffering a lot during ICU treatment. The Erasmus MC provides a platform called IC Connect to helps patients and relatives go through intense time during or after an intensive care unit (Erasmus MC, 2020).

Problem definition

Proved by the high survival statistics, the technological development of ICU is significant. However, the humanistic aspects of care have not been keeping up (Nin Vaeza, Martin Delgado, & Heras La Calle, 2020). “Dehumanization consists of treating someone as an “object” rather than a “person” and is often associated with failures to honor dignity”. The dehumanization behavior includes the loss of personal identity, control, respect, privacy, and support systems (Wilson et al., 2019).

Assignment

My graduation project focus on investigating the missing humane parts of ICU and the readiness of the data infrastructure. Based on the desktop research, new possibilities for practical AI applications will be explored and will be evaluated with nurses in Erasmus MC. The output of this project will be a roadmap of the steps that are needed to take to get prepared for applying AI in the humane ICU.

Figure 1. Patient and nurse (Health Times, 2021)

1.2 | Design Approach

Figure 2 shows the design approach in an iterative process.

First, in the stage of research, three research questions were investigated by literature review and semi-structured interviews with health professionals in Erasmus MC:

- What are the value drivers of intensive care?
- What is humanizing intensive care?
- How artificial intelligence can possibly contribute to a humane ICU?

A patient journey was mapped based on the research to figure out the missing humane parts of intensive care and the design goal was defined.

Second, based on the AI inspirations, an idea mapping section was conducted. Nine ideas were selected to support the future vision. The design ideas were visualized by nine idea cards.

Third, a design evaluation questionnaire was designed to get opinions from nurses in Erasmus MC. The questionnaire evaluated the desirability, importance, effect on providing social support, effect on patient wellbeing. Then the priorities of ideas were discussed based on the questionnaire result, technology scouting and feasibility evaluation. Eventually. a roadmap of the steps that are needed to get prepared for applying AI in a humane ICU was created.

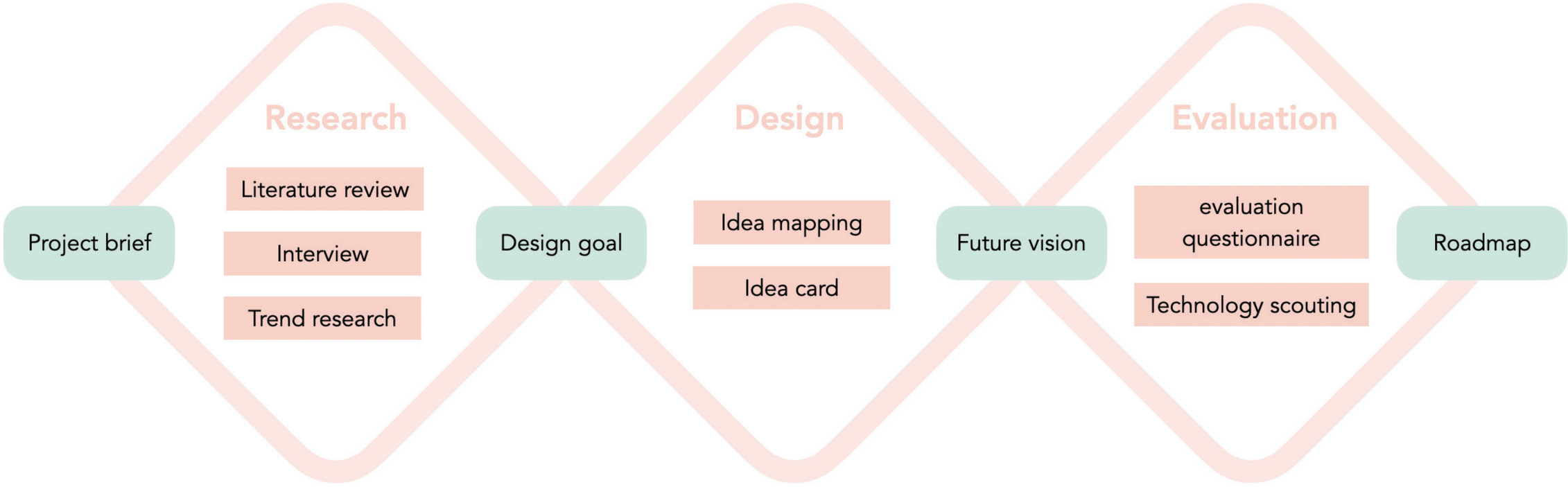


Figure 2. Design Approach

Chapter 2 Value Drivers of Intensive Care

In this chapter, the context of ICU in Erasmus MC will be introduced. Based on the literature review, trend research was conducted to find value drivers in ICU.

2.1 | The purpose of intensive care should be more than saving life

In 2014, the Council of the WFSICCM (The World Federation of Societies of Intensive and Critical Care Medicine) sent the question “What is an ICU?” to approximately 80 professional societies. The conclusion is "an intensive care unit (ICU) is an organized system for the provision of care to critically ill patients that provides intensive and specialized medical and nursing care, an enhanced capacity for monitoring, and multiple modalities of physiologic organ support to sustain life during a period of acute organ system insufficiency (Marshall et al., 2017)." Although an ICU is based in a defined geographic area of a hospital, its activities often extend beyond the walls of the physical space to include the emergency department, hospital ward, and follow-up clinic. There are 5 factors that differentiate intensive care from routine clinical care (Marshall et al., 2017):

1. physical space

Although intensive care can be delivered outside the ICU, a discrete physical space that enables the concentration and efficient sharing of technologies and expertise are vital to the definition of an ICU. An ideal ICU be a single-bedroom, visible from a central nursing station, can access supportive devices such as a ventilator and dialysis machine, monitors, oxygen and a suction system, have sufficient space to allow family members to visit, can access natural light, have one or more negative-pressure rooms and can isolate patients with airborne infections.

2. support and monitoring technology

A big difference between intensive care from ward care is the continuous monitoring of patient physiologic status, including noninvasive monitoring to get the real-time data of oxygen saturation, heart rate, blood pressure and brain activities. If necessary, invasive monitoring is conducted including hemodynamic monitoring and intracranial pressure.

Also, the support system is required to help patients' failing organs keep working, consisting of respiratory support, carbon dioxide removal, hemodynamic support, cardiac pacing, mechanical cardiac support with intraaortic balloon counterpulsation or ventricular assist devices, ECMO to provide tissue oxygenation, renal support in the form of intermittent or continuous renal replacement therapy, continuous need to relieve pain and anxiety and to prevent and treat delirium.

3. human resources

The intensive care team is specially qualified and has ample experience in the care of the critically ill, including not only physicians and nurses, but also may include nurse practitioners, respiratory therapists, physiotherapists, nutritionists, pharmacists, social workers, microbiologists, and spiritual care personnel. Continuous nursing care is essential to ICU patients.

4. Critical care services provided

In addition to the immediate patient care, ICU can also contribute to the large hospital system, such as serving smaller hospitals that don’t have ICU facilities, providing consultative services on the ward, and assisting other teams. Besides, post-ICU care and end-of-life gain more and more attention.

5. research, education and quality improvement

A functional ICU has a responsibility to the domain of continuous quality improvement, evaluating current care, and sharing information.

ICU carries the hope of survival for critically ill patients and their families. The development of technology has always been the main theme of the ICU, and medical scientists have been committed to using better instruments and more precise and controllable treatment procedures to ensure the continuation of patients' lives. In history, every technological revolution has greatly improved the survival rate of patients (Dilip, 2018). However, heavy equipment and treatment often make patients feel violated and out of control. Meanwhile, ICU is shrouded in an atmosphere that is close to death. Patients who have experienced ICU often have experienced different degrees of "dehumane" experience, which will have a great impact on the patient's physical and mental health. Therefore, from another perspective, whether technology can make the patient regain dignity and heal the mental wound while healing the body in the ICU.

2.2 | The context of the intensive care in Erasmus MC

There have been several projects about intensive care by CAL, which is an abundant source to know the context of ICU. Besides, Erasmus MC is an important stakeholder in this project. Interviews were conducted with an experienced intensivist and a Ph.D. candidate in ICU. The main insights about the ICU are:

Main stakeholders to provide social support: nurses and families

Except for medical support, families and nurses are the main stakeholders to provide social support for patients. Families can provide emotional, psychological and social support for patients. Also, they are responsible to make decisions for patients when they are unresponsive. But they are also suffering from stress and anxiety, which may be obstacles for them to provide support. When patients are hard to communicate with others because of special treatment such as a ventilator, nurses can represent the patients to some extent because they have the experience to understand patients' needs, while families can understand more personal needs of patients (Chou, 2020).

Length of stay in ICU

The ICU population is complex and heterogeneous. The length of stay depends on what kind of patients. It is difficult to tell what the average length of stay is for patients, but the distribution of the length of stay is skewed. A lot of people stay for one to 10 days. Moving from 10 to 20 days, there are fewer people. MEWS is a method to identify patients who are at risk of becoming critically ill and will be transferred to the ICU.

Sedation

Some patients are too critical to breathing by themself, so mechanical ventilation is required. To protect the lungs from getting stressed because of the interaction with the mechanical ventilator, sedatives are given to put the patient in an artificial coma. Sedated patients are not or less aware of their surroundings because they are in a state of unconsciousness, so they can't get stressed. When they lower the dose of the sedatives and then slowly the patient starts becoming awake. My project focuses on the experience when patients are conscious in the ICU.

PAD management

Pain, agitation and delirium are three main stressors in ICU. A study shows guidelines that provide a roadmap for developing integrated, evidence-based, and patient-centered protocols for preventing and treating pain, agitation, and delirium in critically ill patients (Barr et al., 2013). In Erasmus MC, the nurses frequently assess the cognitive function/risk of delirium using the RASS score or the CAM-ICU-7. There are several tools to assess the level of agitation-sedation, pain behavior, and delirium for patients who are unable to self-report. Daily sedation interruption/light target level of sedation is recommended. sleep promotion is recommended by optimizing patients' environments, using strategies to control light and noise, clustering patient care activities, and decreasing stimuli.

MyCo - a mobile device for health professionals

The mobile device is already part of the current clinical workflow in the ICU of Erasmus MC. Nurses and doctors are already wearing a mobile device called MyCo that is continuously receiving patients' vital signs, alarms of medication, infusion pumps from the ICU.

VR goggles for orientation

VR goggles to fill up the missing memories after the patients are admitted to the ICU of Erasmus MC, the environment is filmed at 360 degrees. So after patients wake up from a coma they get the VR goggles, watch a short movie, and get explained why they were admitted to the ICU, who treated them, and what things happened to them.

Entertainment

They provide tablets or TVs in a lot of rooms. Patients can have a look at Facebook. During the COVID-19 situation, a video call with families is allowed in ICU.

This section helped me to understand the current situation of ICU in Erasmus MC, and gave me a general expression on ICU.

2.3 | Trend research - Future ICU

Trend research is a crucial process before envisioning the future (Simonse, 2015). This section summarized the topics of trends from the literature review.

Data-driven healthcare

Organizations are working hard on making predictions and envisioning future ICU, although the future impact of technology can not be entirely foreseen, no matter positive or negative. Data-driven healthcare is one of the main trends. Taking advantage of personal data and hospital data can help medical professionals to provide personalized and predictive care for ICU patients. Meanwhile, with data management, treatments and services can be more precise and efficient, so hospitals can better manage costs and provide affordable care. Effective data management strategies and data safety are crucial to providing data-driven care. It requires collaboration among health professionals, hospital managers data analysts policymakers and every patient (Dilip, 2018).

COVID-19 spawned rapid development of virtual ICU support

The COVID-19 pandemic causes challenges in clinical practices. Meanwhile, it spawned the rapid development of virtual ICU support (Igra et al., 2020). Video calls provide patients with opportunities to communicate with families at safe distances. Webcams make it easier for health professionals to communicate about patients' conditions and treatment plans in different zones (These zones are set for quarantine restrictions). Besides, some nurses were rearranged to the areas that they are unfamiliar with and training is required. With the help of the virtual class, the nurse can adapt to the new environment faster. The virtual support can not only benefit during the COVID-19 situation, some of them have been new routines for hospitals.

Humanizing intensive care

Proved by the high survival statistics, the technological development of ICU is significant. However, the humanistic aspects of care have not been keeping up (Nin Vaeza, Martin Delgado, & Heras La Calle, 2020). "Dehumanization consists of treating someone as an "object" rather than a "person" and is often associated with failures to honor dignity". The dehumanization behavior includes the loss of personal identity, control, respect, privacy, and support systems (Wilson et al., 2019). Proyecto HU-CI, an international research project for humanization of the ICU, developed a framework called "H-Evolution of ICUs" that identifies 8 areas for improvement and research, including open ICU visiting policies, communication, the wellbeing of the patient, presence & participation of relatives in ICU, caring for the healthcare professionals, prevention, management and monitoring of post ICU syndrome, humanized architecture & infrastructure, end-of-life care (Nin Vaeza, Martin Delgado, & Heras La Calle, 2020).

New services are required for health professionals to improve comfort

Providing Comfort is crucial to patient wellbeing. The French societies of adult and pediatric critical care convened a conference in 2009 to promote awareness of the importance of preventing discomfort in ICU and a follow-up survey was conducted to know how caregivers view patient comfort and measures to improve it. The studies show even though nurses consider some measures are useful to reduce patients' stress, they have hardly implemented them, such as relaxation techniques, modify noise levels, assess the quality of patients' sleep, keep patients informed of the date and time, and nonverbal means of communication (Lombardo et al., 2013).

Health professionals expect a better monitoring and support system

Continuously monitoring is required in ICU to keep patients safe. An interview study and follow-up questionnaire investigated the clinical requirements of future patient monitoring in the ICU (Poncette et al.,2019; Poncette et al.,2020). It shows health professionals expected intuitive but advanced features on equipment and software, wireless and noninvasive interoperable monitoring sensors for patients, small tablet or mobile phones as remote monitoring (which already existing in Erasmus MC), ambivalent attitude toward Clinical Decision Support System, reduction of false alarm, implementation of hospital alarm standard operating procedures and enhancement of staff members' digital literacy.

the eCASH concept for light sedation

Sedation is very important for ICU patients. They need sedation to relieve

the double pain of the disease itself and the treatment. But sedation has side effects, and memory loss can confuse patients. This study believes that patients should be comfortable, calm, and able to cooperatively engage with caregivers and family at all times. Researchers proposed an eCASH concept for light sedation. But the enhancement of the patient's capacity to interact will benefit the patient only if staff are responsive to what the patient communicates and able to respond in a way that is coherent and comprehensible to the patient.

Digital twin as a data source

The digital twin is a virtual reflection of humans. It includes information concerning lifestyle and environmental factors, reports of visits to doctors and midwives, laboratory results, results of MRI or CT examinations, and data from studies. Through the personal joint lifestyle and medical care path on the digital twin platform, the participant receives very targeted advice, monitoring and coaching with which they can improve their health, both in the hospital and at home. Doctors have direct insight into both the medical health status and context of their patients. Researchers can use the extensive anonymized data that is continuously supplemented to study diseases within a large patient population and to better predict, treat and even prevent future disease risks using artificial intelligence.

The application of robot during COVID-19

Plenty of applications of robots occurred during COVID-19. There are six main application categories, including public safety, clinical care, though robots for quality of life, continuity of work and education, laboratory and supply chain automation, and non-clinical care (Murphy et al., 2020). Robots are immune to viruses, which can reduce direct human-to-human contact and the risk of infection. At the same time, robots are never tired and can free people from redundant and repetitive tasks. This study also suggests future research areas on autonomy, human-robot interaction, and adaptability.

2.4 | ICU Value drivers

After trend research, some keywords appeared that can represent the value drivers of ICU, which are presented in Figure 3. These value drivers can be clustered into three catagories: safety, efficiency and humanity.

Safety is highly relevant to the patient's health outcome. The purpose to keep patients safe is to save their life. To have a higher survival rate, health professionals work hard to better monitor the patient with data, predict the future health status of the patient and provide precise medicine.

Efficiency is about how efficiently the service and support can be provided by health professionals to patients. To make patient stay as short as possible in ICU, standardized routines, new services to provide fast and intuitive responses, and remote care are set in ICU to improve the quality of care.

Humanity is a new trend in recent years. Patients don't want only to survive in ICU, they also ask for humanized care. Their privacy, dignity, identity

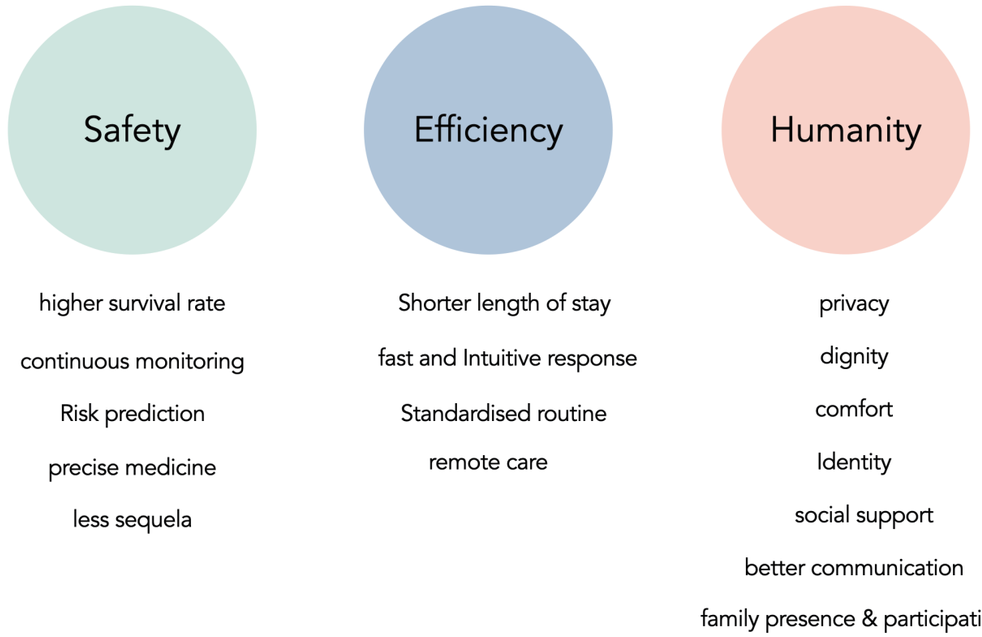


Figure 3. Value drivers

should be respected in ICU. Patients also pay more attention to a positive experience in ICU, like comfort, social support, better communication, family presence, and participation.

These three value drivers sometimes can support each other. For example, providing remote care can improve the efficiency of nurse workflow, at the same time, it can also make patients feel more secure and have a better experience. But sometimes value drivers can be contradictory, For example, to keep patients safe, the ICU patients should be naked on the bed. It makes parents who are awake feel uncomfortable and lack privacy. Also, the family visit restriction can better guarantee patient safety, but both patients and families are suffering from it.

The focus of this project is humanity. Providing humanized care requires new services and routines that may influence safety and efficiency. The new design should balance different value drivers.

Figure 4. Patient and nurse (University of Cambridge, 2020)

Chapter 3 Humanizing intensive care

This project focus on one of the most important value drivers of ICU - Humanisation. This chapter introduces several constructs that are related to humanizing intensive care including humanization, patient wellbeing, and social support. A patient journey was mapped to figure out pain points of ICU patients that hinder patient wellbeing. At the end of this chapter, the design goal is formulated.

3.1 | Humanizing intensive care

In the context of healthcare, humanization frequently describes taking a person-centered approach. Listening to the needs of patients, families, and professionals is vital to a humane ICU. (Velasco Bueno & La Calle, 2020)

A Research Program in Respect and Dignity was initiated to identify disrespectful approaches and respectful approaches for health professionals to change their behavior in different situations (Brown et al., 2017). An International Research Project for the Humanization of Intensive Care Units proposed a model called Proyecto HU-CI. They developed a manual based on good practices including 160 recommendations and can be guidelines for ICUs to be more humanized (Heras et al., 2019). This project promotes a humanizing evolution that will return health professionals to the original role of helping people instead of only curing the disease (Velasco Bueno & La Calle, 2020). Being treated with respect can improve patients' satisfaction and lead to better health outcomes (Brown et al., 2017).

It's impossible to set a standard formula for every ICU to be more humanized, but based on research, there are similar premises for providing humanized care (Velasco Bueno & La Calle, 2020):

- Every patient is being respected
- Patients' dignity is important to consider
- Every patient is unique and require personalized support
- Persons are the center of care instead of diseases
- Patients and families are actively involved in the curing process
- Care is established based on trust and empathy

The main factors that result in the dehumanization of care are: (Velasco Bueno & La Calle, 2020; Brown et al., 2017; Wilson et al., 2019)

ICU patients are lack of typical attributes of human-being

Due to the life-threatening situation, ICU patients often lack many typical attributes of human beings such as consciousness and self-determination. They can't speak. They are naked. Sometimes their arms are restrained. There are tubes inserted into their bodies, etc. Sometimes clinicians are not aware of the dehumanization because of the ICU environment.

Technolatry makes humane care in the second place

Patients come to the hospital with the expectation of restoring health. They hope to find medical caregivers with professional knowledge and skills, and suitable resources and equipment to help them get back to normal life. Scientific advances have contributed to the significant improvement of care outcomes, proven by the increased cure rate and life expectancy. The patients are objectified and health professionals become more focused on the diseases and easily ignored the experience of patients. Care frequently has shifted toward the disease, intervention, or technology instead of the persons themselves. In recent decades, people are more and more aware of the importance of patient-centered and family-centered care, but it is still hard to put into real practice.

Macroexperts in microtopics

The care management has become more and more complex and health professionals are trained with a high degree of specialization, which has produced macroexperts on microtopics and patients are compartmentalized, which makes it difficult to provide comprehensive and complete care of patients. Few health professionals have experience as ICU patients. They may lack empathy although they have professional medical knowledge and skills.

Inadequate working conditions

Intensive care is highly related to the life of patients and leaves small space for error. It is usually hard for health professionals in ICU to provide personalized care because of the High workload, inappropriate working conditions, and lack of resources. The lack of personalization harms building trust between professional caregivers, patients, and families, which may result in burnout. Health professionals may become less sensitized to provide humane care because of high workload and burnout.

Humanizing intensive care is a complex topic. It involves patients, health professionals and families. The focus of this project is patient wellbeing.

3.2 | Patient well-being

Improving patient wellbeing is a crucial part to deliver humanized intensive care. Patient wellbeing refers to "the positive experience of the individual who is in care, both during and after receiving treatment" (Sky Inside UK, 2021). Working on the patient's well-being should be as important as curing the patient. Even if the patient cannot be cured, patient-wellbeing is still very important to the patient and their families. With the development of technology and advanced medical devices, the cure rate of ICU is getting higher and higher, people are gradually more aware of the impact of intensive care on the individual, society, and psychology. Patient-centered care has become an important trend. Evaluation and support of the needs of patients are gradually being regarded as an important part of the quality of care (Velasco Bueno & La Calle, 2020).

> *" Patient wellbeing refers to the positive experience of the individual who is in care, both during and after receiving treatment (Sky Inside UK, 2021). "*

Figure 5. Definiation of patient wellbeing

Patient wellbeing is one of the most popular research domains of adult intensive care in Europe from a study conducted by the European Federation of Critical Care Nurses Associations (EfCCNa). Patient wellbeing concerns topics such as strategies to reduce anxiety fear and stress of ICU patients, communication strategies to ensure patients informational needs, psychological outcomes of ICU patients, confusion reduction, the influence of noise on ICU patients, patients' experience during and after ICU admission, prevention of PTSD of ICU patients, identify mental health problems among ICU patients, etc (Blackwood et al., 2011).

3.3 | Social support framework

Social support has a positive influence on physical, psychological and social health (Glanz, 2015). Providing social support is one of the approaches to improve patient wellbeing.

Social support is the functional content of relationships that can be categorized into four broad types of supportive behaviors or acts (House, 1981):

- **Emotional support** involves the provision of empathy, love, trust, and caring.
- **Instrumental support** involves the provision of tangible aid and services that directly assist a person in need.
- **Informational support** is the provision of advice, suggestions, and information that a person can use to address problems.
- **Appraisal support** involves the provision of information that is useful for self-evaluation purposes—in other words, constructive feedback and affirmation.

This framework provides a nice structure to identify ICU patient's needs for social support, which will be elaborated more in the patient journey later.

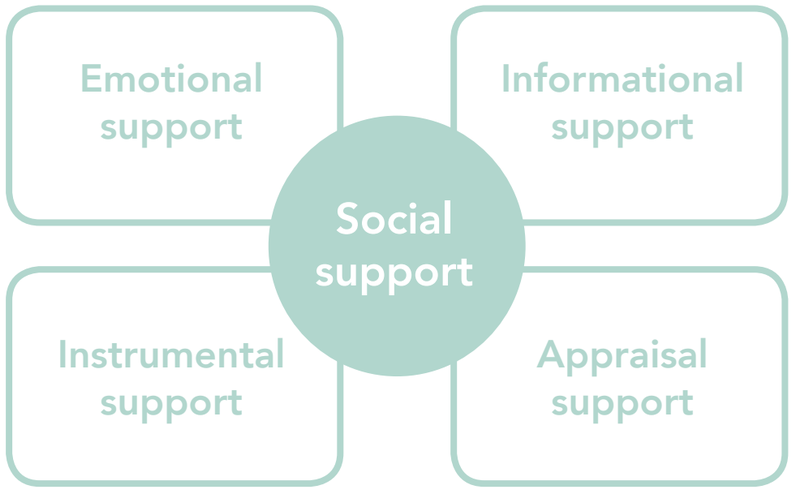


Figure 6. Social support framework

3.4 | Patient journey

Patient experience is an important concept in human-centered design. It is the sum of the interactions that happen in any organization, which influences patients' perception of the care they received during the whole journey (Wolf, 2014). Providing suitable and timely support based on patients' personal needs is important to promote a positive patient experience.

Based on the literature review, figure 8 shows patients' painpoints and social support needs during ICU treatment, ward care and after discharge (King et al., 2016).

Patients can be admitted to ICU after an emergency or planned surgery. They're admitted because the level of care they need cannot be provided in a general ward including medical devices like mechanical ventilation and 24-h nurse care. If patients turn good, they can be transferred to a general ward. (Chou, 2020)

Patients who required intensive care are in life-threatening situations. They need to rely on plenty of medical devices to maintain their lives. The disease itself has already caused discomfort and pain for the patient, this discomfort will only increase with the surgery and relevant clinical procedures. Due to intensive treatment, ICU patients are particularly vulnerable, because they often lack many of the typical attributes of human beings, such as awareness, initiative, and self-determination (Brown et al, 2017).

Many factors cause pain and discomfort in critically ill patients: thirst, cold and heat, difficulty in sleeping, and mobility due to excessive noise and light. In addition to visible physical problems, psychological and emotional suffering are invisible but have a longer impact on patients. Patients will feel lonely, isolated, fearful, loss of identity, loss of intimate dignity, loss of dependence, doubt, and misunderstanding due to lack of information (Velasco Bueno & La Calle, 2020; King et al., 2019).

3.5 | Design goal

My design goal is to explore how artificial intelligence can promote social support, which can mitigate the negative experience of patients and promote well-being, finally contributing to a humane ICU.

The focus of this project is patient experience. But the new services may also influence the workflow of nurses and require participation from other stakeholders, such as families, phycologists, and other post-ICU patients.

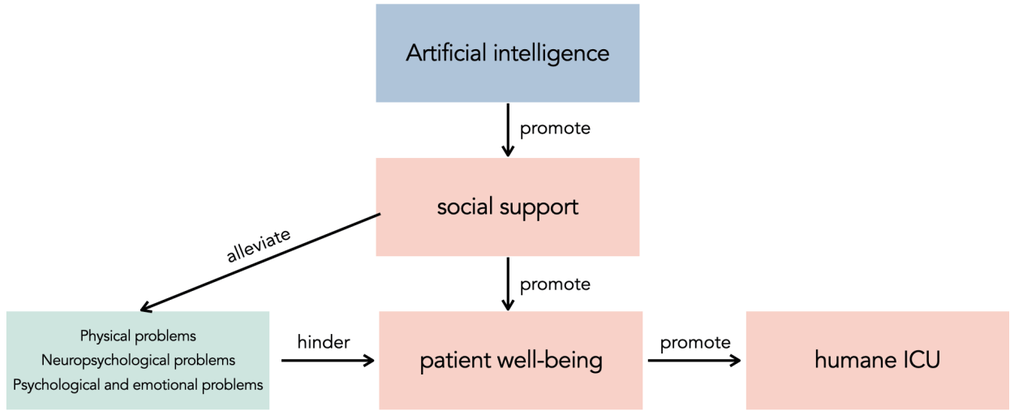


Figure 7. Design Goal

	during ICU treatment	ward care	after discharge
Painpoint	• **memory loss and a sense of being 'drugged'** because of the acuity of illness , use of sedation to facilitate treatment (e.g. mechanical ventilation) and the prevalence of delirium. • **struggled to integrate their own fragmented memories** with factual information provided by ICU staff.	• **a lack of communication between ICU and ward** staff to facilitate continuity of care. • patients felt the information from **ICU discharge summaries was too basic**.	• Patients **do not know where to obtain more information** after discharge.

nformational support need	• **repeated transfer of clear, easily understandable information** from healthcare staff to patients and families, including:
	  • the events surrounding their ICU admission
	  • data and time
	  • current health status, including their inability to speak and think clearly [24, 28].
	  • diagnosis, treatment and prognosis [25, 28].
		• **continued, clear communication** was also essential in the transition from ICU to the hospital ward.
		• **the illness event and prognosis**
		  • progress made since ICU discharge
		  • the treatments and medications needed to ensure ongoing recovery.
		  • to realise the nature, severity and short and long-term implications of their critical illness.
			• **understanding their critical illness**
			• **coping with the long-term sequelae and stress.**

Painpoint	• prior to intubation in the ICU: **terror, dread, uncertainty and facing imminent death**. • just regaining consciousness: **confusing, shattering and a feeling of emptiness**. • Initial reactions included **death anxiety, feelings of loss of control, powerlessness, panic and abandonment, fear.**	• when transferred to the ward, some patients experienced r**elocation anxiety.** • patients feel **abandoned and vulnerable** because of adjusting to a lower nurse to patient ratio as well as feeling **unimportant, isolated and neglected**. • many patients felt **depressed** because of a perception of poor physical progress following transfer.	• felt insecure about **no longer being in the safe hospital environment** in the first few months after hospital discharge • vivid memories of ICU experiences involving **terrifying dreams and flashbacks**. • • **Fear and worry** about the complexities of their illness persisted for months. • **reticent about seeking telephone support** due to a presumption that nurses were busy or had forgotten them. • feel **stressed and depressed** when re-integrate back into the community
emotional support need	• the need for **comfort** in words and touch from nurses. • the **support of family:** During the ICU treatment, patients are easier to develop a coping strategy to stress when they know their relatives could be contacted easily. The family support led to **feelings of happiness and security**. The need for family support and attendance extended across time.	• **security and familiarity**: the need that patients expressed for security and familiarity was often jeopardised.	• **a lot of reassurance from nurses.** • Patients were more optimistic and positive about their discharge with family members and **support networks**. • need for mechanisms to allow an **emotional outlet** for themselves and their family members, including the support of community-based healthcare providers. • **re-building psychological independence and confidence** • **a support group** where they had met others who truly understood the experience.

	during ICU treatment	ward care	after discharge
Painpoint	• **discomfort** arising from a debilitating lack of sleep, noise, fatigue, pain and anxiety.	• they **rarely experienced continuity** of medical care	• **trauma-related disabilities** such as loss of a limb or paralysis, loss of muscle strength and tone resulting in inability to stand, and decreased strength and endurance. • struggled for independence to **re-establish their premorbid physical strength.**
instrumental support need	• **personal care, hygiene and comfort**, particularly relating to **bathing, nutrition and pain relief**. • **better sleep quality**	• need **considerable physical help** from either the staff or family carers	• with a need for **continued observation and support from caregivers** to prevent harm due to patient forgetfulness. • **physical support** at home from community-based healthcare providers to assist them to become independent • the need for support from society to **find appropriate work** to prevent falling into financial difficulties with paying housing and hospital bills.
Painpoint		• many patients noted that **ward staff knew little about them** and therefore could not provide feedback on how they were progressing.	
appraisal support need		• Patients with **high self-efficacy** were sometimes able to meet their own needs by drawing on previous life experience and this provided them with an element of 'appraisal' not captured by House's original definition.	• **building up defence and coping mechanisms** such as active coping, positive reframing, humour, acceptance, optimism, hope, self-sufficiency, goal-setting and spirituality. • **meeting others who had been through the ICU experience** and understood the challenges they were addressing.

Figure 8. patient journey

Chapter 4 AI inspirations and opportunities

The aim of this chapter is to explore AI opportunities that can potentially promote social support for ICU patients and prepared them for ideation. This chapter shows the result of the current research and practices on AI in ICU and more AI inspirations from wider fields.

3.1 | AI in ICU

Artificial Intelligence (AI) is a system “endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from experience.” (Gutierrez, 2020).

Compared with humans, AI has advantages over:
- vast memory storage.
- excels at handling multidimensional problems.
- can discern small or “fuzzy” associations within massive data collections.

Although the application of AI in ICU is still in the initial stage, there are many pilot studies regarding continuous monitoring, risk prediction, and clinical decision support system (Table 1). Most of the research is aimed at using medical data to improve clinical results, improve efficiency and accuracy, and ensure the safety of patients, but there are still some studies relevant to improve patients' experience, such as the reduction of false alarms.

Topic	Solution	Author	Description
Continuous monitoring	Semi-automated tracking of pain	(Kobayashi et al., 2021)	Objective methods of pain assessment, such as the Critical-Care Pain Observation Tool (CPOT)and Behavioral Pain Scale are cumbersome and do not facilitate continuous monitoring of pain. AI-based tools have the potential to provide continuous and automated pain assessments that can eliminate the effects of uncertainty caused by discrete decision-making, such as that based on pain assessment scales.
	Pervasive Sensing	(Davoudi et al., 2019)	Currently, many critical care indices are not captured automatically at a granular level, rather are repetitively assessed by overburdened nurses. This pilot study examined the feasibility of using pervasive sensing technology and artifcial intelligence for autonomous and granular monitoring in the Intensive Care Unit (ICU).
Risk prediction	Sepsis prediction	(Nemati et al., 2018)	The goal of applying AI methods to sepsis evaluation is to rapidly yield an accurate diagnosis of sepsis, earlier than traditional methods, and thereby to reduce complications from sepsis. Much effort has been dedicated towards preventing sepsis via electronic alerts that are designed around the Systemic Inflammatory Response Syndrome (SIRS), quick Sepsis Organ-related Failure Assessment (qSOFA), and Modified Early Warning Score (MEWS). These traditional predictive models currently are being used as benchmarks against the modern rise of ML algorithms.
	mortality prediction	(Nemati et al., 2018)	Traditional mortality prediction models and severity scoring systems, like the Mortality Prediction Model (MPM0) and Acute Physiology & Chronic Health Evaluation (APACHE III), respectively, have limitations, such as missing data points at admission or usable only after 24 to 48 hours of admission. AI methods have been proposed as a solution to these challenges, due to the ability of machines to update and learn from provided data continuously.
	Tachycardia prediction	(Yoon et al., 2019)	Tachycardia is a strong though non-specific marker of cardiovascular stress that proceeds hemodynamic instability. A predictive model of tachycardia was designed using multi-granular intensive care unit (ICU) data by creating a risk score and dynamic trajectory. This study showed that clinically relevant tachycardia episodes can be predicted from vital sign time series using machine learning algorithms.
	Delirium prediction	(Davoudi et al., 2017)	Delirium is a common transient neuropsychiatric disorder exhibited abruptly with fluctuations in consciousness and mental status. Machine learning models were used to predict postoperative delirium based on preoperative Electronic Health Records.
	Thromboembolic complications prediction	(van de Sande et al., 2020)	Clinically relevant thromboembolic complications frequently occur in critically ill COVID-19 patients, which can successfully be predicted using a decision tree model based on electronic health record data of 108 consecutive COVID-19 patients.
CDSS: Clinical Decision Support System	Reduction of false alarms	(Au-Yeung et al., 2019)	Based on signal processing, feature extraction, and machine learning tools, this study proposed a new method to reduce the number of false alarms generated by bedside monitors in the intensive care unit (ICU), as a majority of current alarms are false.
	mechanical ventilation	(Nemati et al., 2018)	Mechanical ventilation is the mainstay treatment for acute respiratory failure (ARF), a common occurrence in ICU patients. Using an ML framework, a study was able to replicate human expertise by interpreting different patient-ventilator asynchrony waveforms. AI has the ability to alleviate workload through automation and by its ability to monitor patients continuously.
	Sepsis treatment	(Komorowski et al., 2018)	This study developed a reinforcement learning agent, the Artificial Intelligence (AI) Clinician, which extracted implicit knowledge from an amount of patient data that exceeds by many-fold the life-time experience of human clinicians and learned optimal treatment by analyzing a myriad of (mostly suboptimal) treatment decisions and demonstrate that the value of the AI Clinician’s selected treatment is on average reliably higher than human clinicians.

Table 1. Current research on AI in ICU

3.3 | AI in Healthcare

This section shows more possibilities to provide social support in the healthcare domain, which may also be applied to ICU patients.

Figure 9 shows a therapeutic robot in the nursing house that can stimulate interaction between patients and caregivers. It was proved to reduce patient stress (Parorobots, 2014).

Figure 10 shows a prototype of an avatar as a psychologist to reduce the stigma of seeking help. They found humans are more forthcoming with an avatar than they did with a real doctor because they feel less judgemental (SimSensei, 2021).

Figure 11 shows how a team from google helps an ALS patient to better control a virtual assistant app by voice. It involves speech recognition. First, the sound of the voice is converted into a waveform, and waveforms are then matched to transcriptions. This is where machine learning takes over. Using millions of voice samples, a deep learning model is trained to map input sounds to output words. Then the algorithm uses rules, such as grammar and syntax, to predict each word in a sentence. Also, the team reproduced the patient's original voice before the illness. Voice imitation, also known as voice synthesis, was used to clone the voice based on videos when the patient was healthy. Voice imitation is speech recognition in reverse. First, machine learning converts text back into waveforms. These waveforms are then used to create sound (Cattiau, 2019)

Figure 12 shows an example of mental health app. Because of the lockdown due to covid-19, people have to change lifestyles and get easier to have mental health problems. Also, it's hard to turn to psychologists in person. Thus, mental health apps have become popular. Most mental health apps involve natural language processing to understand people's emotional and psychological states such as Wysa and Woebot. Some apps also collect data from wearable devices such as BioBase. An app called Ginger monitoring the behavior data including the duration of their talking, sleeping, or exercising. These apps help people manage to go through the lockdown period when they need emotional and psychological support (The Medical Futurist, 2019).

Figure 13 shows the Skywalker Hand that uses ultrasound tech to help the disabled. Ultrasound uses high-frequency sound waves to capture live

Figure 9. Paro (Parorobots, 2014)

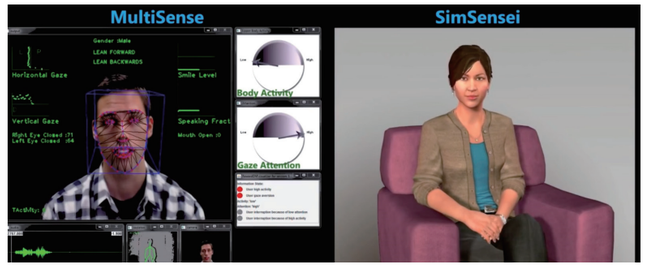


Figure 10. Avatar as a psychologist (SimSensei, 2021)

Figure 11. Voice control for ALS patients (Cattiau, 2019)

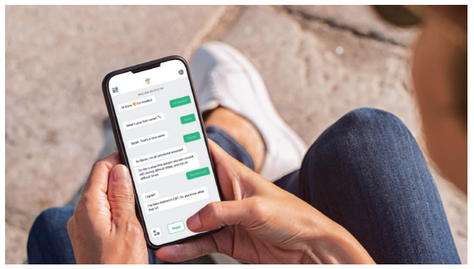


Figure 12. Chatbot for mental health (The Medical Futurist, 2019)

Figure 13. Skywalker Hand (Ackerman, 2021)

Figure 14. Baby X (Fxguide, 2017)

images from inside the body. As a person flexes his muscles to move each of his missing fingers, ultrasound generates live images that visualize his intention. The A.I. then uses machine learning to predict patterns, letting a man who's lost one of his hands move all five of his fingers individually (Ackerman, 2021).

Figure 14 shows Baby X, an avatar on-screen that can interact with people. Baby X uses a type of A.I. called "object recognition." It's how a computer identifies an object or tells the difference between objects. It's something that humans can do naturally. But machines, like Baby X, need to sift through enormous piles of data to search for patterns. Also, the research group is working on "affective computing," which means that A.I. interprets and simulates human emotion through perception and conversation. A.I. needs to understand humans and emotion A.I. can enable machines to have empathy (Fxguide, 2017).

3.4 | AI in other fields

This section shows more possibilities to provide social support in other fields, which can be inspiring for this project.

Figure 15 shows a website that can clone voice. 200 voice samples are required to clone a voice. People can record voice samples based on the sentences provided on the website. Through a text-to-speech generator, any text can be transformed to audios with your voice (Resemble AI, 2021).

Figure 16 shows an AI algorithm that can make it easier for users to find the right person using the dating apps, which is called collaborative filtering. The decisions of current users can affect the options seen by future users. This can affect what dating profiles that users are suggested. For apps like Tinder and Bumble, submitting to collaborative filtering is a necessary component of the experience (ITRex, 2021).

Figure 17 shows a chatbot of smart customer services. The overall volume of interactions is rapidly increasing, as consumers have more questions about the products and services that they are using, and expect more from the brands that they deal with. Machine learning can be used to drive efficiency and speed up service. A customer may be suggested an existing answer immediately or a customer can be immediately directed to the right staff member with the relevant expertise to deal with their problem (Trifork, 2020).

Figure 18 shows Magenta, which is an open-source research project exploring the role of machine learning as a tool in the creative process. By training the open-source models using provided datasets, musicians can get a melody with the same style (Magenta, 2021).

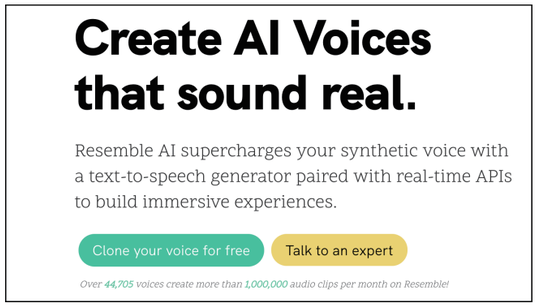


Figure 15. Voice clone (Resemble AI., 2021)

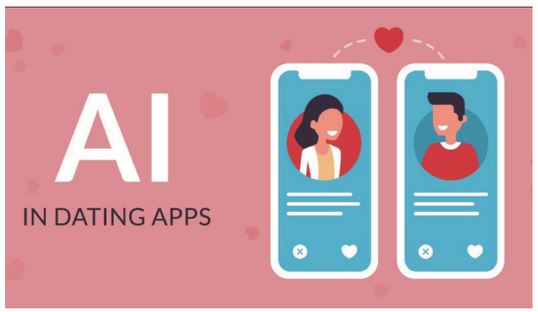


Figure 16. dating apps (ITRex, 2021)

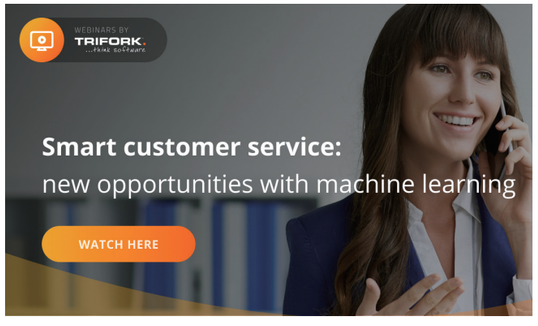


Figure 17. Smart customer service (Trifork, 2020)

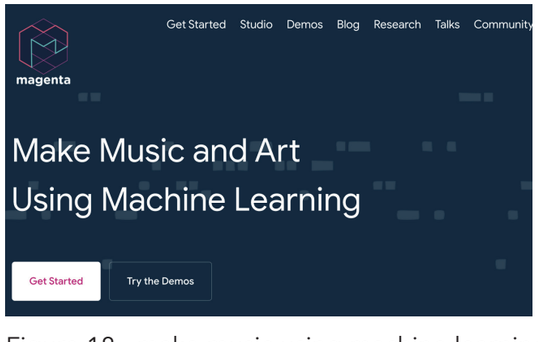


Figure 18. make music using machine learning (Magenta, 2021)

Chapter 5 Design concept - Cricare

Based on the AI inspirations, a brainstorming section was conducted. Nine ideas were chosen and a future vision called Cricare was framed. Nine idea cards were made to better elaborate the future vision.

4.1 | Brainstorming

Based on the social support framework and all the AI inspirations, a brainstorming section was conducted to explore ideas.

Criteria were set to select ideas:

- The ideas should target on a painpoint in the patient journey,
- The ideas should be relevant to a feasible A.I.
- The ideas don't require sensitive data
- The ideas can be provided through similar touchpoints, such as an earphone, an iPad, a mobile phone, or a robot.

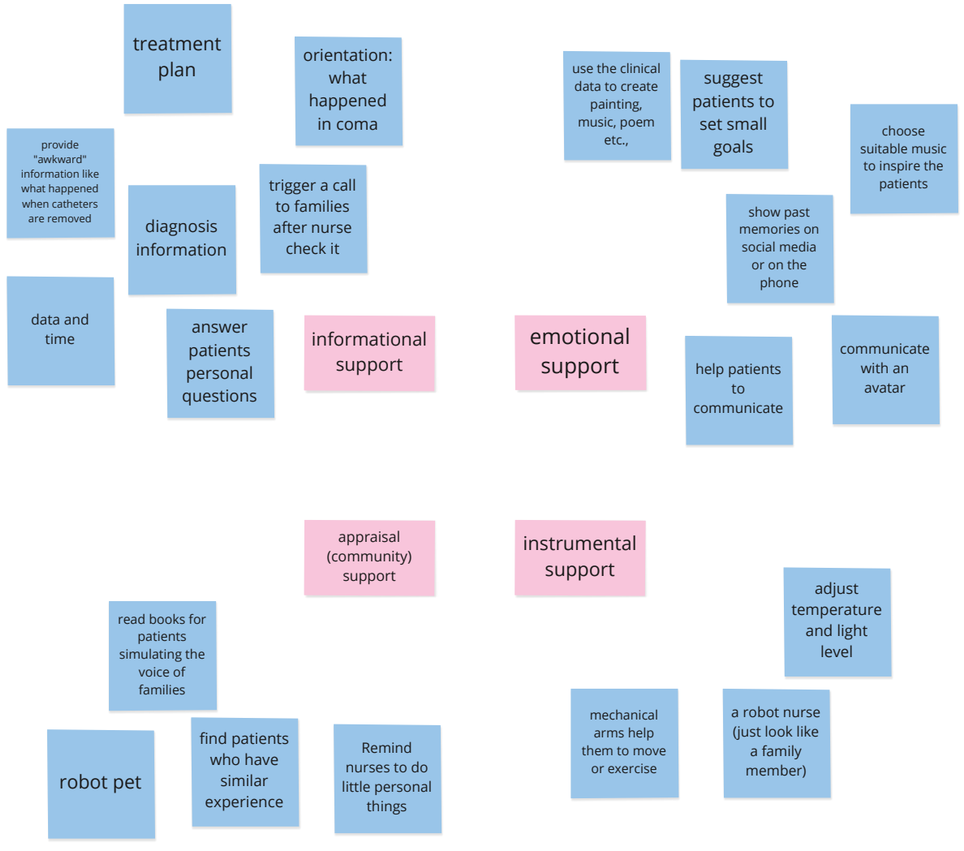


Figure 19. Brainstorming

4.2 | Design ideas

In the end, nine ideas are chosen. All of them can be provided through an iPad and a mobile phone. Figure 20 shows a drawing of all selected ideas. When putting them on the journey map, five of them (with pink background) can be provided in ICU and the other four can be provided during the whole journey (with blue background).

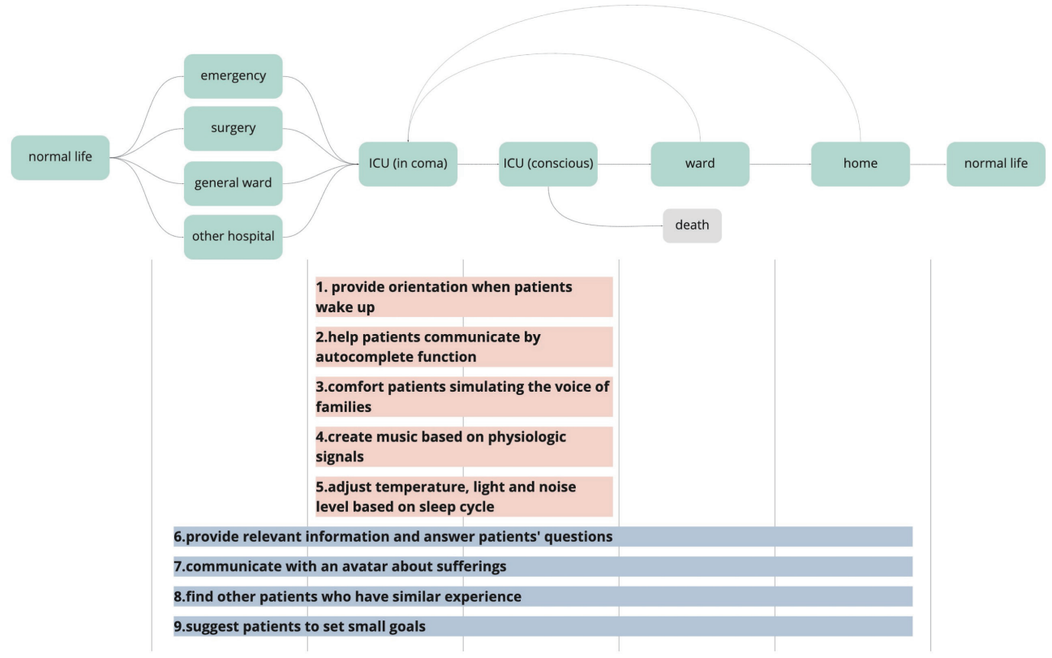


Figure 20. Design ideas on patient journey

help patients to type by autocomplete

Some patients use alphabets to communicate when they can't speak, The smart device can help patients by autocomplete.

NLP

answering questions

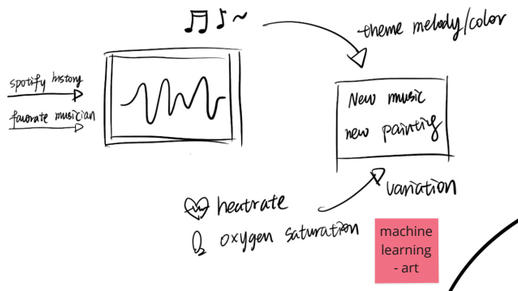
The smart device can provide relevant information for patients or answer questions that patients ask, such as some awkward questions like what happened when catheters are removed.

Create music & painting by physiologic signals

When patients are unconscious, the smart system can create music/paintings by physiologic signals.

- create theme melody based on patients' habit of listening to music
- create variations based on the physiological signals of patients

monitoring data
personality data - machine learning



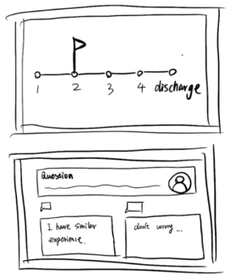
NLP

communicate with an avatar about sufferings

When patients don't want to show their pain to families. They can communicate with an avatar about their pain and suffering.

voice recognition
NLP

recomendation system

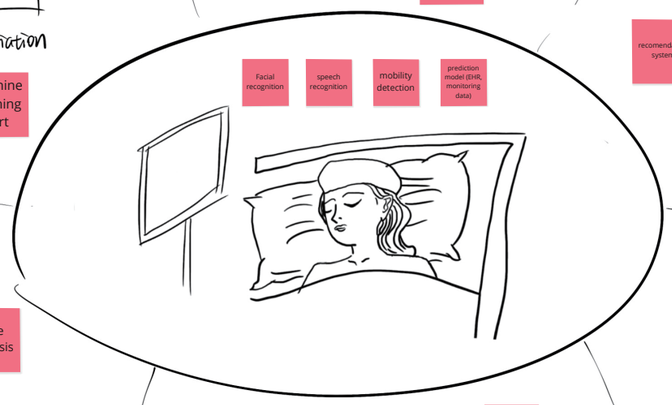


suggest patients to set small goals

The smart system can motive patients by suggesting to set small goals based their own health condition. suggest patients to get rid of supporting machines one by one

emotion recognition
recommendation system

- past practices of other patients
- own EHR



recognise the consciousness of patients and provide orientation

The smart device can recognise the consciousness of patients and tell patients what happened, the data and time, and introduce the nurse who is going to take care of the patients, and trigger a call to families.

consciousness detection
voice synthesis

voice synthesis

find patients who have similar experience

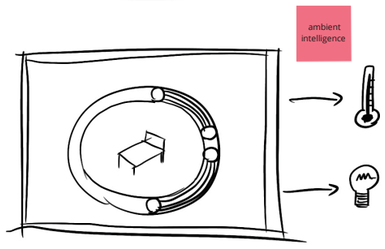
Smart devices may find someone who had similar experience online to answer patients' questions. And it can create an online community for patients to share experiences.

emotion recognition
recommendation system

read books for patients simulating the voice of families

When patients are semiconscious or have a little delirium, perhaps the voice of family can make them calm. So maybe we can let AI simulate the voice of families to read books for them.

consciousness detection
voice recognition
voice simulation



ambient intelligence

adjust temperature, the level of light and alarm based on sleep cycle

the system will adjust the light level and temperature based on the patients sleep cycle. If alarm system rings, the light will gradually become lighter before the nurses come.

Figure 21. design ideas

4.3 | Future vision

Envision a smart system called **Cricare** that can **provide social support** for ICU patients to promote **patient well-being.**

Figure 22. Future vision

The selected nine ideas support a future vision. It is a smart system that can provide social support for ICU patients to promote patient well-being. The name Cricare comes from the first three letters of "Critical" and "care".

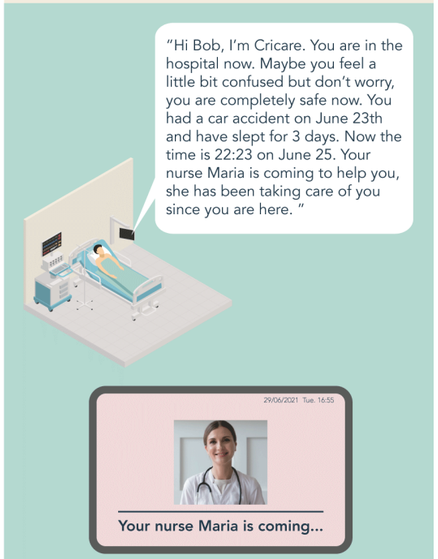
4.4 | Idea card

Figure 23 - 31 shows nine idea cards to better elaborate the concept.
For each idea, it showed a description of the painpoint and solution, an illustration of the scenario, AI capability, and what nurses need to help deliver the service.

1 | Provide orientation when patients wake up

Many ICU patients experience memory loss and a sense of being 'drugged' because of the acuity of illness, use of sedation to facilitate treatment (e.g. mechanical ventilation) and the prevalence of delirium. They feel confused when they wake up in the ICU.

Cricare can provide orientation when patients wake up. This service happens in the ICU or the ward if the patient is still delirious.



The orientation includes:
- words for comfort
- what accident/surgery happened on which date
- how many days the patient has been in a coma
- an introduction of the nurse who is coming
- current date and time

AI capability

Image recognition: Cricare can recognize when the patients wake up by telling if they open their eyes.

Text-to-Speech: Cricare can provide orientation by speakers based on the EHR of patients.

Nurse input

When patients wake up, Cricare will alarm the nurse and provide orientation before the nurse arrives.

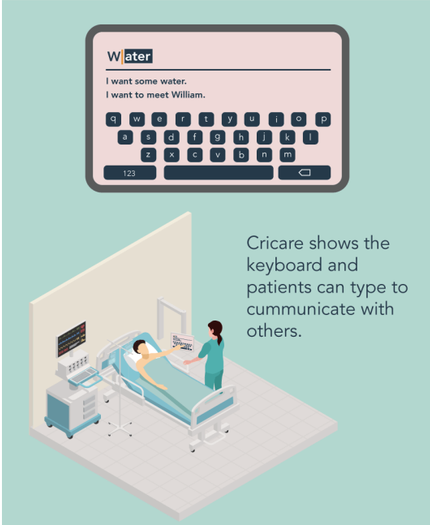
If this is the first time that the patient wakes up, after the nurse checks the state of patients and makes sure they have the ability to meet families, the nurse can push a button to send families a message or trigger a call to let families know that the patient is ready to meet.

Figure 23. Orientation

2 | help patients communicate by autocomplete

In ICU, some patients can't speak because of the oxygen mask, which makes it hard to communicate with nurses.

Criticare can help patients by autocompleting the words and sentences that they want to say. It can save time and energy for patients to communicate with others when they can't speak.



AI capability

Autocomplete prediction: machine learning is used to give the most relevant autocomplete result based on popularity, freshness and similarity between target patients and other patients according to EHR data.

Nurse input

When nurses notice that patients want to communicate, they can help open the keyboard on Cricare.

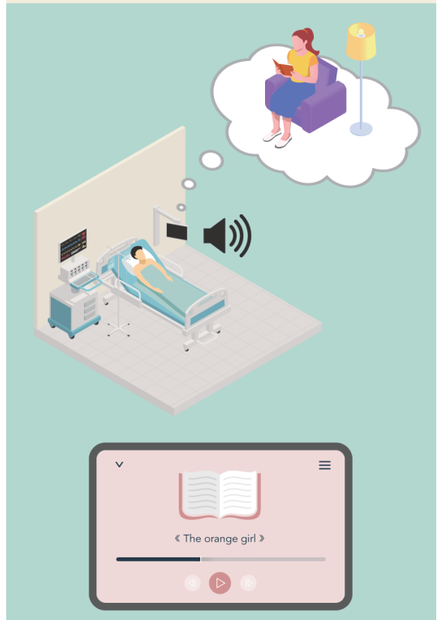
Nurses and patients can enrich the data-base of possible questions when the recommendation result is not accurate.

Figure 24. Autocomplete

3 | Comfort patients simulating the voice of families

The presence of family members is important for ICU patients, but it's hard for family members to accompany patients anytime they want.

Cricare can simulate the voice of the family to let them calm down when the patient is anxious and delirious. It can also read books for patients regularly during the day to make patients feel less lonely.



AI capability

Voice clone: Cricare can simulate the voice of a family based on pre-recorded voice samples.

Nurse & family input

The family needs to record standard voice samples in order to clone the voice.

Nurses can set how often the Caricare read books based on patients' health condition.

Figure 25. Voice simulator

4 | Create music based on physiologic signals

Being in ICU is usually a negative experience for patients. Cricare can create music based on the physiologic signals of patients. When patients wake up, they can get personalized music as gifts. The music can make them feel proud of how they manage to overcome the difficult time when they go back home and remember the ICU experience. Besides, the music can be an inspiration for those patients who are musicians to create new music.

AI capability

Machine learning: Cricare creates the theme melody based on patients' habits of listening to music. For example, if the patient is a fan of the Beatles, the theme melody is similar to the style of the Beatles. Then the variations are created based on the physiological signals of patients (heart rate, respiration rate, etc.)

Nurse input

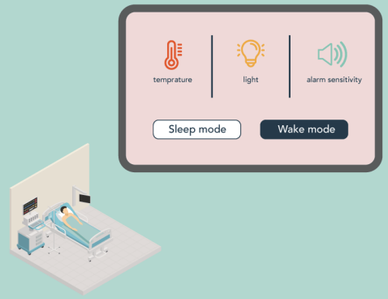
If patients are admitted because of planned surgery, nurses can ask patients' habit of listening to music before they are admitted to ICU.

If patients are admitted because of an accident, nurses can ask families to choose which music may represent the style of the patient.

Figure 26. Music Creator

5 | Adjust environment based on sleep cycle

Many ICU patients have sleep problems. Caricare can suggest nurses adjust the light and temperature level based on the patient's sleep cycle and lower the sensitivity of alarm when patients fall asleep. In case of emergency, if the alarm system rings while patients are sleeping, the light level will gradually become higher before the nurses come.



AI capability

Image recognition: Cricare can recognize if the patient is awake or asleep and automatically switch the mode.

Machine learning: Cricare can reduce false alarms based on signal processing and feature extraction.

Nurse input

Nurses can check the settings of sleep mode and wake mode.

Figure 27. Environment adjuster

6 | Provide relevant information and answer patients' questions

In the ICU, sometimes patients don't want to ask nurses awkward questions like what happened when catheters are removed. Besides, after discharge, when patients want more information, they don't know where to obtain it.

Cricare can provide relevant information for patients or answer questions that patients ask, including:
- Could you explain my disease?
- What will happen to me until recovery?
- How long can I get out of the hospital?
- When can my families visit me?
- What will happen when catheters are removed?

.....

AI capability

Collaborative filtering: Cricare can give the most relevant articles based on the similarity between target patients and other patients according to EHR data.

Machine learning and Natural language processing (NLP): Cricare can provide human-like conversational experience.

Nurse input

The nurse will answer the question if Cricare can't handle it and update the database.

Figure 28. Chatbot

7 | Communicate with an avatar about sufferings

When patients feel unmotivated or anxious, but they don't want to show their pain to families, they can communicate with Cricare about their pain and sufferings.

This service happens in the ICU when patients can speak or type, in the ward, or after discharge.

AI capability

Machine learning and Natural language processing (NLP): Cricare can provide human-like conversational experience.

Affective computing: Cricare can interpret the patients' emotion.

Psychologiest input

If Cricare recognizes that the patient has a mental health problem, the test result will be sent to a psychologist for further treatment after getting the patient's consent.

Figure 29. Virtual Psychologist

8 | Find other patients who have similar experience

By communicating and comparing with paitents who had similar experience and already recovered, ICU pateints can become more rational about their own recovery process and feel supported by a community.

Cricare can create an online community for ICU patients and post-ICU patients to share experience. ICU patients may find similar patient online to have a chat. Patients can also ask questions in the online community to get answers from recovered patients.

This service happens in the ICU when patients can speak or type, in the ward, or after discharge.

AI capability

Collaborative filtering: Cricare can find the most relevant patients based on the similarity between target patients and other patients according to EHR data.

Recovered patient input

Every ICU patient will be asked if they want to join the online support community and share their data for the recommendation algorithm.

Recovered patients can get a notification to answer the questions from patients who have similar experiences based on the EHR data.

Figure 30. Peer support

9 | Suggest patients to set small goals

Many ICU patients feel unmotivated because of the severity of the disease and terrified by the fact that they need to stay in ICU for a long time. Some patients feel disappointed after discharge because they can't go back to the normal life as they expected.

Caricare can motivate patients by suggesting they set small goals. Patients can get a feeling of control gradually and regain the hope of getting back to normal life.

This service happens in the ICU when patients can speak or type, in the ward, or after discharge.

AI capability

Collaborative filtering: Cricare can show examples of similar recovered patients and give goal-setting suggestions based on the similarity between target patients and other patients according to EHR data.

Nurse input

Nurses can check the feasibility of the goal.

Figure 31. Goal setter

Chapter 6 Evaluation with Nurses

To test the design concept Cricare, an evaluation questionnaire was designed to get the nurses' opinions. This chapter shows how the questionnaire was designed and the key insights of the responses from nurses.

4.1 | Questionnaire design

The purpose of the questionnaire is to get nurses' opinions on the design concept. The questionnaire consists of 5 parts.

Part 1. Introduction (Figure 32): This part consists of a short introduction of the project background, the purpose of the questionnaire, an illustration of the design concept, and a guide for the questionnaire.

Part 2. Informed consent (Figure 33): This part introduces what kind of data are required from participants and the rights of participants.

Part 3. Nine idea cards to get nurses' opinion (Figure 34): This part shows nine idea cards one by one. Following each idea, there are 5-point linear scale questions on the desirability, importance, to what extent it would satisfy patients' social support need, and to what extent it would promote patients' well-being. In the end, is an open question to get suggestions on how to improve this idea.

Part 4. Overall comments about Cricare (Figure 35): This part includes one 5-point linear scale question to rate the overall concept, one question to pick 3 favorite ideas, and open questions for comments and new ideas.

Part 5. Background information about participants: The purpose of this part is to know participants' roles in ICU, age range, working years, and gender.

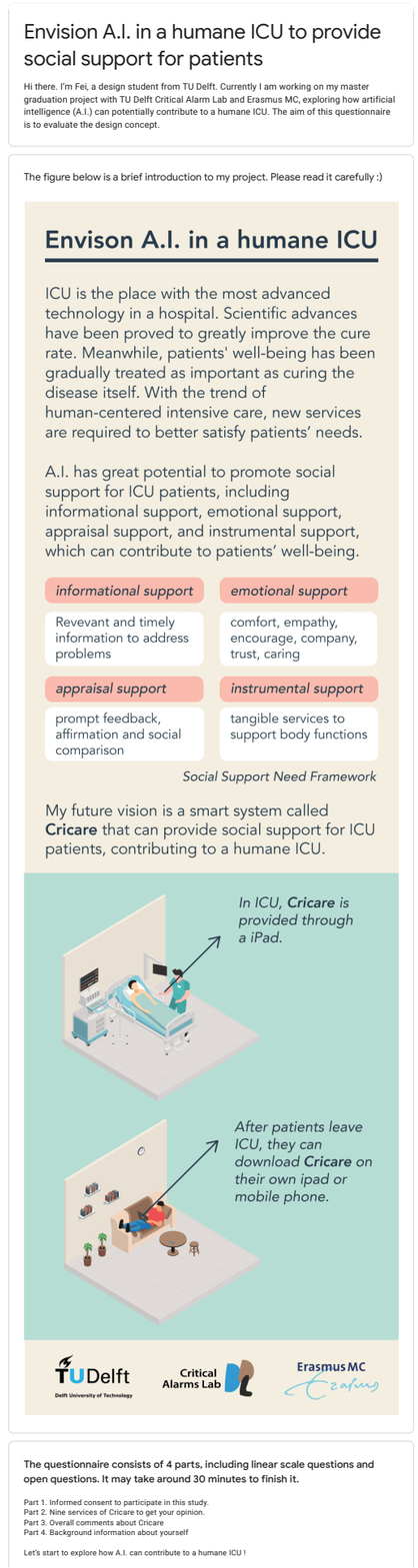


Figure 32. Introduction

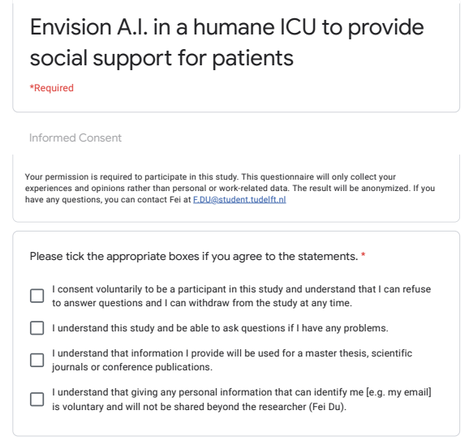
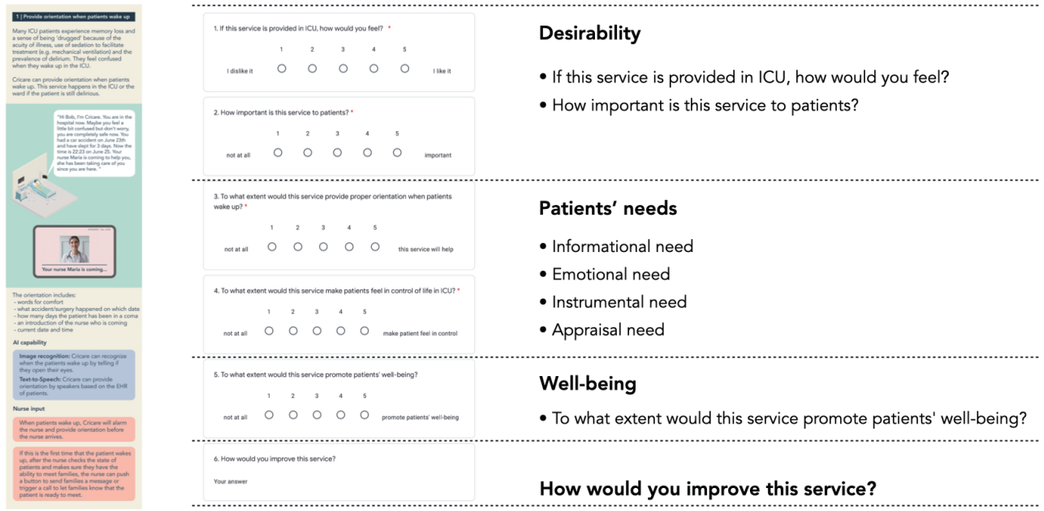


Figure 33. Infromed consent



Desirability

- If this service is provided in ICU, how would you feel?
- How important is this service to patients?

Patients' needs

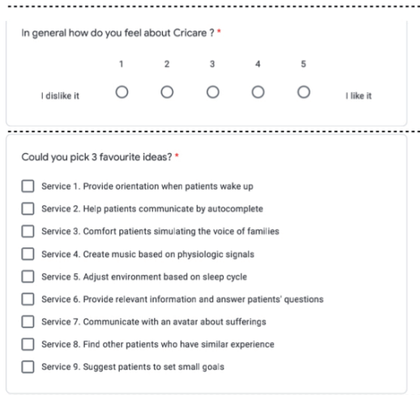
- Informational need
- Emotional need
- Instrumental need
- Appraisal need

Well-being

- To what extent would this service promote patients' well-being?

How would you improve this service?

Figure 34. One of Nine idea cards to get nurses' opinion



Overall comments about Cricare

Pick 3 favourite ideas

Open question for comments

Open question for new ideas

Figure 35. One of Nine idea cards to get nurses' opinion

4.2 | Key insights

The questionnaire was sent to nurses in the ICU of Erasmus MC and got five responses. Table 2 shows the basic information of participants. Four participants are female and three participants have been working as nurses for more than 10 years.

	role in ICU	working years	age	gender
1	Nurse	>10 years	50-60	Female
2	Psychologist, researcher and nurse	>10 years	50-60	Female
3	Nurse	2-5 years	20-30	Male
4	Nurse	less than 2 year	20-30	Female
5	Nurse	>10 years	30-40	Female

Table 2. Participants

Figure 36 shows most of the participants rated a score of 4 for the concept. They said in general it's an interesting tool, but It still needs tweaks. Not all ideas are worth a big investment. It also requires a feedback system (the AI cannot test how the information arrives and thus potentially cause a lot of confusion).

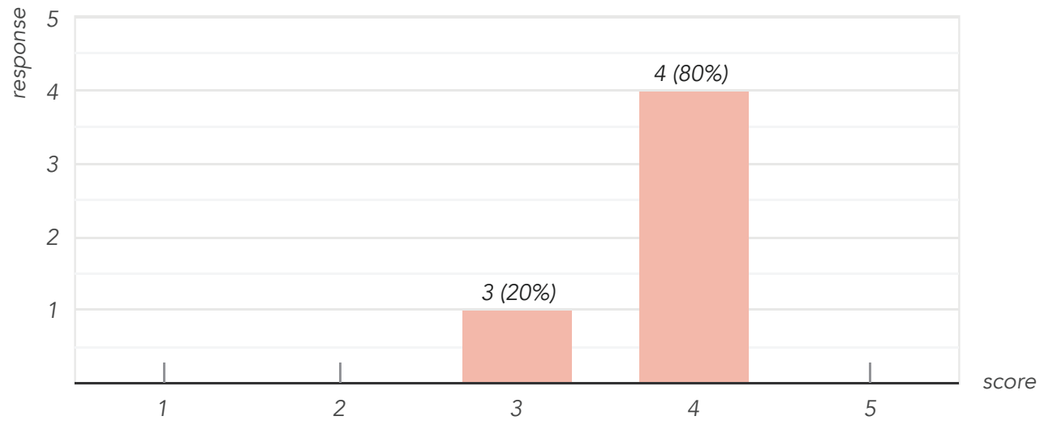


Figure 36. In general how do you feel about Cricare ?

Figure 37 shows the results of picking 3 favorite ideas. *Idea 2 Help patients communicate by autocompleting function* and *Idea 5 adjust environment based on sleep cycle* got the highest score, followed by *Idea 1 Orientation, Idea 4 Music creator, Idea 8 Peer support, and Idea 9 Goal setter.*

Figure 38 shows how people rate desirability (Green), importance (pink), and effect on the well-being of nine ideas (blue). The dot shows the mean score while the line describes the range. It tells that *Idea 5. Environment adjuster* got the most stable response because all participants rate the score of 4. *Idea 1 Orientation, Idea 8 peer support, and Idea 9 Goal setter* also got a relatively high score.

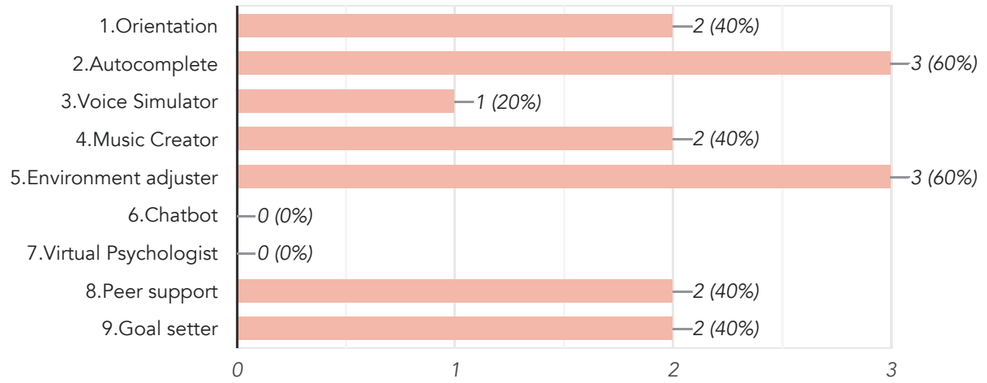


Figure 37. Could you pick 3 favourite ideas?

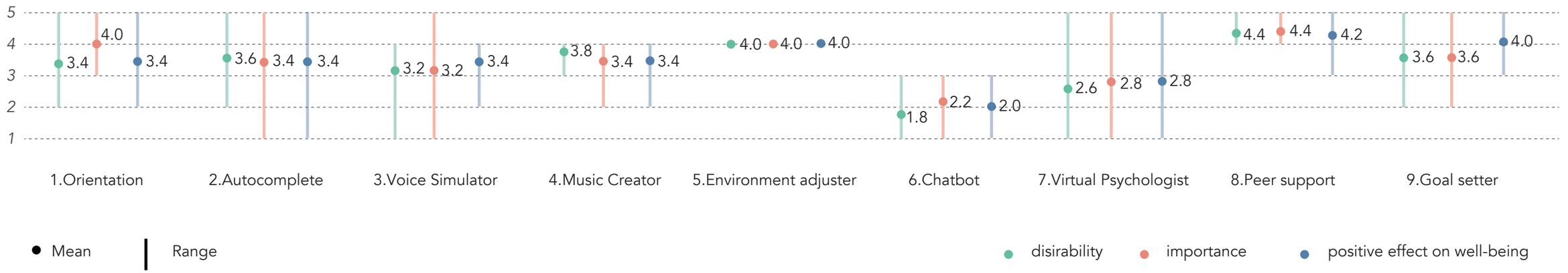


Figure 38. the disirability, importance and effect on well-being of nine ideas

Table 3 shows the category and effect of social support that nine ideas can provide. In general, most (12/17) of the responses are above the score of three, which means that the ideas can provide social support for ICU patients. However, some participants thought *Idea 1 Orientation* can only provide informational support but can't provide emotional support. *Idea 6 Chatbot and Idea 7 Virtual psychologist* got scores under three.

Below are the insights of the open questions - *How would you improve the idea?*

Idea 1 Orientation: Because patients are dizzy, sleepy, disoriented, and forgetful, they need repetition of the messages. The message that Cricare provides should be thought over. For example, use 'sleep' instead of ‘days in coma’. Also, information on and from families can be provided. There is a risk that this service can make some patients restless.

Idea 2 Autocomplete: a participant told a lot of patients can’t type, so the addition of pictures is preferred. Another participant mentioned there already are apps about communication that are under development for further improvement, so they can be combined into the whole journey.

Idea 3 Voice Simulator: There are not many comments on *idea 3 Voice simulator*. Just a participant pointed out that a voice can be comforting but can never replace the real presence of family members. But the purpose of this service is not to replace family members, but to provide comfort when families are not available.

Idea	Question	Social support	Min	Max	Mean
1.Orientation	3. To what extent would this service provide proper orientation when patients wake up?	informational support	2	4	3,6
	4. To what extent would this service make patients feel in control of life in ICU?	emotional support	1	4	2,6
2.Autocomplete	3. To what extent would this service help patients to communicate?	instrumental support	1	5	3,4
	4. To what extent would this service make patients feel in control of life in ICU?	emotional support	1	5	3,4
3.Voice Simulator	3. To what extent would this service make patients feel being supported by families?	Appraisal support	3	4	3,4
	4. To what extent would this service help patients feel less lonely?	emotional support	3	5	3,6
	5. To what extent would this service make patients feel less anxious?	emotional support	2	4	3
4.Music Creator	3. To what extent would this service help patients feel positive about ICU experience?	emotional support	2	4	3,2
	4. To what extent would this service make patients feel proud of managing to overcome the difficult time during ICU?	emotional support	2	4	3,2
5.Environment adjuster	3. To what extent would this service help patients to sleep well?	instrumental support	4	4	4
6.Chatbot	3. To what extent would this service help patients to obtain information?	informational support	1	3	1,6
	4. To what extent would this service make patients feel in control of life?	emotional support	1	3	2
7.Virtual Psychologist	3. To what extent would this service help patients deal with emotion problems?	emotional support	1	5	2,8
8.Peer support	3. To what extent would this service make patients feel supportive?	Appraisal support	4	5	4,6
	4. To what extent would this service help patients find relevant information?	informational support	2	5	4
9.Goal setter	3. To what extent would this service make patients feel in control of life in ICU?	emotional support	3	5	4
	4. To what extent would this service make patients feel motivated?	emotional support	3	5	4

Table 3. the catogory and effect of social support that nine ideas can provide

Idea 4 Music creator: From the comments, two patients misunderstood this service, because they thought it is about playing music for patients instead of creating music based on physiological signals. There is also a risk that the music could also be a bad reminder of a very bad, painful, and lonely time.

Idea 5 Environment adjuster: Two participants mentioned that apart from the ‘wake or sleep’ mode, it should have a setting for the time-blocks for day and night. It cannot switch to a daytime mode when patients wake up at night.

Idea 6 Chatbot: Two participants didn’t believe that a chatbot can answer all questions from patients. They thought every situation is different and needs its own approach and answers aren't black and white. And if the chatbot can’t answer the questions, it would be very much work for the nurses to fill the answers in for every patient.

Idea 7 Virtual psychologist: Two participants mentioned they didn't understand this question.

Idea 8 Peer support: Two participants point out there are already similar services provided on IC connect, so the service can be combined into the whole journey.

Idea 9 Goal setter: It can include also a rehabilitation schedule from a physiotherapist to help patients set goals.

Chapter 7 Roadmap for A.I. to provide social support

Based on the nine ideas, technology scouting was made to understand the feasibility. Eventually, a roadmap shows how A.I. can possibly provide social support for ICU patients.

4.1 | Technology Scouting

The technical feasibility of the future vision is an important factor that influences the design of the roadmap (Calabretta, 2016). In this project, data and AI capability are two important considerations. Figure 39 explains the data and AI capabilities that each idea may require.

Based on Figure 39, similar AI capability and data were combined. Figure 40 shows the combined result. It shows there are four kinds of AI capability that are required, including recognizing if patients are awake, chatbot and recommendation system, text to speech and machine learning to create music.

	AI capability	Data
1. provide orientation when patients wake up	Recognise if the patient is awake or fall asleep	patient image data, voice data and monitoring data
	Text-to-Speech	patient name, what accident/surgery happened on which date, how many days have patients been in coma, nurse name, current time.
2.help patients communicate by autocomplete function	collaborative filtering	patients' age, gender, diagnosis result, health condition from the EHR system.
		a database for questions that the patients want to ask in ICU.
3.Comfort patients simulating the voice of families	Voice clone	voice samples from families
	Text to Speech	a database for comfort words.
		a database for books.
4.Create music based on physiologic signals	machine learning - create melody based on music styles	music sample of patients' favorite musicians.
	creates variations based on the physiological signals of patients.	record patients' physiological signals (heart rate, respiration rate) when transitions happen, such as being hospitalised, waking up at the first time, the first time meeting family, emergency, transition to the ward.
5.adjust temperature, light and noise level based on sleep cycle	Recognise if the patient is awake or fall asleep	patient image data, voice data and monitoring data
6.provide relevant information and answer patients' questions	collaborative filtering	patients' age, gender, diagnosis result, health condition from the EHR system.
		a database for the questions that the patients want to ask during the whole ICU journey.
7.communicate with an avatar about sufferings	natural language processing and affective computing	a database for the questions that relate to patients' mental health.
8.find other patients who have similar experience	collaborative filtering	EHR data of post-ICU patients
9.suggest patients to set small goals	collaborative filtering	EHR data of patients and similar patients including demographic data, diagnose result, health condition.

Table 39. techonology scouting for each idea

AI capability		Data
Recognise if the patient is awake **1.Orientation** **5.Environment adjuster**	image recognition	patient image data
chatbot + Recommendation system **2.Autocomplete** **6.Chatbot** **7.Virtual Psychologist** **8.Peer support** **9.Goal setter**	natural language processing affective computing collaborative filtering	EHR data including patients' age, gender, diagnosis result, health condition a database for questions and answers that the patients want to ask in ICU. a database for the questions and answers that the patients want to ask after ICU. a database for the questions and answers that relate to patients' mental health.
Text to Speech **1.Orientation** **3.Voice Simulator** **7.Virtual Psychologist**		EHR data: patient name, what accident/surgery happened on which date, how many days have patients been in coma, nurse name, current time. a database for comfort words. a database for books. a database for questions from pateints and answers
	voice clone	voice samples from families
Machine learning to create music **4.Music Creator**	machine learning - create melody based on music styles	music sample of patients' favorite musicians.
	creates variations based on the physiological signals of patients.	record patients' physiological signals (heart rate, respiration rate) when transitions happen, such as being hospitalised, waking up at the first time, the first time meeting family, emergency, transition to the ward.

Table 40. combined result of techonology scouting

4.2 | Feasibility evaluation

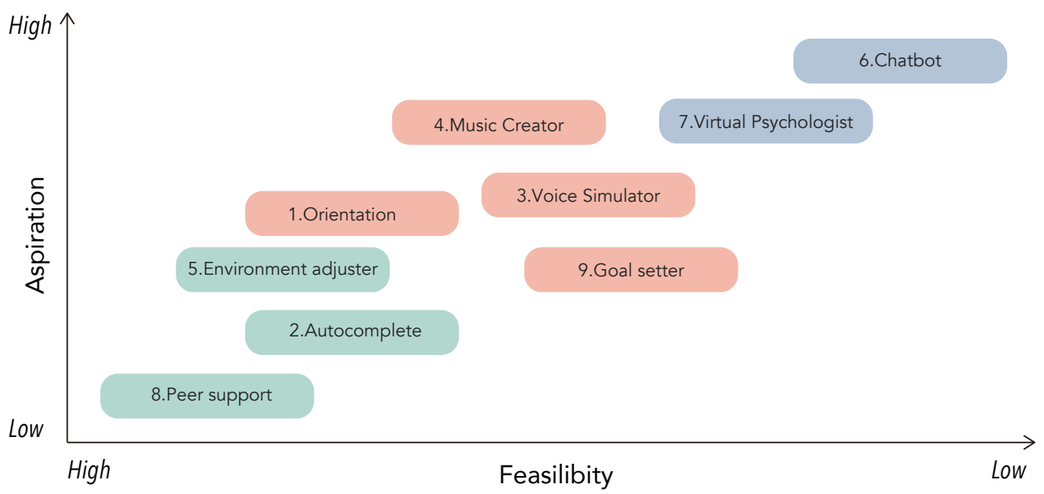


Figure 41. Feasibility evaluation

Evaluating the feasibility of an idea requires understanding the existing resources in the internal environment of the organization. But at the same time, it should not be limited to the existing resources, because too much attention to the existing resources may lead to that the final offerings will be similar to the existing solutions, which hinders innovation. The final offerings will not help the organization establish its own competitive differentiation.

So when evaluating feasibility, two aspects should be considered, aspiration and feasibility. Figure 41 shows how the ideas were evaluated. The vertical axis shows the level of aspiration from low to high, which means that to what extent the idea can provide the organization with competitive differentiation. The horizontal axis shows the feasibility from high to low, which mean to what extend the idea require the organization to develop new resources or capability.

The ideas in the first cluster are those with high feasibility but low aspiration, which means the organization doesn't require much effort to implement them, but it won't bring many completive advantages. The ideas in the third cluster are those with high aspiration but low feasibility, which means if the organization wants to build these completive advantages, it should spend many efforts on it to develop relevant resources and capability.

4.3 | Roadmapping

Many innovation projects that fail to implement make organizations feel risky and radical because they require organizations to develop their capability too far. Innovation requires a developing process, which requires continuous research to accumulate resources and extend capabilities. A roadmap can help to build innovative ideas in an iterative process (Simonse, 2015). Figure 42 shows the roadmap to build Cricare.

The goal of the first horizon is to set up the foundation of the platform based on the existing resources of the organization. *Idea 2 Autocomplete* and *Idea 8 Peer support* are both mentioned by the participants of the evaluation questionnaire that there is already similar research conducting in Erasmus MC, including providing communication tools for ICU patients and nurses and provide peer support for post-ICU patients. These two ideas also got a high score in the evaluation. It is a good choice to start to build Cricare from these two ideas.

Horizon 2 focuses on the services in ICU while horizon 3 focuses on the services that can be both be provided in ICU and after ICU because the feasibility of services provided in ICU is higher than those provided during the whole journey. In Horizon 2, *Idea 5 environment adjuster, Idea 1 orientation, Idea 3 Voice simulator and Idea 4 Music creator* are provided. The AI technology behind these four ideas is already can be found in some products that exist in the market.

The services in horizon 3 require collaboration with professionals from other disciplines includes the physiologist (*Idea 9 goal setter*), psychologist (*Idea 7 virtual psychologist*), physicians and nurses (Idea 6 chatbot after discharge). Also, based on the current technology, it is difficult to build *Idea 7. Virtual psychologist and Idea 6. Chatbot* fully powered by A.I.

This roadmap is a preliminary reference for the development of Cricare. In the actual development process, with the more in-depth design of the function of Cricare, the continuous research on AI technology, the integration of data, and the establishment of data infrastructure, this roadmap should also be continuously adjusted.

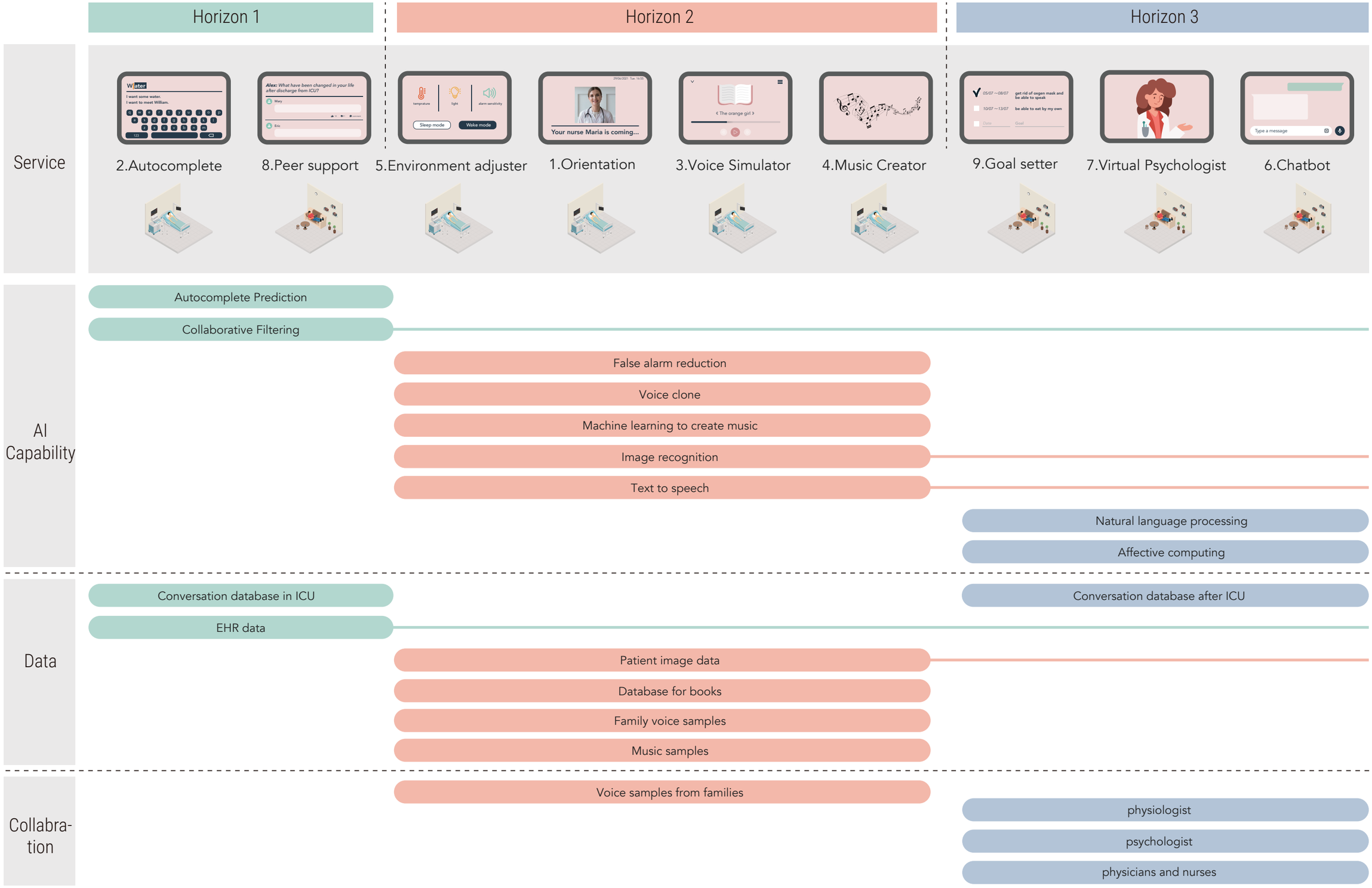


Figure 42. Roadmap

Chapter 8 Conclusion

This chapter summarizes the all project and pointed out the limitation and future recommendations, followed by a personal reflection and acknowledgment.

8.1 | Summary
8.2 | Limitation and recommendation
8.3 | Personal reflection
8.4 | Acknowledgement

8.1 | Summary

Patients are admitted to ICU when they are in a life-threatening situation. But the purpose of ICU is more than saving a life. In addition to physical illness, ICU patients are also suffering from emotional and psychological problems. Humanizing intensive care is the future trend and caring for patient wellbeing is as important as curing the disease. Based on the social support framework, a patient journey was mapped to summarize the painpoints and support needs during ICU treatment, in the ward and after discharge.

Artificial intelligence can be a strong force to shape the future of ICU. Inspired by good practices of A.I. in different fields, a platform called Cricare was designed to provide social support for ICU patients, contributing to patient wellbeing. The design concept was evaluated by nurses from Erasmus MC and the result shows it can contribute to a humane ICU, although there is still room for improvement. Based on technology scouting and feasibility evaluation, a roadmap was made to further develop Cricare.

8.2 | Limitation and recommendation

This project is a complex project involving multiple stakeholders from design, AI and ICU. Also, it is open and exploratory. If more cocreation section can be conducted during the process to get opinions from experts with different backgrounds, the results can be more convincing. For example, cocreation workshops can be organized during ideation and feasibility evaluation.

In terms of the design, the scope of this project is to explore the application of AI in ICU. But considering the purpose of the project, there are many approaches to contribute to a humane ICU, and the application of AI is one of them. Future research can pay more attention to the purpose of a humane ICU and focus on the needs of patients. Participants from the questionnaire evaluation section also mentioned that if a platform like Cricare is already developed, a diary function can be added. A diary has nothing to do with AI, but it can also contribute to a humane ICU. Cricare is the potential to become a platform that involves multiple services that can provide social support for ICU patients during the whole journey, which can be very valuable for patients.

Regarding the manifestation, some ideas were not understood by a few participants, which led to deviations in the evaluation results. There is room for improvement in the design visualization and description.

In addition, patient data is a very sensitive topic. Also, this project involves some data related to personality. How to open data barriers and ensure patient privacy required future research.

8.3 | Personal reflection

I encountered a lot of difficulties in the project, such as fully online work, unfamiliarity with ICU and AI fields. But I tried my best and I am satisfied with the results.

Knowledge

This project involves two areas that I am very interested in but was not familiar with. I tried to understand the project context through literature review, interview, trend report, website, and documentary. The collected knowledge was evaluated by value mapping, idea mapping, and feasibility evaluation. But the argumentation requires more elaboration.

Method

A variety of methods were used in this project, including literature review, interview, trend research, idea mapping, evaluation questionnaire, feasibility evaluation, road mapping. There can be more cocreation tools used in the process of communicating with stakeholders to facilitate the process.

Project result

Desirability

At the beginning of the project, the social support needs of ICU patients were analyzed. The design ideas in the project responded to the pain points and needs mentioned in the patient journey map and were evaluated by the questionnaire with nurses.

Feasibility

Through technology scouting and feasibility evaluation, a preliminary feasibility analysis of each idea was carried out. However, it would be nice to discuss the feasibility with experts from the ICU and AI backgrounds.

Viability

Patient-centered design and humane ICU are the future trends. Cricare can help Erasmus MC improve the quality of care in a long term. But it requires more research on the current resources of Erasmus MC to conduct a better viability analysis.

Communication

Working online brought me many unexpected difficulties, but in the process, I constantly try to better communicate with stakeholders. However, I still need to further think about how to improve communication quality and how to better transfer the results of communication into the project.

Project management and planning

Because I am not familiar with the ICU and AI fields, in the begining of this project, I often took detours during the whole project process and was very entangled in decision-making, so the project did not go as smoothly as expected. However, the project was successfully completed after adjustment.

8.4 | Acknowledgement

I was doing this project during the covid-19 pandemic and working fully online, which brings me many unexpected difficulties. But I learned a lot from this unique and impressive experience, not only how to initiate a design project, but also how to overcome difficulties as a person.

I appreciate the people who helped me during my graduation project. Thanks to my chair Elif and my mentor Himanshu for helping me conduct the design project, broaden my academic view and give me suggestions on how to choose the design method and how to make decisions. Especially thanks for Elif to organize a CAL meeting every week for students who are doing graduation projects to share ideas. Thanks to Jasper and Davy from Erasmus MC for the interviews that help me to better understand the context of ICU. Thanks to Sebastian for helping me distribute the evaluation questionnaire to nurses. Thanks to Alessandro and Lianne for giving me critical feedback. Thanks to Qinglong and Weidong for showing me the environment of ICU in China. Thanks to Gjis, Chen, Doudou and Ruud who are also doing projects related to ICU, for their suggestions. Thanks to my parents, families and boyfriend for always being there to help me. Thanks to all the friends who chatted with me for their advice and emotional support.

Reference

Ackerman, E. (2021, June 24). "Skywalker" Prosthetic Hand Uses Ultrasound for Finger-Level Control. IEEE Spectrum. https://spectrum.ieee.org/skywalker-prosthetic-hand-uses-ultrasound-sensors-for-fingerlevel-control

Artificial Intelligence In Mental Health Care. (2019, October 24). The Medical Futurist. https://medicalfuturist.com/artificial-intelligence-in-mental-health-care/

Au-Yeung, W.-T. M., Sahani, A. K., Isselbacher, E. M., & Armoundas, A. A. (2019). Reduction of false alarms in the intensive care unit using an optimized machine learning based approach. Npj Digital Medicine, 2(1), 86. https://doi.org/10.1038/s41746-019-0160-7

Barr, J., Fraser, G. L., Puntillo, K., Ely, E. W., Gélinas, C., Dasta, J. F., Davidson, J. E., Devlin, J. W., Kress, J. P., Joffe, A. M., Coursin, D. B., Herr, D. L., Tung, A., Robinson, B. R. H., Fontaine, D. K., Ramsay, M. A., Riker, R. R., Sessler, C. N., Pun, B., … Jaeschke, R. (2013). Clinical Practice Guidelines for the Management of Pain, Agitation, and Delirium in Adult Patients in the Intensive Care Unit: Critical Care Medicine, 41(1), 263–306. https://doi.org/10.1097/CCM.0b013e3182783b72

Birdja, D. (2018). Exploring possibilities for patient monitoring in the future care context | TU Delft Repositories. https://repository.tudelft.nl/islandora/object/uuid:e361079e-ac88-489a-beb2-d6223a411c86?collection=education

Blackwood, B., Albarran, J. W., & Latour, J. M. (2011). Research priorities of adult intensive care nurses in 20 European countries: a Delphi study. Journal of advanced nursing, 67(3), 550–562. https://doi.org/10.1111/j.1365-2648.2010.05512.x

Brown, S. M., Azoulay, E., Benoit, D., Butler, T. P., Folcarelli, P., Geller, G., Rozenblum, R., Sands, K., Sokol-Hessner, L., Talmor, D., Turner, K., & Howell, M. D. (2018). The Practice of Respect in the ICU. American Journal of Respiratory and Critical Care Medicine, 197(11), 1389–1395. https://doi.org/10.1164/rccm.201708-1676CP

Calabretta, G., Gemser, G., & Karpen, I. (2016). Strategic Design: 8 Essential Practices Every Strategic Designer Must Master. Laurence King Publishing.

Cattiau, J. (2019, December 18). How Tim Shaw regained his voice. Google. https://www.blog.google/outreach-initiatives/accessibility/how-tim-shaw-regained-his-voice/

Chou, C. (2020). CareTunes for Families | TU Delft Repositories. https://repository.tudelft.nl/islandora/object/uuid%3A43210f38-23c1-4e92-a471-6c68c03fdcee?collection=education

Davoudi, A., Malhotra, K. R., Shickel, B., Siegel, S., Williams, S., Ruppert, M., Bihorac, E., Ozrazgat-Baslanti, T., Tighe, P. J., Bihorac, A., & Rashidi, P. (2019). Intelligent ICU for Autonomous Patient Monitoring Using Pervasive Sensing and Deep Learning. Scientific Reports, 9(1), 8020. https://doi.org/10.1038/s41598-019-44004-w

Davoudi, A., Ozrazgat-Baslanti, T., Ebadi, A., Bursian, A. C., Bihorac, A., & Rashidi, P. (2017). Delirium Prediction using Machine Learning Models on Predictive Electronic Health Records Data. 2017 IEEE 17th International Conference on Bioinformatics and Bioengineering (BIBE), 568–573. https://doi.org/10.1109/BIBE.2017.00014

Dias, D. de S., Resende, M. V., & Diniz, G. do C. L. M. (2015). Patient stress in intensive care: Comparison between a coronary care unit and a general postoperative unit. Revista Brasileira de Terapia Intensiva, 27(1). https://doi.org/10.5935/0103-507X.20150005

Erasmus MC. (2020). Intensive Care (IC). https://www.erasmusmc.nl/nl-nl/patientenzorg/specialismen/intensive-care

Ervin, J. N., Kahn, J. M., Cohen, T. R., & Weingart, L. R. (2018). Teamwork in the intensive care unit. American Psychologist, 73(4), 468–477. https://doi.org/10.1037/amp0000247

Escudero, D., Viña, L., & Calleja, C. (2014). For an open-door, more comfortable and humane intensive care unit. It is time for change. Medicina Intensiva (English Edition), 38(6), 371–375. https://doi.org/10.1016/j.medine.2014.01.001

Fxguide. (2017, February 6). Avatars and Agents: BabyX. https://www.fxguide.com/fxfeatured/avatars-and-agents-babyx/

Glanz, K., Rimer, B. K., & Viswanath, K. (2015). Health Behavior: Theory, Research, and Practice (Jossey-Bass Public Health) (5th ed.). Jossey-Bass.

Gutierrez, G. (2020). Artificial Intelligence in the Intensive Care Unit. Critical Care, 24(1). https://doi.org/10.1186/s13054-020-2785-y

Health Times (2021). What is a Critical Care or Intensive Care Nurse?. https://healthtimes.com.au/hub/nursing-careers/6/guidance/nc1/what-is-a-critical-care-or-intensive-care-nurse/532/

Heras, G. (2019). We have a plan. Proyecto HU-CI. https://proyectohuci.com/en/weve-got-a-plan/

House, J. S. Work Stress and Social Support. Reading, Mass.: Addison-Wesley, 1981.

ITRex (2021, August 9). AI is the new frontier for dating apps. Here's proof. ITRex. https://itrexgroup.com/blog/ai-for-dating-apps/#header

King, J., O'Neill, B., Ramsay, P., Linden, M. A., Darweish Medniuk, A., Outtrim, J., & Blackwood, B. (2019). Identifying patients' support needs following critical illness: A scoping review of the qualitative literature. Critical Care, 23(1), 187. https://doi.org/10.1186/s13054-019-2441-6

Kobayashi, N., Shiga, T., Ikumi, S., Watanabe, K., Murakami, H., & Yamauchi, M. (2021). Semi-automated tracking of pain in critical care patients using artificial intelligence: A retrospective observational study. Scientific Reports, 11(1), 5229. https://doi.org/10.1038/s41598-021-84714-8

Komorowski, M., Celi, L. A., Badawi, O., Gordon, A. C., & Faisal, A. A. (2018). The Artificial Intelligence Clinician learns optimal treatment strategies for sepsis in intensive care. Nature Medicine, 24(11), 1716–1720. https://doi.org/10.1038/s41591-018-0213-5

Magenta. (2021). https://magenta.tensorflow.org/

Marshall, J. C., Bosco, L., Adhikari, N. K., Connolly, B., Diaz, J. V., Dorman, T., Fowler, R. A., Meyfroidt, G., Nakagawa, S., Pelosi, P., Vincent, J.-L., Vollman, K., & Zimmerman, J. (2017). What is an intensive care unit? A report of the task force of the World Federation of Societies of Intensive and Critical Care Medicine. Journal of Critical Care, 37, 270–276. https://doi.org/10.1016/j.jcrc.2016.07.015

Nemati, S., Holder, A., Razmi, F., Stanley, M. D., Clifford, G. D., & Buchman, T. G. (2018). An Interpretable Machine Learning Model for Accurate Prediction of Sepsis in the ICU: Critical Care Medicine, 46(4), 547–553. https://doi.org/10.1097/CCM.0000000000002936

Nin Vaeza, N., Martin Delgado, M. C., & Heras La Calle, G. (2020). Humanizing Intensive Care: Toward a Human-Centered Care ICU Model. Critical Care Medicine, 48(3), 385–390. https://doi.org/10.1097/CCM.0000000000004191

PARO Therapeutic Robot. (2014). http://www.parorobots.com/

Resemble AI. (2021, July 19). Cloned. https://www.resemble.ai/cloned

Simonse, L., Whelton, J., & Iwanicka, B. (2018). Design Roadmapping: Guidebook for Future Foresight Techniques. Laurence King Publishing.

SimSensei. (2021). SimSensei. https://ict.usc.edu/prototypes/simsensei/

Sky Inside UK. How to enhance patient wellbeing. (2021b, April 9). https://skyinsideuk.com/2019/09/get-well-sooner-how-to-enhance-patient-wellbeing/

Smart customer service: new opportunities with machine learning. (2020, August 7). Trifork. https://trifork.com/events/smart-customer-service/

University of Cambridge. (2020, March 24). Intensive care units in England could run out of beds within two. https://www.cam.ac.uk/research/news/intensive-care-units-in-england-could-run-out-of-beds-within-two-weeks-study-finds

van de Sande, D., van Genderen, M. E., Rosman, B., Diether, M., & Endeman, H. (n.d.). Predicting thromboembolic complications in COVID-19 ICU patients using machine learning. Journal of Clinical and Translational Research, 8.

Velasco Bueno, J. M., & La Calle, G. H. (2020). Humanizing Intensive Care. Critical Care Nursing Clinics of North America, 32(2), 135–147. https://doi.org/10.1016/j.cnc.2020.02.001

Wilson, M. E., Beesley, S., Grow, A., Rubin, E., Hopkins, R. O., Hajizadeh, N., & Brown, S. M. (2019). Humanizing the intensive care unit. Critical Care, 23(1), 32, s13054-019-2327–7. https://doi.org/10.1186/s13054-019-2327-7

Wolf, J. A. (2014). Expanding the dialogue on patient experience. Patient Experience Journal, 1(1), 1–3. https://doi.org/10.35680/2372-0247.1000

Yoon, J. H., Mu, L., Chen, L., Dubrawski, A., Hravnak, M., Pinsky, M. R., & Clermont, G. (2019). Predicting tachycardia as a surrogate for instability in the intensive care unit. Journal of Clinical Monitoring and Computing, 33(6), 973–985. https://doi.org/10.1007/s10877-019-00277-0