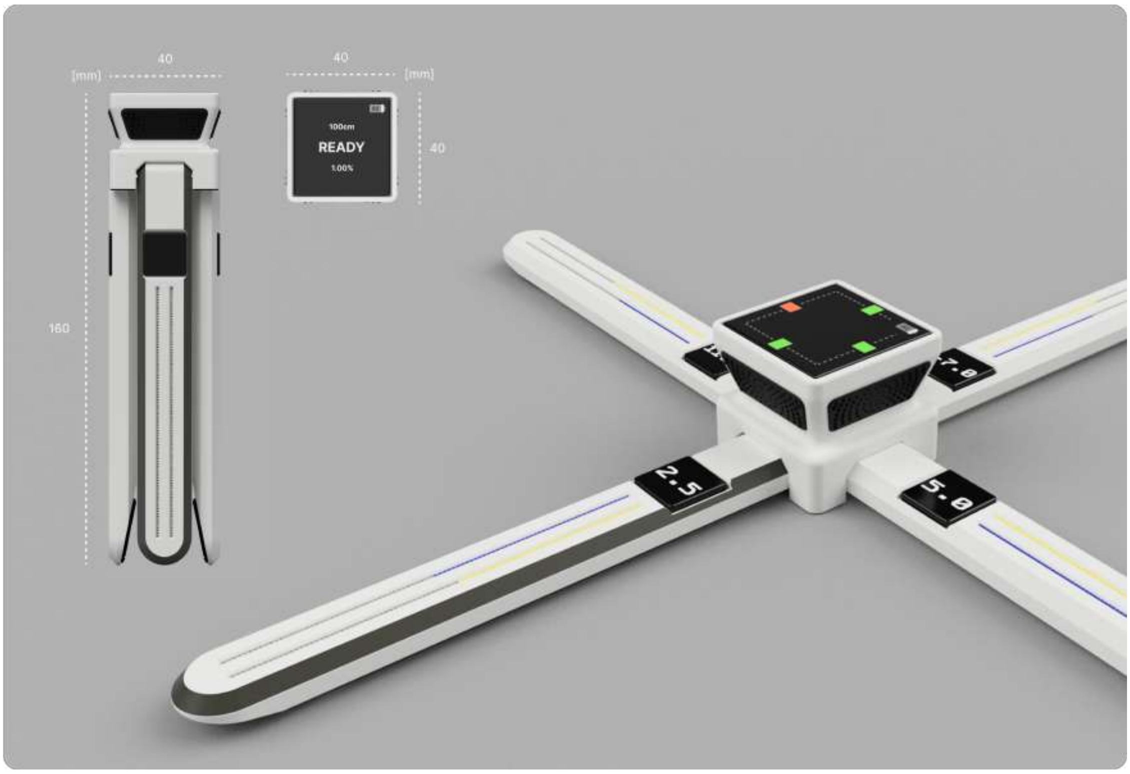
CHALMERS
UNIVERSITY OF TECHNOLOGY



Design the Direct X-ray Ruler, Don’t Let the Direct X-ray Ruler Design You

Redesigning a Medical Quality Assurance Device Through a User-Centered Design Process

Master’s thesis in Interaction Design and Technologies

EIMER AHLSTEDT, DAVID JOHANSSON BONGIOVANNI

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se

Master's thesis 2026

Design the Direct X-ray Ruler, Don't Let the Direct X-ray Ruler Design You

Redesigning a Medical Quality Assurance Device Through a User-Centered Design Process

EIMER AHLSTEDT, DAVID JOHANSSON BONGIOVANNI

Department of Industrial and Materials Science
Division of Human Factors
Chalmers University of Technology
Gothenburg, Sweden 2026

Design the Direct X-ray Ruler, Don't Let the Direct X-ray Ruler Design You
Redesigning a Medical Quality Assurance Device Through a User-Centered Design Process
EIMER AHLSTEDT, DAVID JOHANSSON BONGIOVANNI

Supervisors: Lars-Ola Bligård, Department of Industrial and Materials Science
Frida Hagelberg, RaySafe
Examiner: Lars-Ola Bligård, Department of Industrial and Materials Science

Master's Thesis 2026
Department of Industrial and Materials Science
Division of Human Factors
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Renderings of the final design concept for the next generation Direct X-ray Ruler.

Typeset in LaTeX
Printed by Chalmers Digitaltryck
Gothenburg, Sweden 2026

Design the Direct X-ray Ruler, Don't Let the Direct X-ray Ruler Design You
Redesigning a Medical Quality Assurance Device Through a User-Centered Design Process
EIMER AHLSTEDT, DAVID BONGIOVANNI JOHANSSON
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

Quality Assurance (QA) checks are important in ensuring medical equipment functions properly. The complex and irregular environment the checks are carried out in places high utility and usability demands on QA products. In this project a design concept is developed for the next generation RaySafe DXR+, a QA tool for aligning an X-ray machine's visual light with its radiation field. The focus of the design concept is improving user experience and usability, specifically aimed at the Swedish market. A five phase iterative design process is described. The phases involve an initial user study, ideation and prototyping, a usability study, refinement of the design concept and validation. A list of requirements is developed alongside the concept. The result is a detailed design concept and an extensive list of requirements. Final evaluations indicate that the concept is a significant improvement and suits its QA task very well. Future work includes adapting the design to decrease production costs and evaluate it with international users.

Keywords: Interaction Design, UCD, Medical Devices, Quality Assurance, X-ray Machines.

Acknowledgements

Hello there!

We want to thank Lars-Ola Bligård for his words of wisdom and encouragement through this project, always trust the process. Furthermore we want to thank Frida Hagelberg for her continuous support and guidance. As students it's been a great pleasure to get a glimpse into the industry and meeting so many wonderful people at RaySafe. Also big thanks to the the lovley people in TP, keeping our sanity in check during this spring semester. Lastly a big shoutout to Armando Christian ”Pitbull” Perez for being there and doing that in tough times.

Eimer Ahlstedt, David Johansson Bongiovanni, Gothenburg, May 2026

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AAPM	American Association of Physicists in Medicine
ACD^3	Activity-Centered-Design 3
CT	Computed Tomography
DV	Dependant variable
DXR	Direct X-ray Ruler
GDPR	General Data Protection Regulation
IEC	International Electrotechnical Commission
IV	Independent variable
LIS	Linear Image Sensor
QA	Quality Assurance
RF	Radiofrequency Fluoroscopy
SID	Source Image Distance
UCD	User-Centered-Design

Contents

1

Introduction

Medical equipment plays an important role in many health care workflows. To ensure the equipment functions properly, regular Quality Assurance (QA) checks and adjustments have to be conducted. These procedures are carried out in complex contexts, by different roles, with legal documentation requirements and sometimes with large periods of time between each procedure. This creates a demand for fast, easy to use and powerful QA tools.

In the domain of X-ray machines, one of the QA procedures involves aligning the visual light produced by the machine with its X-rays. Doing so ensures the correct X-ray images can be captured, and importantly minimizes the dosage of X-rays received by patients. One product meant to help in this procedure is the RaySafe DXR+ (Direct X-ray Ruler), a tool that measures the distance between the edge of the visual light and the X-ray. However, the DXR+ is two decades old. With the complex system surrounding its usage and competing solutions offering considerable advantages, the DXR+ has potential to improve. This thesis covers the process and results of developing a design concept for the next generation DXR+ product, with a focus on User-Centered Design.

1.1 Light-Radiation Field Alignment

Many conventional X-ray machines provide a visual light field to be used as a guide for placing the subject to be irradiated. However, because of wear and usage, X-ray machines can drift, leading to the actual X-ray field not aligning with the light field guide. Should the fields not be aligned, the quality of the X-ray image can decrease, increasing difficulty in analyzing the image. The subject can also be exposed to extra radiation, with some studies finding that as much as a 22% increase in dose is possible with misaligned fields (Walsh et al., 2004). Because of this, quality assurance checks are needed to ensure proper alignment of the fields (Kutcher et al., 1994). These checks generally consist of using a tool to measure the deviation between the two fields. In most cases, both fields are rectangular and deviations are measured per side. Once all deviations have been measured, they are checked against the tolerance requirement taken from relevant regulations. These requirements and regulations vary regionally and are further discussed in Section 3.5, but are usually given as a percentage of Source-Image Distance (SID), the distance between the X-ray source and the subject (Kutcher et al., 1994). Based on whether the deviations are acceptable or not, the QA test is marked as a pass or a fail, with a fail requiring the machine to be re-calibrated.

1.2 The Direct X-ray Ruler+

The DXR+, originally released in 2006, is "*a Direct X-ray Ruler for alignment of the light and radiation field*" (RaySafe, 2026). In essence, the DXR+ measures the distance between a visual light field and a radiation field and displays it on a segmented display. Fig. 1.1 shows an image of the product.

Figure 1.1: The RaySafe DXR+ (RaySafe, 2026).

The product is primarily used by two groups of users: X-ray responsible clinical personnel, like clinical physicians and medical device engineers, and the technicians working for the companies producing X-ray machines. In both cases, the DXR+ is used in the same way. The difference lies in that the clinical personnel mostly use it to perform diagnostics QA tests on the X-ray machine while the technicians use it to calculate which adjustments to make in order to maintain the machine.

Using the DXR+ is comprised of three main steps:

1. Aligning the DXR+ with the light field produced by the X-ray machine.
2. Exposing the DXR+ to the radiation field produced by the X-ray machine.
3. Retrieving the measurement of the deviation between the two fields.

These steps must then be repeated for each vertex of the light field, usually totaling four measurements for a four-sided light field. After this, data from the DXR+ needs to be entered into documentation and reports.

1.3 Purpose and Goal

The DXR+ was released 20 years ago. Since then competing solutions with distinct advantages have hit the market, and weak points in the product's design have been exposed through customer feedback to RaySafe. The purpose of this project is to investigate the DXR+'s strengths and weaknesses from a perspective of User-Centered Design. Insights from this investigation are then synthesized into a design concept that a new iteration of the DXR+ can be based upon. By "design concept" is meant a concept that outlines a theoretical product, what features it has and how it is used, and not a complete product with cost analysis and technical implementations or recommendations. Since this project is an early, exploratory project, the focus is on analyzing the DXR+ in the Swedish market, and its use in Swedish hospitals.

The purpose of this work can thus be formulated as ''*Developing a detailed design concept for the next generation DXR+ product for the Swedish market, from a perspective of User-Centered Design*". Note that only a design concept for the DXR+ itself is to be developed, not designs for other systems that it might interact with. The goal of the project is to deliver a detailed design concept that can inform the creation of the next generation of the DXR+ product. This concept covers directives on workflow, interaction, UI Design, and physical product design and affordances.

1.4 Research Questions

Based on the scope and purpose of the project, two key areas of research have been identified. The first one is about gathering requirements on the system in which the DXR+ exists, and the second is on implementing said requirements. This lead to the formulation of the following two Research Questions (RQ's):

- **RQ1:** What usability and utility requirements exist on the interaction between a DXR and its user?

- **RQ2:** How can the requirements from RQ1 be implemented in a new iteration of the DXR+?

1.5 Ethics and Sustainability

Since the project covers the usage of X-ray technology, considering people's exposure to X-rays is critical. This includes both exposure during the project, such as if conducting real-world user testing, and exposure as a result of the proposed design. As such, all tests have been structured around avoiding exposure. The final design concept also takes radiation into account by allowing users to follow safety guidelines, such as leaving the room during irradiation.

Steps have been taken to ensure participants in studies conducted as part of this work are respected in terms of their time and integrity. Scheduling participation was made flexible, especially for participating health care personnel. All personal data was handled in accordance with GDPR, the European Union's General Data Protection Regulations. Before recording data, participants were asked to give informed consent, and only the kinds of data the participants indicated they were comfortable to share was recorded.

Since most of this work was in exchange of information and only involved a limited amount of actual material, the ecological aspect of this work was minor. Basic considerations were made to not be wasteful with material and transport, and material was recycled where possible.

1.6 The Structure of This Report

As this report covers an iterative design process, its structure has been adapted to make following the process easy. After the introductory chapters, a Process chapter outlines the overall process that the work followed. The following five chapters chronologically cover the different phases of the project by introducing the aim of the phase and then presenting the methods and results used. After the phase chapters, the final result is presented, and chapters for conclusion and discussion follow. The following is a brief summary of the chapters to come:

2. **Design Concept Summary** provides a brief overview of the final design concept to contextualize the coming work.
3. **X-ray Machines and Quality Assurance** gives practical background information on the context in which the DXR+ exists.
4. **Theory and Methods** presents the theoretical framework and the methods on which this project is based.
5. **Process** outlines the different phases of the project, their purpose and content.
6. **Phase 1 - Needs and Requirements** builds an initial understanding of the DXR+ and its use, primarily through a user study and a stakeholder focus group.
7. **Phase 2 - Ideation and Prototyping 1** covers the ideation and prototyping of 15 initial concepts, selection between the concepts and their refinement to four low-to-medium fidelity prototypes.
8. **Phase 3 - General Design** focuses on selecting between the four previously developed concepts through a usability study and gathering information on how their design can be improved.
9. **Phase 4 - Ideation and Prototyping 2** improves upon the concept selected in Phase 3 and produces a detailed design concept.
10. **Phase 5 - Concept Validation** evaluates the final design concept with end users and explores the feasibility of it in terms of engineering and costs.
11. **Final Design Concept: the Squid 2.0** describes the final design concept in detail.
12. **Discussion** reflects on the process, methods and results of the project.
13. **Conclusion** summarizes the work done and draws conclusions based on the results in relation to the purpose and research questions of the project.

2
Design Concept: The Squid

The proposed final design implements four foldable arms connected to a central base unit, which allows for all necessary data to be collected in one irradiation. The design allows for easy transport and storage due to its small footprint. Each arm allows for detection of both light-field and radiation-field edges through sensing elements along each arm orthogonal to the base unit. Yellow, for light, and blue, for X-ray, is used to represent each field individually. Field positions are visualized and distance between the fields is calculated and presented numerically. Furthermore, the squid offers input of test parameters such as SID and tolerance which allows for pass/fail analysis to be presented as machine output, see Fig. 2.1. The type and format of information presented on the product itself have been carefully designed to complement current user's workflow and support efficient decision making. Physical maneuvering is afforded through textured black rubber and chamfered edges at the end of each arm, see Fig. 2.2. Intended way of gripping and manipulating the product is presented in Fig. 2.3.

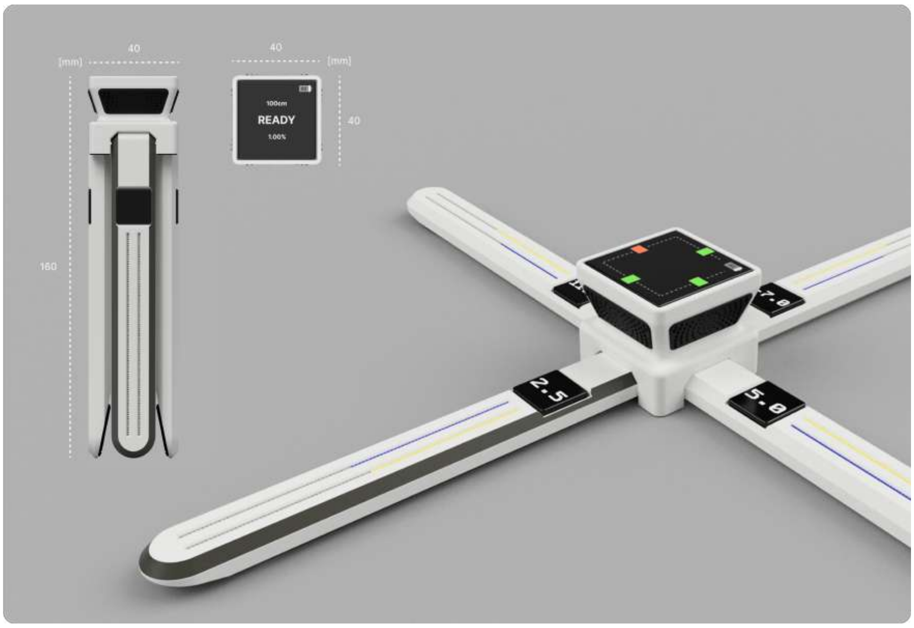


Figure 2.1: Squid 2.0 providing visual feedback regarding measured deviation through visual distance, numerical value and pass/fail analysis

Figure 2.2: Rubberized grip areas that afford easy physical maneuvering

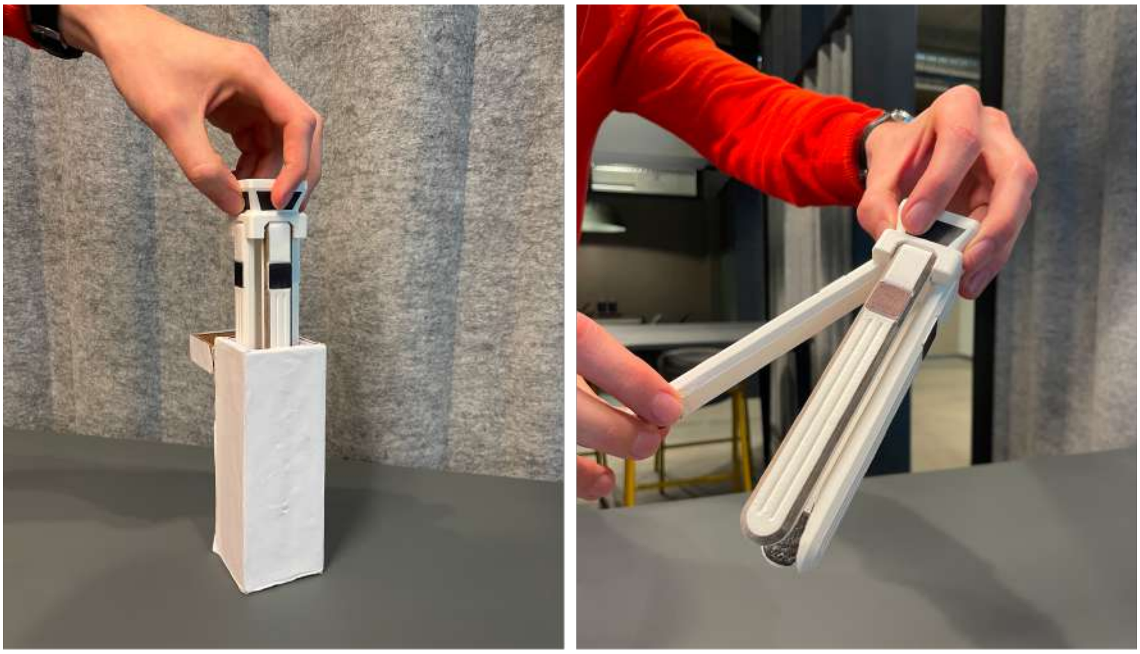


Figure 2.3: Squid being removed from its case (left) and unfolded (right)

3

X-ray Machines and Quality Assurance

In this chapter, the DXR+ is described further, and the context in which the product exists is described. Relevant competing solutions are detailed to highlight their comparative strengths and weaknesses compared to the DXR+. Regulations and guidelines related to the product are discussed. Earlier work relevant to aspects of the DXR+ are covered, and QA tests closely related to light-radiation field alignment are explained.

3.1 X-ray Machines and Collimation

”X-ray machine” is the name for a large selection of radiology machines for medical imaging. In general, they function by emitting electrons towards a target and then quickly decelerating them. This deccelaration causes generates radiation, which is then sent towards a detector, producing an image by analyzing how the radiation hits the detector (Bushberg et al., 2012, p. 171). Triggering the X-ray to emit the electrons, and in turn the radiation, is known as irradiating. Subcategories of X-ray machines include Computed Radiography (CR), mammography, Computed Tomography (CT), and fluoroscopy. Covering the differences and usage of the different kinds of machines is outside the scope of this report. It should be noted however that the types of X-ray where the DXR+ is used are mainly CR, mammography and fluoroscopy (RaySafe, 2026), since these are the machines that tend to use a visual light field to guide imaging.

Adjusting the captured area in an X-ray is known as *collimating*. It is done through a *collimator* which defines the shape and size of the targeted field. A collimator uses two pairs of shutters to control where X-ray beams are sent. The source of the X-rays, the source of the light field and the shutters are all independent and have different positions within the machine. This means that over time, they can drift and become misaligned, especially considering that the shutters are movable mechanical parts (Bushberg et al., 2012, p. 181).

CT machines function quite differently from the ones where the current DXR+ is used. For example, they do not use a visual light field for a guide. Instead, they use rotating scanner emitting X-rays at a certain width (Bushberg et al., 2012, p. 312). This width is referred to as the dose profile or fan width, and just like in the X-ray machines mentioned above, it is adjusted through collimation. As such, QA checks are needed for dose profile in CT machines.

3.2 Detailed DXR+ Description

The DXR+'s ability to measure deviations between a light field and an X-ray field is based around collecting positional data on the edges of the two fields. For the light field, the data is collected by manually positioning a designated line on the product in line with the light field edge, as shown in Fig. 3.1.

Figure 3.1: A DXR+ positioned with its designated yellow line at the light field edge. The light field edge fades out with a so-called penumbra. In this case, the DXR+ is positioned at the end of the penumbra.

To collect data on the radiation field edge the DXR+ uses an array of sensors sensitive to radiation. The sensors are connected to a segmented display, and cause segments to light up if a high enough radiation dose is detected. By assuming it has been positioned correctly on the light field edge and using the yellow line as an origin point, the deviation can be measured as the distance between the yellow line and the last lit up segment on the display. A ruler on the product is meant to help the user determine said distance as shown in Fig. 3.2.

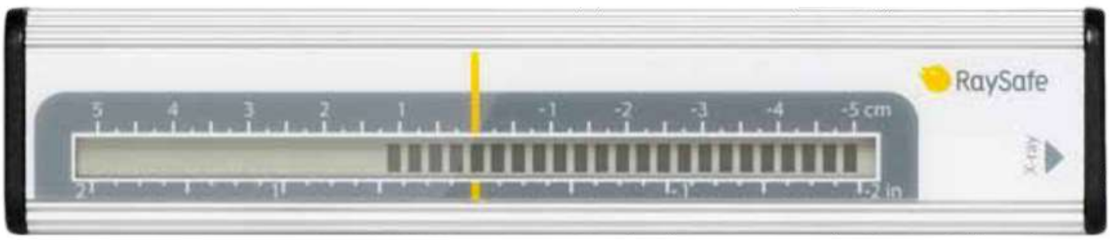


Figure 3.2: A DXR+ showing a measured deviation. In this case the deviation is roughly one centimeter, with the radiation field extending outside the light field.

The segments, and as such the DXR+, have a resolution of 2.5 millimeters (RaySafe, 2026). The segments automatically turn off after one minute. Because of its internal configuration, the product has to be placed with a demarcated side facing towards the center of the measured field. For the DXR+ to work properly, it needs to be irradiated with a dose within its dose range. In other words, the product has a minimum dose needed for it to register anything, and a maximum dose above which operation is not recommended. The irradiation also needs to be at least 10 miliseconds long to obtain a reading. In terms of battery, the DXR+ is rated to last for six to eight years before needing to be sent to RaySafe for a change of battery. The DXR+ cannot communicate with any external systems, its battery cannot be charged or changed by the user, and it is only made to measure the deviation on one side of a field per irradiation. It cannot perform QA checks for dose profile in CT machines.

The DXR+ is a QA device rather than a medical device (Läkemedelsverket, 2021). However, it is used in similar contexts and for closely related purposes. As such, research on medical device design and development will be relevant for this project. While QA and medical devices must conform to different sets of regulatory requirements, the design methodology is the relevant aspect, not regulatory compliance.

3.3 Competing Solutions

A number of other solutions for measuring deviations between visual light and X-ray fields exists. The so-called ”nine penny method” involves placing pennies in pairs of two on each of the four light field edges, and a final, ninth penny somewhere close to a corner to act as a point of reference. When an X-ray image is taken of this setup it is possible to visually discern the misalignment, as shown in Fig. 3.3.

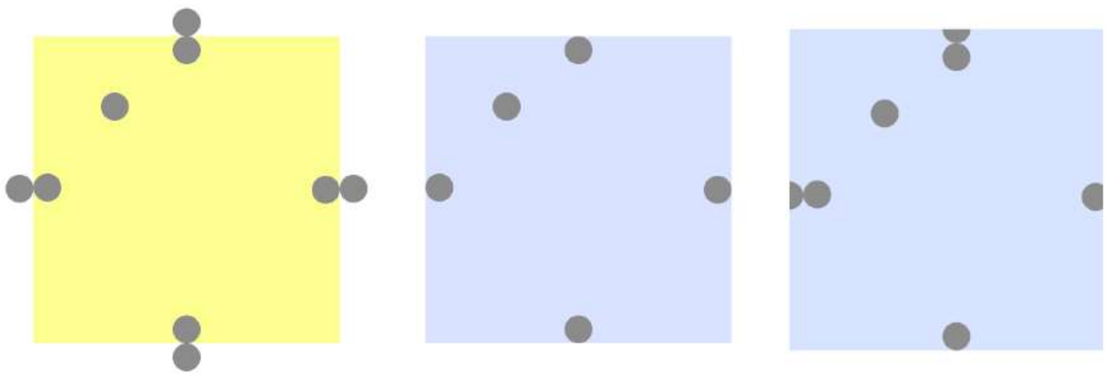


Figure 3.3: Showcase of the nine penny method. **Left:** pennies positioned in relation to the visual light. **Center:** X-ray image if the light and X-ray are aligned. **Right:** X-ray image if the light and X-ray are misaligned.

Compared to the DXR+, this method is considerably cheaper, and only requires one irradiation to capture all four vertices. On the other hand, the DXR+ offers a direct, numerical value rather than visual estimations.

The QUART nonius is a similar tool to the DXR+, with the difference that it takes more measurements and exports them to a desktop application for further analysis (QUART, 2026). Furthermore, the QUART nonius can perform QA on Computed Tomography machines, a feature which the DXR+ lacks.

Phantoms are a type of QA tool that can be used to perform a number of tests on X-ray machines. They are large acrylic slabs placed on the X-ray machine's receptor that give a variety of measurements when exposed to X-rays. Products such as the RTI RAD-DIGIX-4 can perform light-radiation field alignment alongside a number of other QA tests (RTI Group, 2026). This means the usage of phantoms sometimes makes using a separate light-radiation field alignment tool unnecessary. Still, phantoms are not always the easiest way of performing that QA test, meaning the lightweight workflow of purpose-built products like the DXR+ and QUART nonius have distinct advantages.

3.4 Automatic Light-Edge Alignment

The possibility of automatically identifying the light edge and producing a numerical readout out of the measured deviation has been explored in (Lindström et al., 2020). Manual light edge alignment was identified as a key pain point during the initial data collection. The work produced by Lindström et al. provides an indication as to technical feasibility regarding automating the light edge alignment currently performed by the user. Using a Linear Image Sensor (LIS), both light edge and radiation edge were identified.

The prototype produced allowed for automatic light edge alignment and produced a numerical results. However, the user was required to perform four individual measurement, one side per exposure. Further, no machine output was available on the device itself. The prototype used an external software system to provide numerical results.

3.5 Regulations and Guidelines

Different regions and countries use different regulations for radiology QA. Two notable examples of regulations are those of the American Association of Physicists in Medicine (AAPM) Report 150 and Report 151 (Gauntt et al., 2024; Jones et al., 2015) and those of the International Electrotechnical Commission (IEC) standard IEC 61223-3-8 (International Electrotechnical Commission, 2024). The AAPM regulations are, as the name suggests, primarily used in the United States, but have influence over other regulations. In Europe, the IEC standard applies through an adoption made by the European Committee for Electrotechnical Standardization (CENELEC, 2024). This standard is then further adopted in Sweden through the Swedish Institute of Standards (Swedish Institute for Standards (SIS), 2024).

The exact regulations vary slightly between standards, but in general, the tolerance for an offset in light-radiation field alignment is described as a percentage of the Source to Image Distance (SID). The SID is the distance between the X-ray emitter and the subject. IEC standards state that the sum of the deviation on two opposing sides should not exceed 2% of SID. In many cases, this is re-interpreted to state that the deviation on one side should not exceed 1% of SID. The SID is a setting on the X-ray machine, and can vary. This means no true minimum resolution for QA equipment can be calculated.

4

Theory and Methods

This chapter covers the theoretical frameworks and methods on which this design work is based.

4.1 User Centered Design

Today, almost every aspect of our life is influenced by the steady increase of available information. Whether we are scrolling on our phone, walking down the street or sitting on the bus there are agents fighting for our attention. Even though more information is available today than ever before in history, this does not mean we are more informed than ever, see Fig. 4.1. Instead, we now constantly need to decide if information is relevant or not.

Developing new technologies have allowed us to reshape our lives to make them more efficient. Technologies that offers the desired increase in efficiency have then been allowed to dictated the informational landscape. User centered design, as described in (Endsley, 2004, pp. 3–11), aims to shift the focus from *design technologies and let human adapt* to "*design technologies that are adapted to human capabilities*". Meaning, users are the ones dictating what type of information should be presented and when. Within this framework, two principles relevant for this project are presented. These served as theoretical cornerstones throughout the design process.

- Organize technology around user's goals, tasks and abilities
- Technology should be organized around the way users process information and make decisions

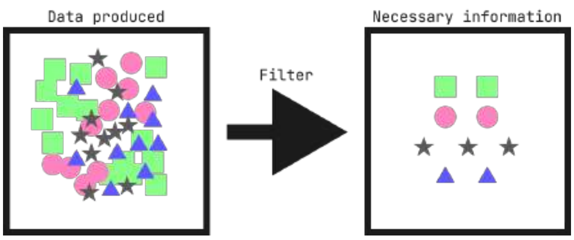


Figure 4.1: Visualization of information gap

4.2 Activity Centered Design^3

Activity Centered Design^3 (ACD^3) is a comprehensive framework for a user-centered design process, providing clarity on how to systematically reduce the design space to ensure full compliancy with user needs (Bligård, Lars-Ola, 2015). The main aspects that have been modified are the number of phases and the corresponding design levels. Design work in this project will start at the effect level and end in the interaction level. The scope excludes design levels on the element level.

4.3 Human-Computer Interface

This project defines an interface as features of a machine that make its abilities available to the user through interaction, inspired by the definition of human-computer interfaces (Lewis & Rieman, 1993, pp. 13–14). In this project, machine abilities are made available through various design solutions corresponding to the identified design challenges. This definition acts as the theoretical base for discussion and structured mapping of both current and intended use of the proposed design.

In the report, the Human-Computer Interface is most often referred to as ”machine output” or ”readout”. This is because expressions with the word ”interface” might lead to associations with traditional, screen-based interfaces on a computer. That is a very concrete interpretation compared to the relatively high level of abstraction which conceptual design work exists on.

4.4 Automation

Automation can be seen as "*the execution by a machine agent (usually a computer) of a function that was previously carried out by a human*" (Parasuraman & Riley, 1997). When a system is automated, it is important the system's users can monitor and maintain trust in it. Among the factors influencing a user's ability to do so are the reliability of the automation, its workload and how clearly the state of the automated system is shown.

One aspect of automation is automated decision-making, (Ivanov, 2023). In such cases, there are different approaches, generally ranging from ”human in the loop”, where a human is fully informed about all factors in the automated decisions, to ”human out of the loop”, where a system makes automated decisions without informing humans about the details. Ivanov (2023) found that repeated, standardized decisions, human out of the loop is a suitable choice, while more critical decisions require the human to be more in the loop.

4.5 Usability

The concept of usability is used to describe how easy an interface is to use to perform a task and achieve a certain goal. Quantifying the usability of a certain interface can be done through usability heuristics, as presented in (Nielsen, 1994). Aspects relevant for this project are presented below:

Visibility of machine status: The machine needs to provide the user with clear feedback when an action is performed. If an action results in a change of machine state, this needs to be shown as a consequence of the user's action. A clear link between cause and effect, through human machine interaction, will result in greater perceived usability.

Match between system and real world: A machine introduced to aid the user in performing a certain task needs to adhere to how the user normally performs said task. Using similar language, symbols, metaphors and systems of thinking will increase perceived usability.

Error prevention: Use errors are results of inadequate communication between the human and machine. A way to implement error prevention is to identify the most common use errors and then to design the machine to handle them. Another way to implement error prevention is to design the overall human-machine interaction so that situations with high error risk do not occur frequently.

4.6 Affordance

The term "affordance" was originally coined as a term in ecological psychology, describing what action possibilities an environment offers an agent (Gibson, 2014, p. 119). In the context of UCD, the most relevant application of the term is "perceived affordances" (Norman, 1999). While an affordance is the possibility of an action, perceived affordances are elements that give the impression of a possible action.

According to Norman, affordances in physical products can be both regular affordances and perceived affordances, and they are not necessarily the same. In this project both kinds are relevant, since a physical design concept is developed. However, the term affordance is used for both concepts since this is now the most common expression (You & Chen, 2007). As such, an affordance is seen as a possibility of an action **and/or** indication of such a possibility.

4.7 Situational Awareness

Situational awareness (SA) can be defined as how well the operator is able to understand what is happening within a defined system (Endsley, 2004, pp. 13–18). SA can be split into three distinct levels, defined as

- Level 1 - perception of the elements in the environment
- Level 2 - comprehension of current situation
- Level 3 - projection of future status

Different principles regarding designing for situational awareness have been proposed (Endsley, 2004, pp. 79–80). A key principle is understanding when and where a specific type of information is useful. If every data point is available at all times, cognitive resources has to be spent by the operator deciding whether or not it is relevant for task at hand. And so, a good understanding of the operators perceived goal is important in order to provide them with the necessary information at the correct time. Another way of designing for SA is to provide the operator with level 2 information directly. This reduces the cognitive resources required to comprehend the implications of a specific data point on the current situation.

4.7.1 SA and Decision Making

In order for the operator to have a good situational awareness and feel confident in their decision making, minimizing points of uncertainty is vital, (Endsley, 2004, pp. 113–116). Different levels of situational awareness are affected by different types of uncertainty.

There is always some uncertainty tied to data that is being gathered and presented. This will affect the operators ability to perceive the correct status of elements in their environment. There are various aspects that affect the uncertainty of perceived data. Sensor act as a way of measuring aspects within a system. No sensor is 100% accurate and will inherently produce some incorrect data. This will produce some uncertainty as to the reliability and credibility of that data. And so, ensuring transparency and traceability of data is important. In any human machine system there has to be a prioritization of what information is to be presented to the operator and when. Not having access to the particular data required to perform a task will lead to uncertainty due to missing data. Due to the existing uncertainties ties to level 1 SA, there will inevitably be uncertainties in the comprehension based on the perceived information.

4.7.2 SA and Automation

When implementing automation within a human machine system, it's crucial to reflect and analyze what effects that will have on the operators situational awareness. Furthermore, what role should the machine play within the system. Automation can be implemented at various levels to support the operator in completing a task, and four ways to do this allocation has been identified (Endsley & Kaber, 1999).

- Monitoring or gathering information relevant for the operator
- Providing options or ways for the operator to achieve their intended goal
- Deciding which options should be deployed
- Performing certain actions

4.8 Task Analysis

Understanding both task and goal is crucial for a user-centered-design process. In this project, a version of hierarchical task analysis (HTA) was used to map how the DXR+ is currently being used (Sandom, Carl, Harvey, Roger S., 2004). This is done through breaking a main task down into sub-tasks, and so creating allowing for a overview of the actions performed by both user and machine. Various version of a task analysis was created but a two layer task description was deemed most relevant. Further detail as to how each subtask was performed became to abstract and did not offer a more nuanced understanding of the current product usage.

4.9 Cognitive Walkthrough

Complimenting user feedback through data collection methods, Cognitive Walkthrough will be used internally within the project group to evaluate design choices and guide new iterations (Sharp et al., 2019, pp. 561–562). After establishing contact with DXR+ users in Sweden, it became clear that access to real world users is quite limited. And so this method was chosen to supplement that deficit and provide the project team with a way to further the process without constant access to real world users. Cognitive walkthrough was performed within the project group using various mediation objects, such as low to medium fidelity prototypes.

This method requires:

- A prototype of the interface intended for evaluation.
- A task description.
- A list of actions required.
- A clear understanding and description of the intended user.

These data points were already intended results within the design process, and so implementing this method required little extra work.

4.10 Likert Scales

Likert Scales are a data collection method to gather understanding of attitude, opinion and satisfaction with a product (Sharp et al., 2019, pp. 281–282). The participant grades a particular statement in relation to specific experience or interaction. A seven step Likert scale is used through this project, from 1 (strongly disagree) to 7 (strongly agree). The amount of steps on a Likert Scale determine how detailed answers users can give, with seven being a commonly used amount for more detailed judgments. Data gathered from Likert Scales is quantitative.

4.11 KJ-Analysis

This method is implemented within the iterative design process to analyze large sets of qualitative data and synthesize categories that indicate aspects of interest. It relies on grouping data points based on intuitive non-logical thinking processes (Scupin, 1997), and so generating results that strict sequential analytics methods might miss. It acted as a highly effective compliment to the quantitative data analytics performed in this project, offering detailed context to statistical results.

4.12 NASA Task Load Index

The NASA Task Load Index (NASA-TLX) is a workload assessment tool producing a overall workload score based on six subscales (S. G. Hart & Staveland, 1988). In this project a version of this tool will be used, known as Raw-TLX. This method reduces the necessary steps and transforms the tool into a simpler method to evaluate workload by forgoing the pairwise comparisons of subscales used for weighting. Applying this version of NASA-TLX has been found to provide results of similar quality while reducing the time spent on the method (S. Hart, 2006).

4.13 Usability Testing

Usability testing entails data collection through various methods (Sharp et al., 2019, pp. 501–504). Tests are most often conducted in controlled and repeatable environments, such as a lab or another location where the test facilitators can control as many variables as possible, ensuring differences in gathered data is a result of the tested prototype and not the environment. Data is commonly collected through note-taking, timing and questionnaires. The amount of use errors and the time to perform certain tasks are two frequent metrics used. After collection, the data is analyzed using appropriate methods and used to draw conclusions about how well a product meets a need.

In this project, observations, interviews and questionnaires are leveraged as part of usability testing in order to gather data and ensure a user centered design process. This acts as one of the main methods of data collection and various usability testing methods will be performed as part of the iterative design process.

5 Process

The way an iterative process is described within the activity centered design 3 framework serves as the base structure for the design process in this project (Bligård, Lars-Ola, 2015, p. 69). It includes Planning, Data Collection, Analysis, Ideation, Synthesis, Evaluation and Documentation. These steps were iterated upon during each phase. The framework was modified into a five-phase process to better suit the resources and final deliverable of the project, see Fig. 5.1. This chapter covers the overall structure of the process applied in this project, with the following chapters diving into each phase of the process in detail, including results. The list of requirements and guidelines were continuously updated throughout each phase. The level of each added requirement was in line with the design level for each phase; see Table 5.1 for requirement and guideline descriptions.

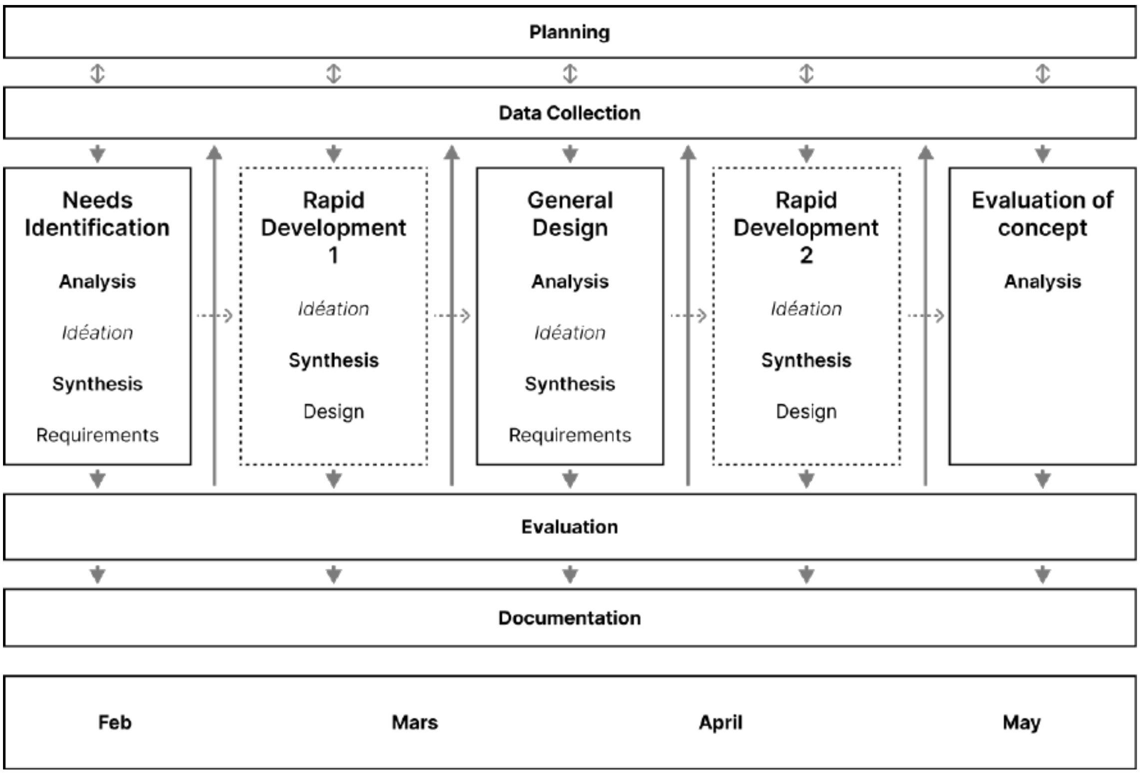


Figure 5.1: A visualization of the process used in this project.

Design work in Phase 1 existed on the design levels Effect and Architecture, generating an understanding of both system goal and current product use. The data collected in this phase was synthesized as usability and stakeholder guidelines as well as utility and usage requirements. Phase 2 explored the design space set by synthesized requirements and guidelines. Concepts were generated through various ideation sessions, iterated upon and then four unique concepts were produced. Phase 3 then evaluated the concepts through a usability study with proxy users. Both qualitative and quantitative data was collected and analyzed. Requirement synthesis was then performed, focused on generating requirements for design levels architecture and interaction. Requirements rework in this phase was guided by how well individual design solutions performed during usability testing. One concept was chosen for further development in Phase 4. Similarly to Phase 2, design work in this phase focused on exploring the newly defined design space and produce a final concept. This concept was then evaluated in Phase 5 with both users and stakeholders to explore possible avenues for future work.

Table 5.1: The types of requirements and guidelines used in the project.

Requirement type	**Description**	Corresponding design level
Usability guideline	Guidelines regarding usage to achieve desired usability	Effect
Stakeholder guideline	Guidelines from RaySafe describing what a presented concept should achieve	Effect
Usage requirement	Requirements on the machine to allow for the desired usage	Effect
Usability requirement	Requirements regarding usages to achieve desired usability	Interaction
Utility requirement	Requirements regarding function to achieve desired utility	Architecture
Stakeholder requirement	Requirements from RaySafe describing what a presented concept should achieve	Interaction

5.1 Phase 1 - Needs and Requirements

The goal of this phase was to gather initial information on the DXR+ and its use. This information was then re-written as utility requirement and usability guidelines, that guided the exploratory design work in Section 5.2. This was done through data-collection methods with real world users and relevant stakeholders. Observations, interviews and focus groups were conducted in as a way to collect both qualitative and qualitative data (Kylén, 2004). The output was analyzed with KJ-analysis. A focus group was held, where requirements and guidelines were presented and evaluated by a diverse group of stakeholders and product owners with various technical expertise at RaySafe. A wide range of expertise within the participant group was deemed highly relevant as to not exclude or miss any perspectives. The group included UX/product designers and technical experts as well as DXR+ specific experts.

System goal and system performance metrics were synthesized based on the data collected. This was done through synthesizing user profiles containing a task description, system goal and comments regarding the usages of the DXR+ for each participant, presented in Appendix D. Participants mainly included DXR+ users, but also users of other product that aid in performing a similar task as well as stakeholders at RaySafe.

5.2 Phase 2 - Ideation and Prototyping 1

The work in this phase served as an intermediate layer between the requirements identified in Phase 1 and the data collection in Phase 3. Through ideation and rapid prototyping, it produced several low to medium fidelity prototypes. These artifacts were created based on the insights from Phase 1. This was done through initially generating a large amount of low fidelity prototypes, evaluating these with users and then iterating on the concepts that showed promise. Throughout this phase, Cognitive Walkthrough was used to perform internal evaluations of each concept during their development and redevelopment. This phase focused on generating prototypes that answer to the identified design challenges Geometry, Light Edge Alignment and Machine Output, presented in Section 7.4. The focus was on creating tangible prototypes, which have been shown to elicit better feedback from stakeholders in the domain of medical devices (Coulentianos et al., 2020; Menold et al., 2019). Multiple prototypes were produced to open up for broader feedback from users (Rodríguez-Calero et al., 2020). Output from this phase included four prototypes with unique ways of solving the identified design challenges.

5.3 Phase 3 - General Design

This phase followed the same structure as described for Phase 1, starting with data-collection and concluding in evaluation and documentation. However, this phase performed data collection using the artifacts created in Phase 2 as part of the usability study. Data collection methods included interviews and use cases, in which users and stakeholders interacted with artifacts from Phase 2 and provided insight, which is described in detail in Section 8.1. The data collected included both qualitative and quantitative data, which were analyzed using KJ-analysis and statistical methods respectively.

The results of the analysis was used to refine the list of guidelines and requirements. New requirements were supported by previously written guidelines in combination with data gathered during the usability study. New requirements based only on the data gathered were also synthesized. During this stage in the process, relevant regulatory requirements were synthesized and added to the requirements list. The final activity of the phase was to use the collected data to select a main concept from the four concepts that the phase worked with.

5.4 Phase 4 - Ideation and Prototyping 2

Similar to the previously performed ideation and prototyping phase, the work in this phase built upon the insights gathered in the previous phase. Based on the results from Section 8.1 and requirements synthesized in Section 8.2 a final design concept was created.

Given the design level at which requirements in Phase 3 where synthesized, high fidelity was necessary to test usability and utility requirements. However, creating a high fidelity physical prototype was not justifiable within the scope of this project. And so, both digital and physical means were leveraged in order to communicate vital aspects of the concept. These included digital renderings and a physical prototype. This set of both digital and physical prototypes was used to present and evaluate the final design to both stakeholders and users. Methodology to create these artifacts was similar to Phase 2, using Brainstorming and Cognitive Walkthrough.

5.5 Phase 5 - Concept Validation

This phase used the design concept produced in Phase 4 to explore feasibility considerations and possible changes to the concept through a final iteration of user and stakeholder evaluations. Methods to gather data included presenting the concept through explaining the use, supported by digital renderings and physical model and then conducting a semi-structured interview.

6

Phase 1 - Needs and Requirements

In the first phase of the project, the focus was on building an initial understanding of the DXR+ and its potential for improvement. This understanding was built by a user study and a focus group, which eventually led to an initial set of needs and some early requirements for the re-designed DXR+. This chapter describes that process in further detail.

6.1 Initial Information Gathering

An initial batch of research was conducted to gain deeper understanding of the DXR+ so that further studies could be more focused. The goal was to gain insights about the product that could be used to structure user studies around. This research consisted of investigating the product's webpage (RaySafe, 2026), having open discussions about the product with stakeholders from RaySafe, trying hands-on usage of the DXR+, and comparing the DXR+ to competing solutions such as the QUART nonious (QUART, 2026), phantoms and the ”nine penny method”.

During the initial research, a few points of interest emerged. These points were identified from multiple sources, or stuck out clearly from a single source. A point of interest here is defined as an aspect of the DXR+ with potential for improvement, and as such, something to investigate further through proper user studies. Table 6.1 shows these points and their sources.

Table 6.1: Potential areas of improvement resulting from initial research.

nr	Point of interest	Sources
1	4 measurements are required for one calibration	Stakeholders, Competitors
2	Aligning DXR+ with light field edge has error margin	Stakeholders, Hands-on Use
3	Retrieving measurement is time dependent	Hands-on Use
4	Resolution and alignment of display pixels make readings difficult	Hands-on Use
5	No indication of battery life on product	Stakeholders, Hands-on Use
6	DXR+ output is not integrated into other systems	Stakeholders
7	DXR+ could be made CT compatible	Stakeholders, Competitors

These points of interest were regarded as starting points to help structure further research and user studies around. As such, they were never seen as requirements. Instead they were worked on to be confirmed, refined or rejected as the process went on, with some eventually leading to some kinds of requirements.

6.2 User Study

As with most design processes, designing a medical device benefits from early user involvement (Martin et al., 2008). Therefore, the central activity of Phase 1 was conducting the first wave of user studies. A semi-structured interview format was chosen for these studies, since the less rigid format was appropriate for the early stage at which the user's were involved. Furthermore, involving users early, even pre-prototype with only interviews, has been shown to be valuable in designing medical devices (Martin et al., 2012).

The goal of the study was to both investigate the DXR+ and its use in general, and to refine, confirm or reject the previously identified areas of improvement. The interview questions were thus prepared to cover the participants work in general, workflow in relation to the task of light-radiation alignment, aspects specific to the DXR+ and the points of interest mentioned in Table 6.1.

To gather participants for the user tests, a combination of personal contacts and contacts through RaySafe was used. Due to a relatively low availability of participants, the only requirement of participation was being a user of the DXR+ or competing solutions. Users were contacted through digital means and interviews were scheduled to in-person meetings where possible and online meetings where needed. A total of seven participants were interviewed across five occasions. Two of the interviews were held in person and included a live demo of how the participant used the DXR+ or a competing solution. Four participants were users of the DXR+ and three used different tools in its place. All interviews started by applying informed consent. Notes were taken during all interviews, and when permission was granted, interviews were recorded.

An in-depth interview with a product manager at RaySafe was also conducted alongside the user study. The interview had a similar structure to the regular user studies, but with a stronger focus on the DXR+'s role on RaySafe's product line-up and the company's vision for the product. This interview was meant as a compliment to the user studies, so that more stakeholder-oriented information could be gathered.

Upon completion of all interviews, answers from each participant were summarized into concrete statements in a format that could be used in a KJ analysis. A task analysis was performed on each user's description of the task of light-radiation alignment to provide an overview of the task workflow, see Appendix D. A KJ analysis was performed to see emerging trends, and compare these to the areas of improvement in Table 6.1.

6.3 Focus Group

The data collected and verified by the user studies were now to be evaluated by stakeholders. This also acted as an opportunity to investigate any aspects of improvement that users and the project team might have missed. As will be discussed later in this section, the stakeholders hold a varying amount of technical and product specific expertise, which could lead to valuable insights. The general goal was to ensure a cohesive and shared understanding of the DXR+ purpose, usage and aspect's of improvement. This was done through a workshop session with participants divided into two groups. An important aspect of the workshop was to include individuals with both technological and product specific expertise. Participants were asked to divide themselves into two groups, with the goal of creating two equally diverse groups. Each participant's professional title and respective group, used for the duration of the workshop, is presented in Table 6.2.

Table 6.2: Roles and group of the participants in the focus group.

Professional title	Group
UX-design engineer	Green
Sensor technology engineer 1	Green
Sensor technology engineer 2	Green
Concept developer	Green
Embedded software developer	Green
Technical writer	Yellow
Software engineer	Yellow
Sensor technology engineer	Yellow

The varying level of DXR+ specific knowledge within the group meant that a baseline had to be established. This was done through a short 5-10 minute presentation, describing the purpose and usage of the DXR+ as understood by the project team. This understanding was primarily based on the data collected and analyzed during and after the user studies.

Participants were then asked to identify aspects of improvement as it pertains to the purpose and usage of the DXR+. Participants were encouraged to speak out if they identified any gaps in the presented understanding. The resulting aspects of improvement produced by each group are presented in Table 6.3 and Table 6.4.

Table 6.3: Aspects of improvement gathered from the green group.

nr	Aspect of improvement
1	Battery replacement, not chargeable
2	The deviation cannot be automated directly and obtained digitally.
3	Human error. Many manual steps open the door to mistakes.
4	Directionally dependent
5	The displayed value disappears automatically
6	No pass/fail analysis
7	4 measurements are required

Analyzing the results provided an indication as to the validity of the previously made assumptions, as well as new perspectives on how to increase utility.

Table 6.4: Aspects of improvement gathered from the yellow group.

nr	Aspect of improvement
8	Increase X-ray dose sensitivity to make DXR+ compatible with more machines
9	Rechargeable battery
10	Measure distance of radiation, can make it CT-compatible for doseprofile
11	Allow for 4 measurements in one irradiation
12	Measure light-field also
13	Higher resolution

Aspects 1 and 9, mentioned by both groups, strengthen the claim of allowing the user to, in some capacity, interact with the battery status of the device.

Aspects 7 and 11 both highlight the possibility of minimizing repetitive tasks as a way of improving the current product. An assumption held in this stage of the process is that this design decision that would offer the most in terms of drastically changing the intended usage and so it offers the most in terms of increased usability.

Aspect 6, No pass/fail in combination with aspect 3, Manual steps open the door to mistakes, highlight an interesting perspective of the stakeholder group. Automation, in varying capacity, is perceived as a positive in the context of usability. This ethos has been reiterated a few times from stakeholders as well as in product documentation and promotional material relating to RaySafe products. How automation can be implemented and at which level will be explored further in Section 7.4.

6.4 Requirement Synthesis

As described in Section 5.1, the desired output of Phase 1 in regards to the overarching system perspective is a defined system goal and a list of system performance metrics that will aid in the evaluation of developed prototypes further along. Furthermore, usability guidelines and requirements from the perspectives of stakeholder, user and utility needs to be synthesized. This will be done based on the data collected and structured as user profiles in Section 6.2.

An initial assumption made in regards to system goal was that its definition would be dependent on the persons role within the larger sociotechnical system. Testing this assumption was done by including a question in the data collection where each participant were asked to define the system goal from their perspective. Resulting in a variety of perspectives on system goal, see Table 6.5.

An analysis of position within the sociotechnical system and stated system goal indicates that physicists view ensuring compliance with standards and ensuring that radiation does not extend beyond the collimated field as the goal of the human machine system. They are also likely to impose more strict compliance tolerances than is technically necessary.

A definitive motive behind this is outside the scope of the data collection and analysis performed within the framework of this project. However, an assumption was made that physicist are more detailed oriented in regards to the scientific con-

Table 6.5: Definitions of system goal gathered from different study participants.

nr	System goal	Source
1	Offer a QA product to be a leading actor in the market	Product Manager
2	Ensure machine is compliant with IEC standards	Physicist 3
3	Verification measurement of X-ray field	Engineer 1
4	Ensure that field is within tolerance	Oncology nurse
5	Ensure that radiation does not extend beyond the collimated field.	Physicist 1 and 2

text and so can go beyond the required compliance standards based on internal motivation. This assumption was strengthened by conversations with stakeholders at RaySafe who have had more extensive relationship with physicists working in the sociotechnical system.

Hospital engineers and nurses defined system goal with an emphasis on tolerance check and quality assurance. During user studies their explanations were perceived as closer to that of actual end use, which is to minimize patient exposure to X-rays, rather than a heavily theoretical understanding as described by the physicists. This of course does not imply a lack of theoretical understanding by engineers and nurses as a user group, but rather highlights how each user group perceives the human machine system and it's intended goal.

System performance metrics were synthesized based on how users and stakeholders define a successfully completed task in combination with the usability heuristics presented in Section 4.5. See Table 6.6 for description of each metric. These will constitute an important part of future usability testing. A lack of available real world users made it so each metric was labeled with type of users. These labels indicate whether measuring a metric is most appropriate with proxy users, real world users or both. Some metrics were deemed most appropriate to evaluate with proxy users in order to save time with real world users for matters where their experience was needed. Furthermore, method for testing these metrics were also mapped in order to aid in the structuring of the subsequent user study.

RaySafe emphasized ease of use, as highlighted by system performance metric 6 and 9. These metrics both point towards some form of automation, either increased abstraction level of machine output or automated decision making. This reasoning is in line with previous comments made by stakeholders at RaySafe in Section 6.3. Regarding the other metrics, key aspects were identified from the qualitative data summarized in each user's profile. If multiple users mentioned similar aspects, it would be written as a metric and implemented.

Synthesized usability guidelines and user requirements relevant for Phase 2 are combined and presented in Table 6.7. An interesting aspect of current DXR+ usage is how requirement 14 - *Aid the user in deciding which sides have been measured* and requirement 11- *Allow overview of value side relationships* are fulfilled. The user currently reports one measurement at a time, limited by the geometry of the

Table 6.6: The system performance metrics identified during Phase 1.

nr	System performance metric	Source	Type of Users	Method
1	Time on task	Multiple users	Proxy users	Time measurement
2	Trust in perceived machine output	Multiple users	Real world	Semantic scale
3	Portability	Multiple users	Real world users	Semantic scale and observation
4	Amount of repetitive work	Multiple users	Proxy users	Observation
5	Perceived accuracy in accordance with legal requirements	Multiple users	Real world users	Interview
6	Instances were system allows for use-error	RaySafe	Proxy users	Observation
7	Clear relationship between measured deviation and measured side (Value-side relationship)	Multiple users	Both	Likert scale
8	Quick light edge alignment	Multiple users	Both	Observation
9	Workload	RaySafe	Proxy users	RAW NASA-TLX

current DXR+, and so labeling what side the reported measurement is related to is important. Through analyzing a number of reporting documents, there were two common ways of labeling measurements and both assume the user as reference point. The first alternative is labeling each side as left, right, chest (towards user) and anterior (away from user). The second alternative is denoting sides 12:00, 3:00, 6:00 and 9:00, based on an analog clock. How these already implemented solutions can be implemented in this project will be further investigated in Section 7.4. Synthesized utility requirement are presented in Table 6.8. These are based on the need to replace the current DXR+ and so the source for requirements 44,45 and 46 were set to the current product. Requirements 47 and 49 are based on data gathered from specific participants and so specified as their source. However, they way in which the source description was created limited the number of sources to 1, and so specified users as source does not exclude the fact that current product could have led to a similar utility requirements. The presented requirements are a selection from the entire requirements list, which is found in its entirety in Appendix A.

Table 6.7: An excerpt of usability guidelines and usage requirements relevant for the subsequent phase.

nr	Requirements	Type	Source
7	Allow for measurement of multiple sides per irradiation	Usability guideline	Physicist 1
11	Allow overview of value side relationship	Usability guideline	Nurse 1
14	Aid the user in deciding which sides have been measured	Usability guideline	Physicist 3
15	Allow the user to decide pass/fail parameters	Usability guideline	Physicist 3
24	Allow clear affordance for placement of product on light edge	Usage requirement	Multiple users
25	Offer numerical readout of deviation	Usage requirement	Physicist 1
26	Offer readout from product itself	Usage requirement	Physicist 1

Table 6.8: Utility requirements synthesized during Phase 1.

nr	Requirements	Source
44	Save 1-dimensional position of light field edge	Current product
45	Save 1-dimensional position of radiation field edge	Current product
46	Offer machine output of measured distance between light and radiation field.	Current product
47	Allow for read-out from ruler element in X-ray image	Physicist 2
49	Allow for stand-alone usage	Physicist 3

6.5 Task Description

Each user described the task with slight variations, and so for this project a generalized task description was synthesized. The task was defined as "Ensure light-radiation field alignment is within tolerance", based on the task goals presented in Section 6.4. A description of task 6 *Retrieve length of deviation* and task 7 *Check if within tolerance* is presented in Section 7.4.4.

A quick mapping of how the user moves in the physical space was also synthesized. As seen in Fig. 6.2, the user has to walk a set distance between the X-ray room and the control room every time they take a measurement. In combination with task 8, seen in Fig. 6.1, the user has to repeat the whole measurement procedure 4 individual times. Meaning a lot of walking back and forth, and a lot of repetitive work.

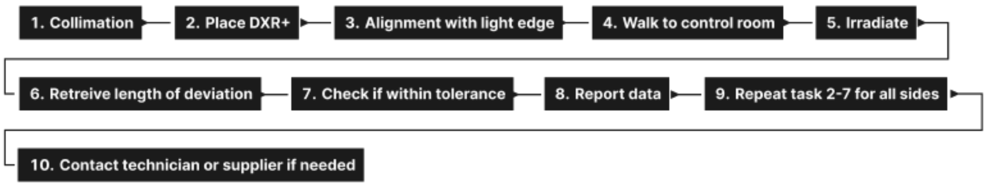


Figure 6.1: Generalized description of the main task which the DXR+ is used for.

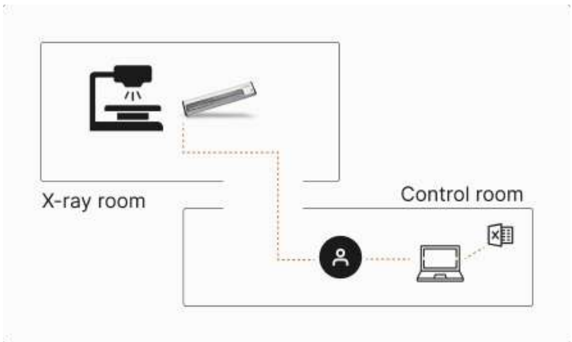


Figure 6.2: Mapping of user movement while using the DXR+.

Summary

In summary, this phase produced insights and understanding regarding current DXR+ usage and users. It allowed for systematic reduction of the design space through synthesis of requirements and guidelines adhering to design levels effect and usage. Further understanding of current use also provided insight into how some aspects should be prioritized. For example, minimizing repetitive work became a priority which in turn led to the first design challenge, Geometry, to be identified.

7

Phase 2 - Ideation and Prototyping 1

As described in Section 5.2, this phase serves as an intermediate layer to produce various tangible artifacts to increase the capacity for data collection in the subsequent phase. Initially, a large number of ideas will be produced. The design challenge at the center of this is how to minimize repetitive work. Ideas will be continuously analyzed in regard to their ability to implement additional design solutions resulting from requirements synthesized in the previous phase. Later, additional solutions to design challenges, such as machine output, will be implemented. And so, guide the further development of the generated design concepts.

7.1 Light Edge Alignment

One major issue identified during Phase 1 was that aligning the DXR+ with the light field edge was a difficult task. Users sometimes felt unsure of whether their light edge alignment was correct, and even just seeing the light field on top of the DXR+ was not always easy to users. A simple solution to this would be to have the DXR+ automatically detect the light field edge the same way it automatically detects the radiation field edge. This specific type of automation, where the machine monitors and gathers information relevant for the operator, falls within the framework for automation and situational awareness outlined in Section 4.7.2. As such all ideas, concepts and prototypes generated in this phase were assumed to be able to automatically detect both light and radiation field edges, and calculate the distance between them. The visual affordance for this is simply a line, like the one found on the current day DXR+, but wider, where the light field edge has to be placed orthogonally somewhere across the line, as shown in Fig. 7.1.

7.2 Initial Ideation

A free-form, open analysis of the requirements list synthesized in Phase 1 made it clear that a number of separate design challenges existed. The product's geometry (its physical form) and machine output (how it displays the measurements it has taken) were the most notable ones, as most of the requirements could be traced to be dependent on one of these challenges. Since aspects of the machine output, such as the location of screens and their content, would be dependent on the geometry,

Figure 7.1: Demonstration of the visual affordance for light edge alignment when using automatic edge detection. **Left:** Not properly aligned. **Right:** Properly aligned.

it was decided that the first design challenge that needed to be handled was the physical form of the product.

To address this challenge, an internal brainstorming session was held. Ideas created by the focus group, as mentioned in Section 6.3, were used as a complement to this session. The goal of the activity was to generate ideas for the physical form of the product that could match the previously gathered requirements.

Since the ability to measure the light-radiation deviation on multiple vertices in one irradiation was one of the highest priorities of multiple groups of stakeholders, all generated ideas were required to be able to measure at least two vertices per irradiation, while remaining portable and relatively small. Measuring three sides in one irradiation still requires a second irradiation for the final side, such solutions were not considered. This means solutions should measure two or four sides per irradiation. Taking rotation into account, three possible constellations allow this, as shown in Fig. 7.2. These were used as a guide in the brainstorming session.

A secondary level of focus was given to the geometry's ability to display and store measurement data. For example, some physical forms might have natural placements for displays, while others only allow slightly suboptimal placements. Fig. 7.3 shows a sketch compiling the 15 ideas generated from this activity.

Due to the relatively large amount of geometrical concepts ideated, it was decided that physical prototypes could not be created for all concepts. Concepts that were very similar, or strictly worse than others in terms of requirement fulfillment, were thus rejected. The following is a list of the rejected concepts, and their reason for rejection:

- Concept 3: Highly similar to Concept 2 and Concept 9.
- Concept 6: Highly similar to Concept 4, and strictly worse in terms of portability.

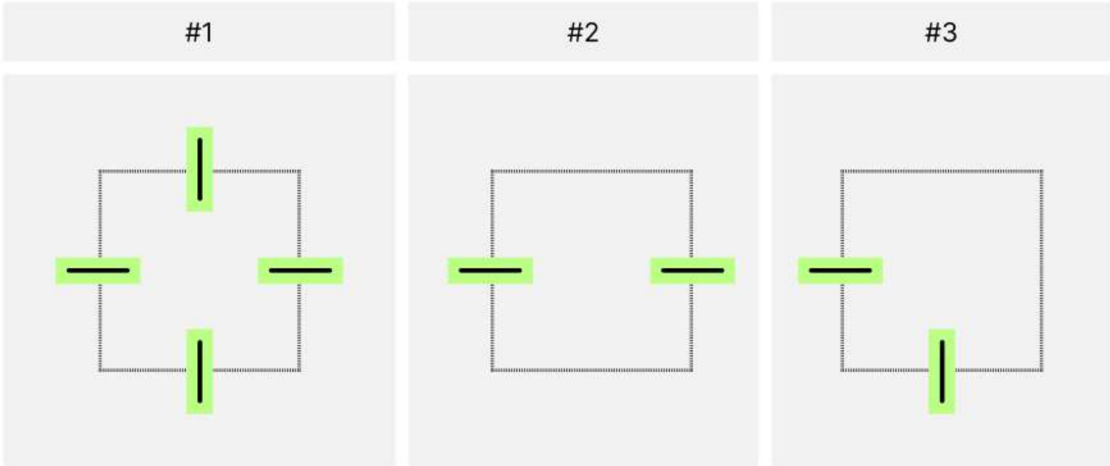


Figure 7.2: Possible constellations that allow for multiple measurements per irradiation.

- Concept 7: Same as above.
- Concept 9: Highly similar to Concept 4.
- Concept 12: Highly similar to Concept 11.
- Concept 13: Highly similar to Concept 11.

After the rejections, nine geometrical concepts remained. For each of these, a physical, low-fidelity prototype was made, primarily from Extruded Polystyrene (XPS) foam, LEGO and paper. The purpose of the prototypes was to enable further testing and exploration through physical form, and to open up for better feedback from stakeholders (Coulentianos et al., 2020; Rodríguez-Calero et al., 2020). A compilation of the low-fidelity prototypes is shown in Fig. 7.4. The prototypes were sized according to assumptions based on the current DXR+'s size, with the goal of displaying an accurate physical scale of the theoretical product corresponding to each prototype.

7.3 Choosing Main Concepts

With nine geometrical concepts now implemented in physical, low-fidelity prototypes, the next step was to gather feedback on which concepts best suit the users and the requirements. Further refining nine prototypes would be time-consuming and offer diminishing returns, since their fidelity was already high enough to receive the kind of feedback needed.

Two methods were chosen to evaluate the nine prototypes, the results of which are shown in Table 7.2. First, Cognitive Walkthrough with particular focus on the previously gathered requirements on size and physical interaction. In practice, this meant the prototypes were judged qualitatively based on whether they would be portable, either in a pocket or in a smaller suitcase, and easy to operate in terms of

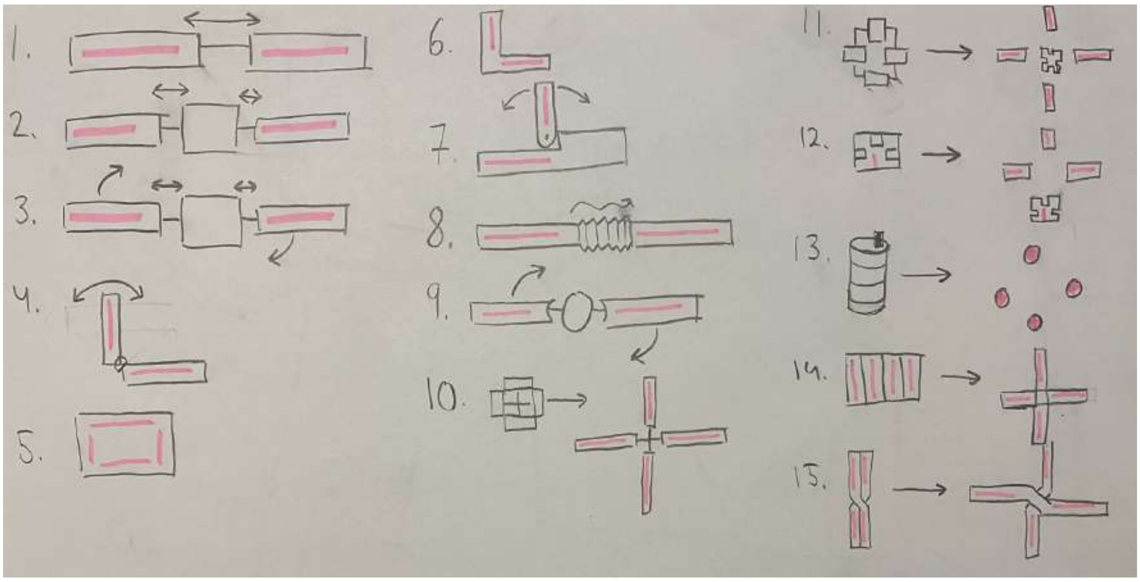


Figure 7.3: Initial sketches of the 15 ideas generated for product geometry, with pink highlighter marking where the product would be able to detect light and X-ray fields. Arrows indicate that the product can fold, expand or move in the arrow's direction.

taking the prototype from its "compact state" to its "measuring state". Solutions that offered the ability to measure all four sides (Concepts 9, 11, 14, 15) in one irradiation were also seen as advantageous.

A second method for gathering feedback from users was also required to ensure user-centered design. With the low availability of users at the time, purely quantitative methods were deemed nonviable. At the same time, the relatively large number of prototypes meant deeply investigating each prototype with users would be extremely time consuming. Finally, the geographical spread of the available users made it impossible to visit all users and let them physically interact with the prototypes. As such, the conclusion was that an online survey was the most viable option for gathering user feedback. To give respondents a better understanding of the physical aspects and usage of the prototypes, the survey included images of the prototypes in their "compact state" and "measuring state", with dimensions given for the compact state, as shown in Fig. 7.5.

For each prototype, four questions were asked:

- How portable do you think the product would be in its compact state?
- How easy do you think the prototype would be to use?
- What advantages and disadvantages do you see in the product compared to the current DXR+?
- Do you think you could make an accurate and trustworthy measurement using this product?

The low amount of questions was a result of the high amount of prototypes, and lead to the questions needing to be very broad to cover the desired topics. At the

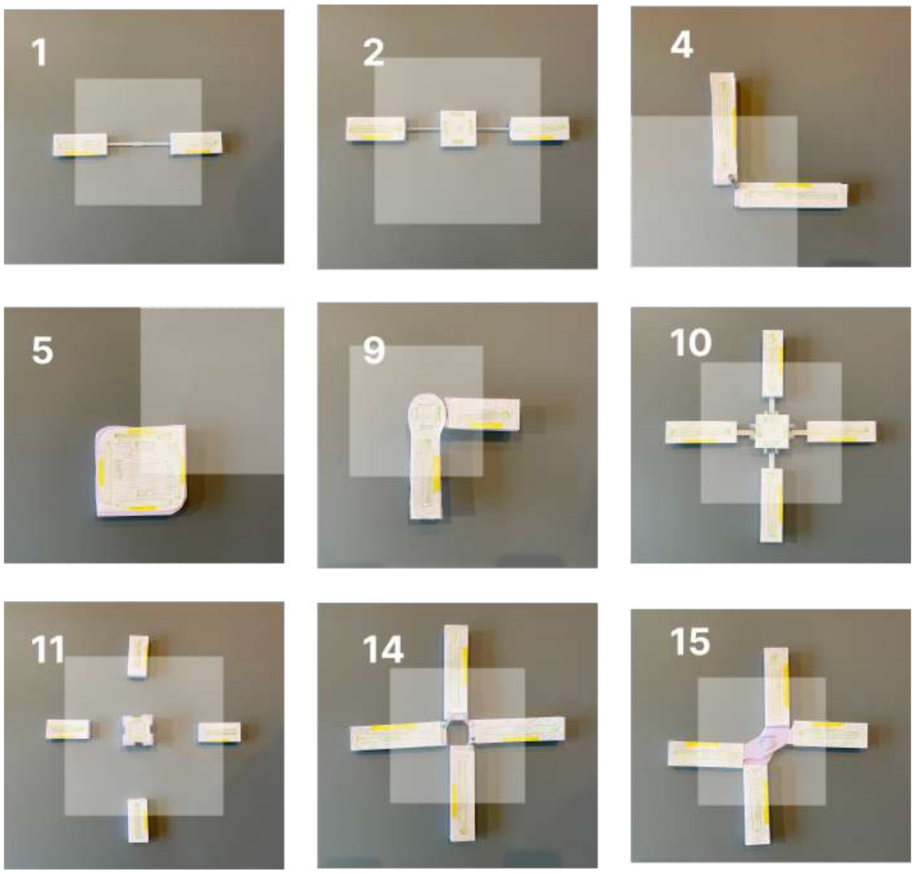


Figure 7.4: Low-fidelity prototypes of the nine geometrical concepts left after rejections. The light field is shown as a light gray square, and is **not** to scale.

Figure 7.5: Example of how prototypes were shown in the online survey, using prototype 14.

end of the survey, the users were asked to rank their top three favorite prototypes and explain their choice. Three users filled out the survey, leading to a response rate of 75%. The respondents ranking of the prototypes is shown in Table 7.1. The answers from the survey were qualitatively analyzed, and together with the requirements-based analysis, the results in Table 7.2 were reached.

Table 7.1: Survey respondents' rankings of their favorite prototype.

Respondent	First place	Second place	Third place
A	9	4	None
B	9	14	1
C	10	2	5

Table 7.2: A summary of the survey and analysis that the decision on which prototypes to proceed with was based.

Prototype	Main User Input	Requirements Analysis	Verdict
1	Easy to use, portable, accurate.	Clear and simple usage, portable.	Good option, develop further.
2	Easy to use, relatively portable.	Relatively clear and simple usage, relatively portable.	Reject due to Prototype 1 likely performing better with similar concept.
4	Easy to use, portable	Clear and relatively simple usage, very portable	Good option, develop further.
5	Relatively easy to use, relatively portable, worries about reliability of measurement.	Relatively clear and simple usage, relatively portable, requires double the components per measurement.	Reject due to extra components and existence of simpler solutions, like Prototype 4.
9	Relatively easy to use, large due to not folding completely.	Easy to read from but hard to handle physically.	Reject due to size and handling.
10	Easy to use, fast, accurate, somewhat large, worry for joints wearing out.	Clear and relatively simple usage, slightly larger than other options	Good option, develop further, investigate size.
11	Portable, difficult placing four products, worry about wireless connectivity.	Clear and relatively simple usage, portable.	Good option, develop further but do not assume wireless connection.
14	Relatively easy to use, worry for joints wearing out, too large, difficulty adjusting to all right angles.	Risk for stacking errors with angles, decent size volumewise but two long dimensions.	Reject due to difficult usage and dimensions.
15	Easy to use, fast accurate, very large in largest dimension.	Clear and simple usage, large in largest dimension.	Reject due to length.

In summary, most options were decent, but some stuck out as being the users' favorites and/or fulfilling requirements well. As shown in Table 7.2, the best solutions were deemed to be Concepts 1, 4, 9 and 11. These are the concepts that will be refined and tested further going forward. To better keep track of the concepts, they were given the following names, roughly inspired by their shapes:

- Concept 1: ”Extender”.
- Concept 4: ”Butterfly”.
- Concept 10: ”Squid”.
- Concept 11: ”Four Cheeses”.

Fig. 7.6 shows a summary of these four concepts, including the dimensions their prototypes in ”compact state” and the prototypes as shown under a light field.

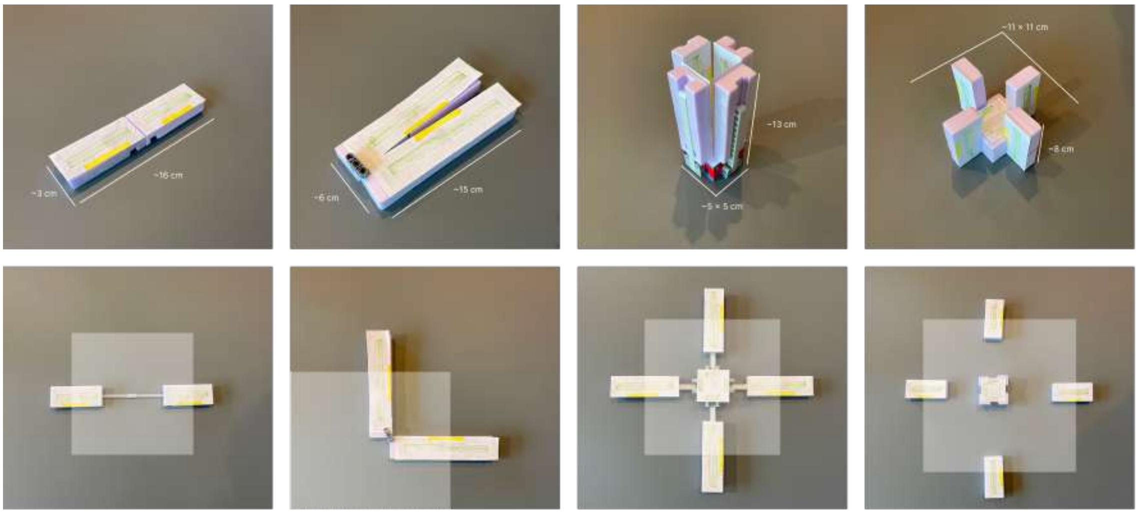


Figure 7.6: Compact and measurements states of the prototypes corresponding to the four chosen geometrical concepts. **From left to right:** Extender, Butterfly, Squid, Four Cheeses. **Top row:** Compact state with dimensions. **Bottom row:** measurement state.

7.4 Further Development

To guide the further development of each concept, an evaluation matrix inspired by morphological and Pugh matrix was created. The method resulted in a comprehensive evaluation of each concept and their individual ability to meet specific requirements. Evaluating the concept with this method prompted quick ideation sessions when the concept did not meet specific requirement. This resulted in the abstraction level of each design solution to be decreased.

Performing the analysis highlighted similarities in the type of design challenges the various requirements placed on the concepts. And so, each requirement was labeled with type of design challenges it placed on the concepts. The labels used were: Geometry, Machine output, Light edge alignment, Storage, Reporting and Increased utility. There was no limit to the amount of labels that could be placed on a specific requirement, see Table 7.3 for example. The following sections discuss how the four chosen design concepts were developed further to tackle the different design challenges.

Table 7.3: Examples of categorization for requirements relevant for this phase.

nr	Guidelines	Categorization
7	Allow for measurement of multiple sides per irradiation	Geometry
11	Allow overview of value side relationship	Geometry
15	Allow the user to decide pass/fail parameters	Geometry
24	Allow clear affordance for placement of product on light edge	Light edge alignment
25	Offer numerical readout of deviation	Machine output
26	Offer readout from product itself	Machine output, Geometry
27	Allow for easy transportation and storage	Machine output, Geometry
46	Offer read out of distance between light and radiation field	Machine output

7.4.1 Design Challenge: Light Edge Alignment

As discussed previous in this chapter, these concept all include the function of automatic light edge detection. Instead of a small orange/yellow strip, as on the current DXR+, the concepts have a broad yellow band where the light edge can be place along. This was done by applying a thin strip of paper on each prototype and simply painting it yellow with a marker.

7.4.2 Design Challenge: Geometry

The concepts' unique geometries imply more than their ability to meet guideline 7. They also dictate how solutions for guideline 11 can be developed. The use case of concept 4 "Butterfly" highlight why. For example, a measurement of two sides is done with concept 4 and then the machine output is retrieved. This can be done through either reading the machine output when the product is laying where it was irradiated or by picking it up and bringing it to the room where the users laptop is placed. If the product is picked up, then the orientation of the product in relation to the user has to be preserved or the connection between measure value and side will be broken, and so decreasing the reliability of the reported deviation. Each concepts ability to meet this guideline will be discussed further when each concept is presented in full later in this chapter. The geometry and size of the concept also indicated the possibility of SID and tolerance input, fulfilling guideline 15. For the Butterfly, its main advantage is its simplicity. And so, adding the ability for input, through sliders, knobs or buttons will increase the complexity of the product. Furthermore, the geometry of the concept also allows for different ways of storing and transporting the product. This guideline has been central in the development of the concept geometries as all of them allow some form of mechanical movement, in order to decrease their size. How each individual concept meets this guideline is presented in Fig. 7.7

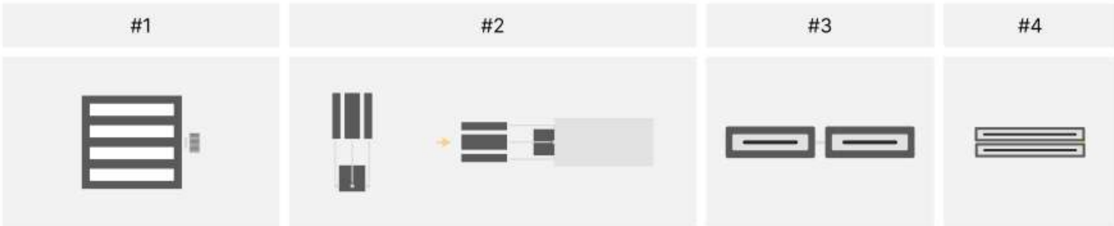


Figure 7.7: Visualization of how concepts allow for transportation and storage.

7.4.3 Input of Parameters for Pass/Fail Analysis

There were two concepts where the specific geometry allowed for interesting ways of letting the user to decide input parameters. Four Cheeses, as seen in Fig. 7.8, allows the user to turn a knob on the side of the base unit in order to set a desired tolerance. By pulling the knob outwards, an interaction inspired by setting the time on wrist watches, the user can then switch to control over SID input.

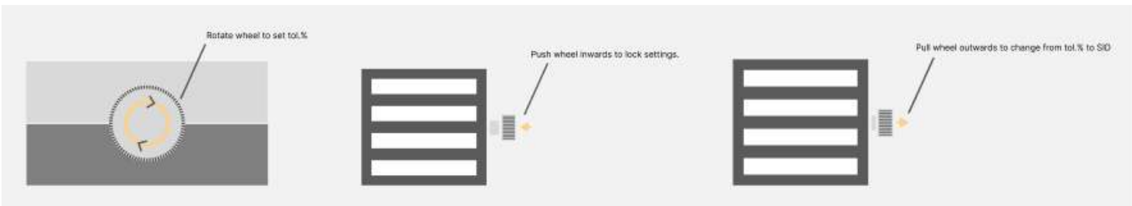


Figure 7.8: Visualization of the input on Four Cheeses.

The possibility of input on Extender relies on the geometry's inherent ability to be pulled apart and rotated around it's own central axis. The extender concept has 3 distinct states in relation to "extending". First state is where both parts are place close together, this is where tolerance is set. Semi extended, where SID is set and fully extended where the device is ready to be irradiated.

To set tolerance, the user rotates the right part of the device 20 degrees away from the user to increase the set value by 0.1%, and towards them to decrease the value by the same amount. The default value is set to 1%, as this was the most common tolerance according to the initial data collection. To set SID, the user performs the same action as when setting tolerance. Each step now increases the value by 1 cm and starts at 100 cm, as this was the most common SID value used based on the initial data collection. See Fig. 7.9

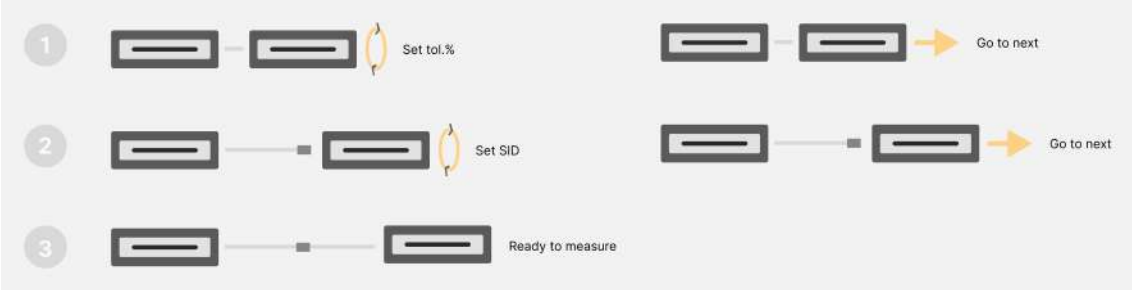


Figure 7.9: Visualization of the input on Extender.

Furthermore, the Squid's geometry allowed for an interesting possibility. Since the base of the geometry is place in the middle of the light field, it might be possible to place a distance sensor in it's base. This would allow for automatic SID detection which would subsequently provide the machine with the necessary data to directly calculate the % of SID and have that as part of it's machine output.

7.4.4 Design Challenge: Machine Output

Design solutions corresponding to requirements labeled as Machine output required further development. This was not unexpected as the main design challenge up to this point had been minimizing repetitive work, solved mainly through product geometry. However, analysis prompted further idea generation and led to each concept becoming more unique and complete. Regarding the design challenge Machine Output, each concept now solves this in a unique way, see Fig. 7.10.

Each of the design solution encompasses different types of information relevant to the main goal. The goal of creating multiple unique examples of machine output is to test which combination is preferred in order to support the user's situational awareness and decision making. Implemented in design solution #1 and #2 is feedback regarding an automated pass/fail analysis. This is done in order to present level 2 - SA directly, and so minimize cogntitive resources required to perform the task. In all these design solutions: orange/yellow is used to represent light edge, the X-pattern represents radiation edge and green is PASS for the automated pass/fail analysis. Design solution 1 presents order of edges, pass/fail analysis as well as numerical readout. Design solution 2 presents distance between edges with pixels representing 2,5mm each, inspired by the current DXR+, pass/fail analysis as well as numerical readout. Design solution 3 presents distance between edges with two lines, numerical readout of distance as well as percent of SID. Design solution 4 is very similar to design solution 3 except it does not present a numerical readout of percentage of SID.

In combination with the 4 unique geometries, there are now in theory 16 different concepts if design solutions for these two challenges are combined. The goal of this is to test the concepts as a whole, but also allow for feedback on individual design solutions. This will allow for data collection that could serve as the basis for a new concepts, created by combining the best performing individual design solutions into one concept. This will be done in Chapter 7.

The type of information presented to the user as machine output is varied be-

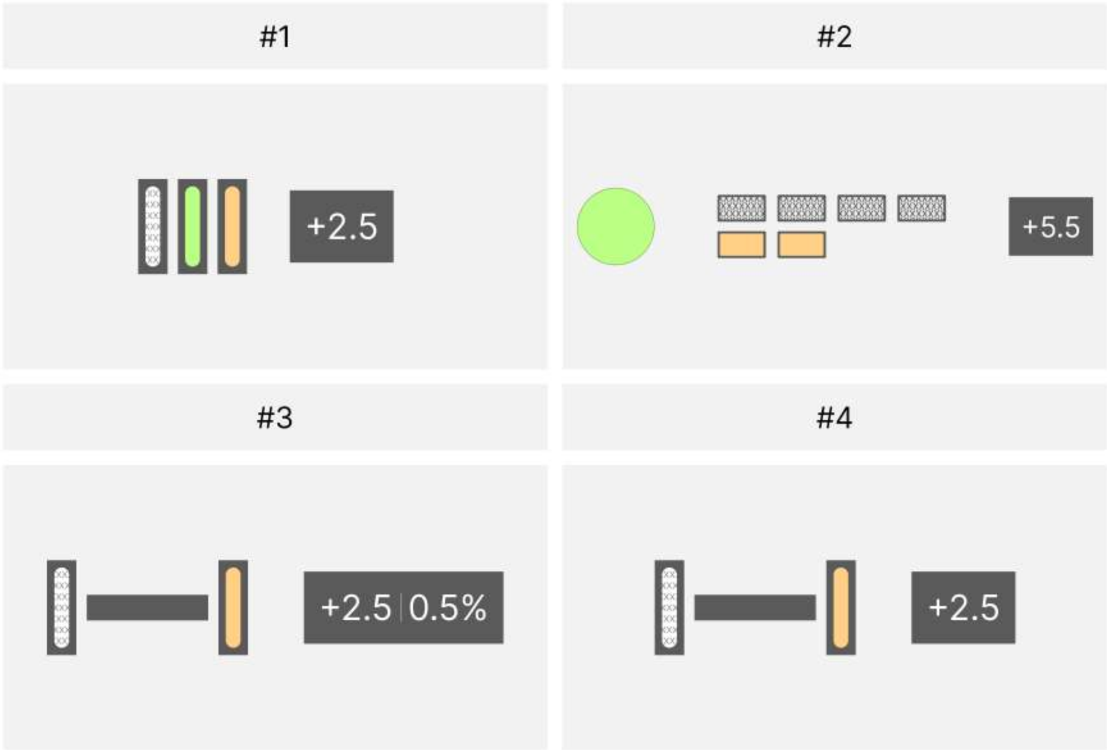


Figure 7.10: Visualization of the four design solutions corresponding to requirements 25 and 46.

tween the four different design solutions but all serve as to aid the user in performing the tasks 6 *retrieve length of deviation* and task 7 *check if within tolerance.*

A task analysis was performed on the current DXR+ workflow in order to gain further understanding of information critical for the users decision making.

Task 6 retrieve length of deviation can currently be performed in two ways, see Fig. 7.11 and Fig. 7.12 respectively. In alternative 1, the user *6.1 identifies both radiation and light field edges*, *6.2 check order of edges* and *6.3 counts the number of pixels in between.* Followed by *6.4 multiplying the number of pixels with 2,5 mm* to obtain the length of the measured deviation. This requires the user to have some information in their working memory. However, simple multiplication, amount of pixels times 2,5, is something users have done many times and it can be argued that this particular multiplication task can be described as skill-based within Rasmussen's SRK framework (Rasmussen & Vicente, 1989). Alternative 2 includes *6.1 identify X-ray field edge* and *6.2 check the corresponding numerical readout.* Task 6.2 is performed by *6.2.1 identifying the center of the last pixel* and *6.2.2 look for the corresponding numerical readout on the ruler element.*

In order to perform this task the first or second way, requires slightly varied types of information. For example, *6.2 check order of edges* is done in order to gather information regarding the sign of deviation. If positive, the radiation field edge lies further away from the center than the light field edge. If negative, this is reversed. If the ruler element is used to retrieve length of deviation, then sign is already accounted for.

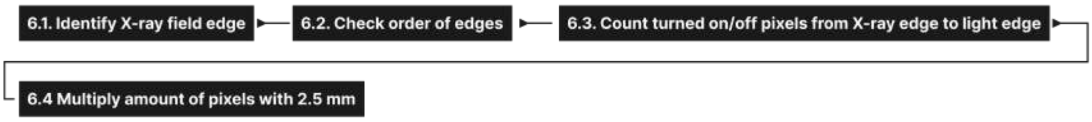


Figure 7.11: Alternative 1 for performing task 6.

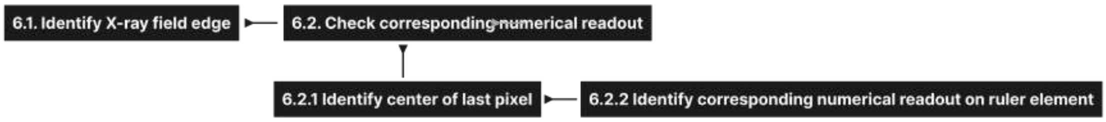


Figure 7.12: Alternative 2 for performing task 6.

Task 7 *check if within tolerance* can like task 6 currently be performed in two ways, see Fig. 7.13 and Fig. 7.14 respectively. Alternative 1 relies on using the external documentation tool, an excel spreadsheet, with implemented calculation models. The users then *7.1 Input SID [cm] & Tolerance [%] into excel*, which is usually done in advance or the test parameters are kept from a previous instance of this task. The user then *7.2 Input the deviation into excel* based on the results provided by the machine in task 6. The excel sheet then does the necessary calculations and provides the user with pass or fail in text or as green or red markings in designated boxes in the excel sheet. All the user then has to do is *7.3 check calculation output* to decide whether or not the measured side is within tolerance. Alternative 2 relies on the user to perform the necessary calculations in their head, *7.1 Calculate SID [cm] * Tolerance [%]*. This is a simple multiplication and since the SID is usually set to 100 cm then calculating 1% of that is quite easy, especially for users with a lot of task specific experience. Then the user *7.2 check if calculated output > retrieved measurement*, which could entail a simple operation of whether 10 (calculated output) > 2.5 (retrieved measurement).

Figure 7.13: Alternative 1 for performing task 7.

A strong argument for numerical read out of measured deviation is the subjective nature of decisions made by users based on only visual feedback. The light field projected by the machine has a clear gradient at its edge, called the penumbra. In the study by (Kron & Ferguson, 2000), radiation therapists were asked to mark the edge of the light field and a variation between participants was observed. This subsequently affects the consistency of manual light edge alignment, and so the performance of completing task 6.

Figure 7.14: Alternative 2 for performing task 7.

7.4.5 Development of Prototypes for Usability Testing

Prototypes of these variations of the concepts where designed using Fusion 360 and then produced through 3D printing. Most features, that allow for mechanical movement of parts where either made in Fusion 3D and then printed or, in the case of Extender, created by reusing the LEGO mechanism used in the previous iteration. All prototypes where designed with slots for imitation screens, see Fig. 7.15. These could be slid in and out of the prototype. This was done in order to test the various machine outputs. For example, the butterfly can only measure two side per irradiation. This would require one state of the prototype before irradiation, one after the first irradiation and an another state after the second irradiation. The imitation screens where 3D printed plates with self attaching paper applied on one of their faces. The machine output was drawn by hand for each imitation screen.

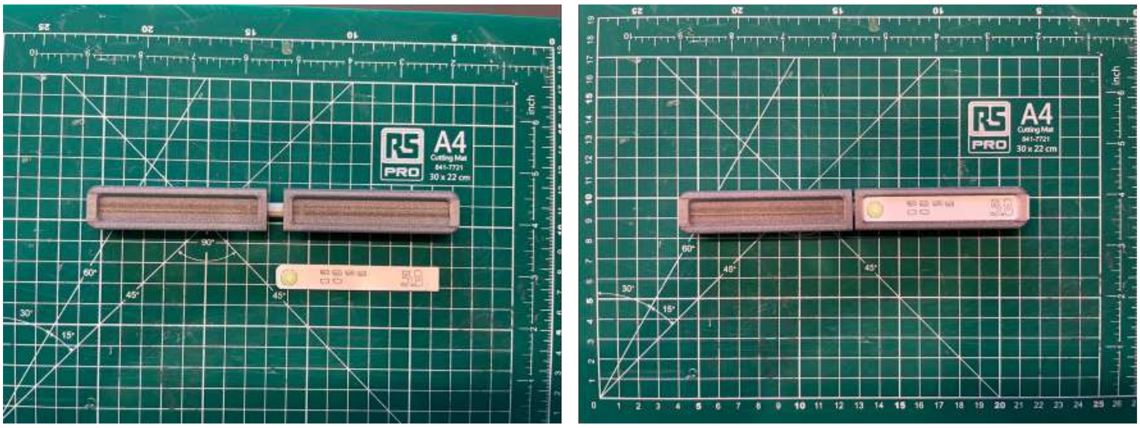


Figure 7.15: Imitation screen for the Extender prototype.

Squid The user takes the product out of its case and place it in the middle of the light field. They fold out each of the four arms, noticing that one of the four arms are white while the others are yellow. The user places the white arm towards them, be used as a reference when retrieving the machine output, see Fig. 7.16. They make sure they are perpendicular to the vertices of the light field, and that the light field crosses the marked areas on each arm.

The product automatically detects the SID and displays it. This is done through an integrated sensor inside the base unit. The user makes sure it seems correct. They then walk out of the room and irradiate. They walk back in, pick up the product and bring it to their computer, where they place the product based on the white reference arm. Each deviation is displayed, see Fig. 7.17, and then reported. When done, the product is folded together and placed back in its case.

Butterfly They remove the tool from its own case, and unfold it to a 90 degree angle, to which the product snaps, see Fig. 7.18. The user places the product with

Figure 7.16: Prototype of the Squid.

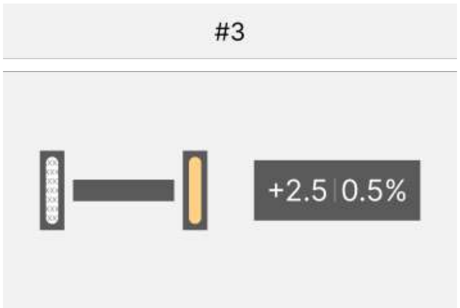


Figure 7.17: Machine output #3, which was used for the Squid prototype.

each leg crossing two different perpendicular vertices of the X-ray machine's light field, aligning them so that the light field intersects the marked area along each leg. The user now walks out and irradiates. They then walk back in, pick up and fold the product back together. They check and memorize the two values and their corresponding side, see Fig. 7.19. After which they once again place and align the product, now with the two opposite light vertices. The user walks out, notes the measurements from the product, and then irradiates again. Finally, the user walks back in, picks up the product, folds it together and brings it with them to note the two last results.

Figure 7.18: Prototype of the Butterfly.

Figure 7.19: Machine output #4, which was used for the Butterfly prototype.

Four Cheeses The user picks up the product and presses the side button on the rotational wheel to wake the product up. It then displays SID and set tolerance for the QA task. If the user wishes to change these, they simply rotate the wheel. By default it adjusts SID first, if the user wishes to alter the tolerance, they pull the wheel outwards. When the user is satisfied with the parameters they open the box, see Fig. 7.20.

User now places the sensor units on each edge of the light square according to the markings on each individual sensor unit. Each unit is marked with 3,6,9 and 12, inspired by an analog watch, representing each corner with the user as a reference point. Aligning the light edge somewhere on the horizontal line running along the product. Then walks outside the room and performs the irradiation.

Walking back in, the users check for the pass/fail analysis, see Fig. 7.21. If they only see green, then all the edges has passed the QA test. If one or more are red, then further work is required and the user will contact either an in-house technician or the supplier of the machine. Then the user picks up the units and walks to their laptop where each measurement is reported. Each sensor unit and it's measured deviation is correlated with the excel sheet, 3:00, 6:00, 9:00 and 12:00.

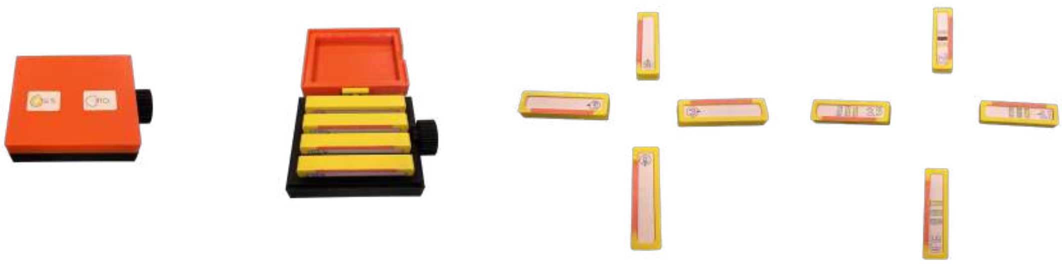


Figure 7.20: Prototype of the Four Cheeses.

Figure 7.21: Machine output #1, which was used for the Four Cheeses prototype.

Extender The user picks up the extender and rotates the right side unit 20 degrees in any direction to wake the product up. To set tolerance the user rotates the right unit 20 degrees either towards them to decrees or away from them to increase the tolerance. When satisfied, the user pulls the right unit away from the left one, entering the intermediate state. The tolerance is then set, and now SID is set with the same interaction as previously. Again, when satisfied the user pulls the right unit into its final state which is fully extended, see Fig. 7.22. The product is now ready to take a measurement. It's places horizontal to the user, so it measures sides 9:00 and 3:00. The user walks out of the room and irradiates.

Walking back in, the user checks the pass/fail analysis, see Fig. 7.22. If a side is green then it has passed the QA test. The user then picks up the product and is careful to keep the orientation the same throughout transportation. They then place the product on the table where their laptop is and reports the two measured values. When done, the user walks back in, places the product rotated 90 degrees in comparison to the previous placement. The same procedure of irradiating and reporting is then performed and the QA task is complete.

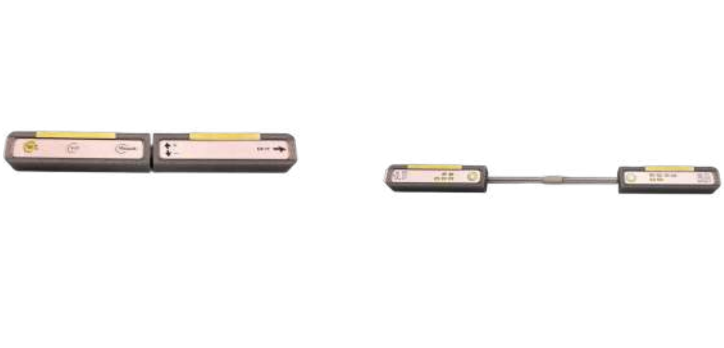


Figure 7.22: Prototype of the Extender.

Figure 7.23: Machine output #2, which was used for the Extender prototype.

Summary

In summary, this phase produced four medium fidelity prototypes representing four unique design concept. This allowed for data collection in the subsequent phase, as stated in the process description. The segmented design and prototyping approach allowed for data collection regarding specific solutions regarding design challenges Geometry and Machine output. Initially prototyping concepts only regarding the design challenge Geometry allowed for an extensive exploration of the design space. Creating medium fidelity prototypes with imitation screens that could be swapped out was a cost effective way of allowing testing a concept with different machine states.

8

Phase 3 - General Design

This phase aims to evaluate the usability of the prototypes, refine the list of requirements and finally narrow down the selection to one concept. This will be done through a usability study. The study will gather qualitative data through interview questions and observations and qualitative data through time tracking, error tracking and ordinal scales. The data gathered will be based on performance metrics identified in Phase 1. After the study, gathered data will be analyzed using appropriate statistical methods for the quantitative data, and KJ-analysis for the qualitative data. These results will then be used to synthesize usability, usage and utility requirements. Increasing the specificity of the requirements list, and so narrowing the possible design space.

8.1 Usability Study

The main part of this phase was a usability study on the four concepts. In Section 6.4, nine key performance metrics for the task of light-radiation-alignment were identified and compiled in Table 6.6. The purpose of the usability study is to quantitatively evaluate the performance of the concepts in regards to these metrics. Qualitative data will also be gathered as a complement to the quantitative data, and to provide insights in how the concepts can be improved.

8.1.1 Preparations

A real X-ray machine was not available for these tests. To create conditions as close as possible to the real-world scenario, a rig showing a light field was created. While a simple paper square placed on a table would give a similar impression, an actual light field would be much more true to life. A paper cannot simulate the penumbra of a light field, and a product placed in a light field should have the light on top of it, not below it, like it would be with a paper based solution.

Access to real-world users able to participate in the study physically was highly limited. As such, the decision was made to invite proxy users to the study. Design proxies have been shown to give valuable design insights, especially when the proxies have a solid understanding of the real user (Islind et al., 2023). The primary users of the DXR+ are engineers and physicists, so engineering students were seen as a close enough proxy.

Participants were recruited through personal contacts. There was no ability to offer remuneration. Other than the engineering students, a few engineers from

RaySafe were recruited as well, since they were more familiar with the product and likely to offer more nuanced feedback. In total, nine students and three RaySafe engineers were recruited, with one student participating in a pilot study.

8.1.2 Relevant Data

The methods for carrying out the tests were structured around the system performance metrics. Table 6.6 contains all the previously identified performance metrics along with a breakdown on which can be gathered in tests with proxy users and not. Further more what methods can be used to gather each metric. This was used as the main source for which methods to use for data gathering in the study, with some adaptations to better suit the purpose of this specific study. The following adaptations were made to the performance metrics:

- ”Amount of repetitive work” was not tested with a quantitative metric because it could be objectively evaluated based on the capabilities of the concepts to perform either 2 or 4 measurements per irradiation.

- ”Instances where system allows for use-error” was rephrased as ”Use errors” to be measurable across different experiments.

- ”Severe use errors” was added to track errors that would lead to incorrect or unusable machine output.

- ”Simplicity of use” and ”Ease of use” were added to gather more detailed data on the actual use of the concepts. It should be noted that the study was carried out in Swedish, and that ”Ease of use” was described as ”Smidighet”, a word with no direct translation to English. In this context, the translation is roughly *smooth and easy, without friction.*

- ”Overall performance, geometry” and ”Overall performance, machine output” were added as a general metric where users were asked to rank each prototype based on preference.

The final performance metrics and the methods of gathering them is shown in Table 8.1.

Table 8.1: The system performance metrics gathered as part of the usability study, and the method used to gather them.

System performance metric	Method
Time on task	Time measurement
Portability	Semantic scale and observation
Use errors	Observation
Severe use errors	Observation
Clear relationship between measured deviation and measured side	Likert scale
Workload	Unweighted NASA-TLX
Simplicity of use	Semantic scale
Ease of use	Semantic scale
Overall performance, geometry	Ranking
Overall performance, machine output	Ranking

8.1.3 Method

With four prototypes to test and eleven participants, a within-subject study using the prototypes as the Independent Variable (IV) and the performance metrics as Dependent Variables (DV) was deemed a suitable study design. Since most participants would be unfamiliar with the process at first, there was a risk for an ordering effect as participants grew more comfortable with the task. As such, the standard method of counter-balancing by randomizing the order of the prototypes for each participant was used.

At the beginning of each experiment, participants were given baseline information on the DXR+, its purpose and how it is used. Participants were also given the opportunity to conducted mock measurements using a proxy of the DXR+. This was done to bring the skill and knowledge of the participants closer to those of a real world user. Questions asked by the participants about the utility or use of the prototypes were not answered during the experiment. If a user was completely unable to proceed, hints were given until they were able to.

For each prototype, participants were handed the prototype and asked to fully measure and report all deviations on the fields created by the cardboard X-ray proxy described in Section 8.1.1. Participants were prompted to think aloud about their use and experience, and to announce when they thought they had completed the task. To activate the X-ray proxy, participants had to walk out of the room and press a mock button, to mimic the real world procedure. After participants pressed the button, the test facilitators replaced the screens on the prototype to simulate the machine output. Reporting was done in a spreadsheet designed to be similar to those used by real world users. The computer with the spreadsheet was placed outside the X-ray room, but participants were allowed to move it around as they wished.

For prototypes with user input, a digital prototype was shown on a computer. As participants interacted with the physical prototype, the digital prototype was modified to simulate the state of the prototype based on the participants' interactions.

Time on task was recorded using a cell phone timer. The timer was started when participants were handed the prototype, and stopped when the participants announced they believed they had completed the experiment. While the test facilitators changed screens on the prototypes, the timer was paused. Notes were taken during the entire experiment process, including on user errors and severe use errors. After using each prototype, participants filled out a survey with the semantic and Likert scales, as well as the unweighted NASA-TLX. Upon conducting the experiment with all four prototypes, participants were asked to rank the concepts based on geometry and machine output respectively, and motivate their choice. The complete questionnaire used can be found in Appendix B.

The output of the study was the results of the survey and the notes taken during each test. Each form of output contained both quantitative and qualitative data. To allow for proper analysis, the data was split into separate quantitative and qualitative sources.

Quantitative data was analyzed using three different statistical methods. The parameters of the test was one categorical IV's with four categories (either the prototype or the order of appearance), and within-subject testing. The DV's were all continuous. Due to the relatively low sample size and ordinal nature of most DV's, data was assumed to not be parametric. Statistical methods were chosen with these parameters in mind. For ordinal data, such as RAW-TLX, Likert scales and semantic scales, Friedman's ANOVA was chosen. For nominal data, the Repeated Measures ANOVA was chosen. To test for ordering effects, Spearman's Rho was used. As is standard, a p-level of 0.05 was chosen for significance.

With one exception, all data was deemed usable in the statistical analyses, excluding the pilot test. The time on task for the participants from RaySafe was very different because of a different setup in the testing location, meaning their times were not used in statistical analyses.

Qualitative data was analyzed using KJ-analysis. Each concept was analyzed separately based on the comments gathered during usability testing. During each test, the participants comments were manually written down for the specific concept that was being tested. Some comments where removed when preparing the analysis due to unclear context. The analysis was done in Figma and each concept got their own space where all the collected qualitative data was placed. The data was then clumped together and categorized in accordance with the KJ-methodology.

8.1.4 Results

This section describes the results of the usability study, and the results of the analytical methods applied to them. For the complete results of the usability test, see Appendix C. All quantitative results are shown using descriptive statistics in Table 8.2. Because of how the data was gathered, lower is better applies to most metrics.

The quantitative data was analyzed using both the prototype and the order of appearance as IV. When the order of appearance was used, the only statistically significant result was time on task: Spearman correlation analysis revealed a signif-

Table 8.2: Descriptive statistics of the quantitative results gathered during the usability test. For all metrics lower is better, except Value-side relationship, where higher is better.

System performance metric	Extender	Butterfly	Squid	Four Cheeses
Time on task (seconds)	191 (± 44)	157 (± 76)	**137 (± 83)**	200 (± 120)
Portability	1 (1-2)	**1 (1-1.5)**	2 (1-2.5)	2 (1-2.5)
Total use errors	2 (1-3.5)	**0 (0-1.5)**	1 (1-1.5)	2 (1-2.5)
Severe use errors	2 (0.5-3)	0 (0-1.5)	**0 (0-0)**	1 (1-2)
Value-side relationship	5 (3.5-6)	5 (3.5-6)	**6 (5-6)**	6 (4.5-7)
Workload	30 (27-32)	25 (14-29)	**18 (11-22)**	28 (12-43)
Simplicity of use	4 (3.5-4.5)	2 (1.5-3)	**2 (1.5-2.5)**	3 (3-4.5)
Ease of use	3 (1.5-3.5)	**2 (1.5-2)**	2 (2-3)	3 (2-3)
Overall performance rank, geometry	3 (3-4)	2 (2-3.5)	**1 (1-2.5)**	2 (2-3.5)
Overall performance rank, machine output	3 (2-3)	**2 (1-3)**	**2 (1.5-2.5)**	4 (2.5-4)

icant result, rs(30) = -0.35, p = .047, ρ = -0.35. All other DV's had no correlation in a Spearman's Rho test, as shown in Table 8.3.

Table 8.3: Statistical results of Spearman's Rho analyses using the order of appearance as IV, and a p-value of 0.05. Significant p-values are marked in bold

System performance metric	p	ρ
Time on task	**0.047**	-0.35
Portability	0.734	-0.05
Total use errors	0.637	-0.07
Severe use errors	0.501	-0.10
Value-side relationship	0.519	-0.10
Workload	0.657	-0.07
Simplicity of use	0.774	-0.04
Ease of use	0.255	-0.18
Overall performance, geometry	0.646	-0.07
Overall performance, machine output	0.346	0.15

When using the prototype as the IV, four metrics showed statistically significant results. Since time on task resulted in nominal data, that metric was analyzed using Repeated Measures ANOVA, and the results were not significant, with n = 8, p = 0.135 and η = 0.09. The other metrics were analyzed using Friedman's ANOVA, and the results are shown in Table 8.4.

Table 8.4: Statistical results of Friedman's ANOVA analyses using the prototype as IV, and a p-value of 0.05. Significant p-values are marked in bold.

System performance metric	**p**	χ^2
Portability	0.266	3.95
Total use errors	0.076	6.87
Severe use errors	**0.036**	8.64
Value-side relationship	0.308	3.60
Workload	**0.020**	9.85
Simplicity of use	**0.003**	13.72
Ease of use	0.241	4.20
Overall performance, geometry	**0.043**	8.13
Overall performance, machine output	0.183	4.85

The resulting categories of the qualitative analysis had close resemblance to the design challenges that were intended to be tested, see Table 8.5 for identified categories. This could point towards a well structured and executed test were the data collected was in line with the desired output. However, internal bias of viewing comments as apart of larger preconceived structure, such as the design challenges previously presented, might have affected the categorizing during the KJ-analysis. On the other hand, there were new categories that emerged during the analysis which indicates that even though a bias might be present, new points of view were not overlooked.

Generally the qualitative results indicated where in the user journey use error can occur and why. The underlying reasons for why concepts that implemented tolerance and SID input scored as they did can be understood better if the quantitative data is analyzed in combination with the qualitative data. For example, qualitative data collected during usage of the Extender highlight the confusion regarding not implementing touch as a feature and instead relaying on fully tangible interaction. It also provided context as to how the fidelity of input on the concepts could have affected their performance in the tests.

Confusions regarding test parameters and reporting were quite common and this was to be expected since the tests were conducted with a majority of proxy users and not real-world users. The qualitative data collected from tests with stakeholders did not reflect the same procedural confusion but instead touched upon technical aspects such as utility and feasibility of the individual concepts.

8.1.5 Conclusion

Since there was a significant correlation between Time on task and order of appearance, but not between Time on task and prototype, the Time on task metric can be largely disregarded. It is highly likely that the participants gradually became better at the task, and since there were similarities between the usage of the prototypes, the ordering effect became significant.

As per Table 8.2, The Squid was the best, or tied for best, performer in six out of the nine remaining performance metrics. The Butterfly was the best performer in

Table 8.5: Categories identified in the qualitative analysis.

Butterfly	**Four Cheeses**	**Squid**	**Extender**
Guessability	—	—	—
Measure opposite sides	—	—	—
Measure over a corner	—	—	—
Machine output	Machine output	Machine ouput	Machine ouput
Reporting	—	Reporting	—
Portability	Portability	Portability	Portability
Alignment	Alignment	Alignment	Alignment
Ready for next irradiation	—	—	Ready for next irradiation
—	SID & Tolerance input	—	SID & Tolerance input
—	Case	Case	—
—	—	Moving parts	Moving parts

the remaining three. In all cases where the results were statistically significant, the Squid was the best performer. As such, it can be concluded that the quantitative data distinctly favors the Squid, with the Butterfly as a somewhat distant second. When it came to machine output, the data indicates the simpler readouts of the Butterfly and Squid, and the Extender to some extent. This leads to the conclusion that simple but positionally correct machine output is preferred.

Testing the guessability of input interactions implemented on Extender and Four Cheeses in combination with their low fidelity affected results of the quantitative data analysis. However, the qualitative data provided a valued context in regard to this type of interaction. Even if the tests were not accurate in testing the overall usability of these specific interactions, it indicated that any input interaction on such a small device would increase the possibility of use errors, and so go against usability guideline 16 *Minimize the possibility for use error.*

Using a single white colored arm in the Squid did provide an indication as to its function. as reference. However, additional reference points needs to be added if a specific orientation for light edge alignment of the Squid is to be consistent.

Using an analog clock as reference for each side, as implemented in the Four Cheeses prototype, worked in some cases, but could also cause confusion. However, the reference point of 3:00, 6:00, 9:00 and 12:00 as orientation is something gathered from real-world users, and so these results might not be reproducible if the usability test was conducted with only real-world users instead of proxy users.

In the qualitative data analysis it was quite clear that pass/fail analysis was very much appreciated in the cases were participants noticed it. However, the concepts that implemented pass/fail analysis then had a lot of data presented to the user at once. This caused some confusion, which led to the pass/fail analysis to sometimes be overlooked and not used during the reporting part of the tests. This then might explain the results of the quantitative analysis where more simple machine outputs, such as the buttefly and squid performed better.

The qualitative data provided important context as to how reporting was done during the tests. Most participants did not pick up the prototypes and instead walked back and forth between the prototype and the laptop when reporting. A key aspect of this work is to minimize the repetitive work needed to perform this QA task, and so clear affordances for picking up the product is important.

Most participants unfolded the Squid in their hand. This was not the intended use, as the prototype was designed to be placed on the table first and then to be folded out one arm at a time.

8.2 Requirements Re-work

The conclusions from the qualitative analysis provided the base for a new iteration of the requirements and guidelines. A large part of this work was to analyze existing guidelines and see if the results indicate if they were to be rewritten as requirements or not. If guidelines where rewritten, then usability test Phase 2 was noted as source as well as the previous guideline. This was done in order to keep continuity and traceability of the requirements list. For full requirements list, see Appendix A

During this work, new labels for design challenges were added. This was in addition to the lables presented previously in Section 7.4. The labels added were longevity, automation and value-side relationship.

Longevity When synthesizing the first iteration of the guidelines and requirement list in Phase 1, the aspect of battery maintenance was introduced as usability guideline 9 - *Allow the user to change battery.* This was later rewritten as requirement 90. However, during usability testing in Phase 2, the perceived fragility of movable parts became apparent and was introduced as requirement 82 and 85. These newly formed requirements shared an underlying challenge, but there was no existing label that would fit them both. And so, longevity was added to categories requirements under the same overarching design challenge, see Table 8.6.

Table 8.6: Requirements synthesized and labeled with design challenge Longevity

nr	Requirement
82	Movable parts should not deteriorate due to normal usage
85	Moving parts should feel sturdy
90	Allow for battery service without specialty competence

Automation The aspect of automation had been parallel to the design process from the beginning, but never fully incorporated into the design framework. As discussed previously in Section 7.4, two concepts that were evaluated in Section 8.1 allowed for input of test parameters. Central to the formation of the design challenge Automation were six guidelines, presented in Table 8.7. Synthesized requirements are presented in Table 8.8.

Results from the usability tests indicated an increased complexity if input of test parameters was done through tangible interaction on the product itself. And so, the labeled of geometry as no longer accurate. This, in combination with guideline

Table 8.7: Guidelines relevant for the design challenge Automation.

nr	Usability guideline	Previous label
1	Automatic light edge alignment	Light edge alignment
6	Display results on a higher abstraction level, pass/fail or % of SID	Machine output
15	Allow the user to decide test parameters	Geometry
20	Offer automatic detection of SID	Geometry & Increased utility
23	Increased trust in machine decision making	Machine output
59	Offer increased value if used together with the X2 system	None

6 and 23 was rewritten as requirements 87, 88 and 89. The possibility of using the external X2 system as a complement to the product was something developed together with stakeholders at RaySafe. However, stakeholder requirement 52 states that functionality should still be available if the product is used alone, without any external systems. The decision to add these requirements was also based on stakeholder guideline 59. In these automated decisions, the human is kept somewhat out of the loop, but because it is a simple routine decision, that is non-problematic or even desirable.

Guideline 20 was discussed with a stakeholders at RaySafe with utility specific expertise. The conclusion was that implementing a sensor inside the base unit to allow for automatic SID measurement would be a technical challenge not worth pursuing. And so, this guideline was not rewritten as a requirement.

Table 8.8: Requirements synthesized and labeled with the design challenge Automation.

nr	Requirement
52	Replace the current DXR+
87	Offer pass/fail analysis if test parameters are available through X2 system
88	Allow for communication of data between product and X2 system
89	Allow for test parameters to be inputted from X2 system

Value-side relationship This design challenge, similarly to Automation, had been present through the previous phases but requirement relevant to it was labeled with geometry and or light edge alignment. However, the importance of a clear value-side relationship is crucial for any type of automated reporting. Any reported value needs to have two corresponding attributes in order to have value in relation to the general task. Firstly, what side of the light field it belongs to and secondly the orientation of that specific side to a known reference point. Furthermore, in the case of multiple irradiations, where 1 or 2 sides are measured per irradiation, it's also crucial for the user to understand what sides have already been measured. The current solution for this is following a procedural structure, that can be found in the users internal documentation. Sides are denoted with 3:00, 6:00, 9:00 and 12:00 following the arms of an analog clock, the reference structure that was identified in Section 6.4. E.g start with side 12:00 then 3:00 and so on. This provides the measured value with the surrounding information in order to make it useful.

Guidelines regarding this design challenge are presented in Table 8.9 and the subsequent requirements are presented in Table 8.10.

Table 8.9: Guidelines relevant for the design challenge Value-side relationship.

nr	Usability guideline	Previous label
11	Offer overview of what value belongs to which side	Machine output & Geometry
14	Aid the user in deciding which sides have been measured	Machine output & Geometry

Table 8.10: Requirements synthesized and labeled with the design challenge Value-side relationship.

nr	Requirement
64	Offer one correct way to perform light edge alignment
73	Aid the user in deciding which sides have been measured
91	Offer reference point for light edge
93	Save value-side relation during transportation of the product

8.3 Choosing Concept

Considering the data from the user study, the choice of concept to proceed with was obvious. As presented in Section 8.1.4, quantitative results were highly in favor of the Squid. Meanwhile, the qualitative results did not distinctly favor any specific concept, but they did show a clear, feasible path forward for the Squid in terms of improvement opportunities.

While the Butterfly performed well and was the top performer, or tied therefor, in three out of nine categories, it lacked the ability to measure the deviation on four sides in one irradiation. This lead to the Squid being chosen as the concept to proceed with and develop further.

Summary

In summary, this phase successfully evaluated the usability of four quite unique design concepts without frequent access to real world users. Relying on proxy users meant the structure of the usability test had to be designed so that relevant information was still collected. It also resulted in insights regarding usability testing with physical prototypes in combination with digital elements, as with evaluating different input methods with concepts Extender and Four Cheeses. The qualitative and quantitative analysis provided valuable insights that together created the basis for deciding which concept to develop further. The subsequent requirement synthesis successfully produced requirements that were reflective of real world users needs. Segmenting aspects of the design into design challenges offered structure and clarity to the subsequent design work. The synthesized requirements were reflective of individual design solutions performance in the usability study and were rewritten as to guide further development of the chosen concept. The design space was now describing a possible redesign of the squid concept.

9

Phase 4 - Ideation and Prototyping 2

During this phase methods of exploration through sketching with pen and paper, vector images in Figma, 3D modelling in Fusion 360, 3D rendering and 3D printing will be conducted. The goal is to experiment with different design solutions for each design challenge to generate a new iteration of the concept **Squid**. The output of this phase will be visual and physical prototypes, each contributing based on the inherent strengths of each modality. Design solutions that meet design challenges such as Geometry and Light edge alignment lends themselves to be communicated through a physical prototype whereas e.g machine output and automation are better communicated through a visual prototype. This assumption is based on the fact that a high fidelity functioning prototype will not be developed.

9.1 Ideation

Based on the newly synthesized requirements from Phase 2, an ideation session within the project team was conducted. Using the 3D printed prototype of the squid as mediating object, possible improvement regarding each design challenge where explored, see Fig. 9.1. Some design challenges were already quite well developed and did not require much work while some, e.g Longevity, Increased utility and Machine output were discussed at length.

Initially basic vector prototypes were made to explore the design of the squid arm, see Fig. 9.2 . Version 1 was inspired by the machine output used for the squid during usability testing, using visual feedback to relay distance between radiation and light edge as well as order relative to the center of the light field. Yellow represents light field and black represent radiation field. Numerical output and pass/fail analysis was combined into one where the backlight would turn green/red depending on the automated pass/fail analysis. Version 2 kept the same design for numerical and pass/fail feedback but separated the representation of light and radiation field. Version 3 separated the feedback for pass/fail analysis and numerical readout. Furthermore the color representing the radiation field was changed to blue. Version 3 was chosen for further development.

In order to acquire an accurate representation of how the arms would look in combination with the base unit a vector prototype of the entire squid was made, see Fig. 9.3 . In version 1 the color of the arm denoted as 6:00 was chosen to be white, similar to the old squid prototype used in the usability test. However,

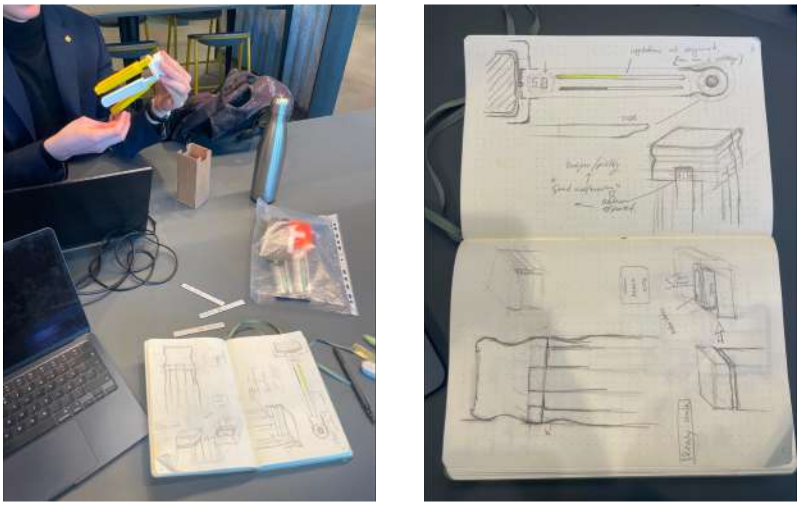


Figure 9.1: Process of ideation during Phase 4.

Figure 9.2: Initial vector prototype of the Squid's arms. **Top:** Version 1. **Middle:** Version 2. **Bottom:** Version 3.

additional affordance for light edge alignment was introduced by placing text on the base unit. Continuing with this design, a 3D model was made in Fusion 360 and simple renderings were made. Furthermore, the same model was 3D printed in order to get some hands on feedback regarding the geometry. One of the biggest differences between this model and the previous iteration of the squid is that the hinges are now placed inside the base unit and fold from the bottom up to a 90 degree angle, this is presented in more detail in Section 11.3.

Getting the geometry in hand and trying out how the geometry allows for picking up, through gripping the base unit and unfolding through grabbing the bottom part of each arm and folding it outwards 90 degrees, led to some further redevelopment. Firstly, the base unit's side profile was iterated. A more curved profile was produced for version 2, see Fig. 9.4. However, this shape did not provide a more satisfying grip around the base. The overall side profile of version 1 was kept, with the modification of slightly deeper cuts into the profile at it's deepest point.

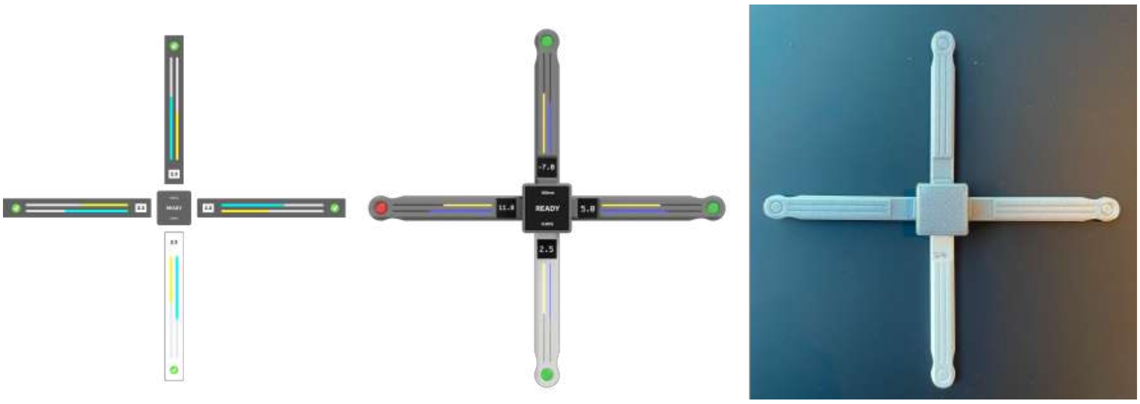


Figure 9.3: Initial prototype of the Squid with arms and a base unit. **Left:**Vector prototype. **Middle:** Rendered prototype. **Right:** 3D printed prototype.

Figure 9.4: Development of the Squid base unit. **Left:** Version 2. **Right:** Version 1

Secondly, three design solutions were prototyped regarding unfolding the arms, see Fig. 9.5. Version 1 implemented a slight angle at the edge of each arm. When folded together and connected to the base unit, this cut out would provide affordance as to how to unfold the arms, see Fig. 9.6. Version 2 continued with the same chamfered edge, but additionally added a cut out for easier finger placement. This aided in grip but made the arm at that specific point very thin and made it feel quite fragile. Version 3 instead implemented a raised area where a textured material could be added. The chamfered edge was also made shorter and steeper.

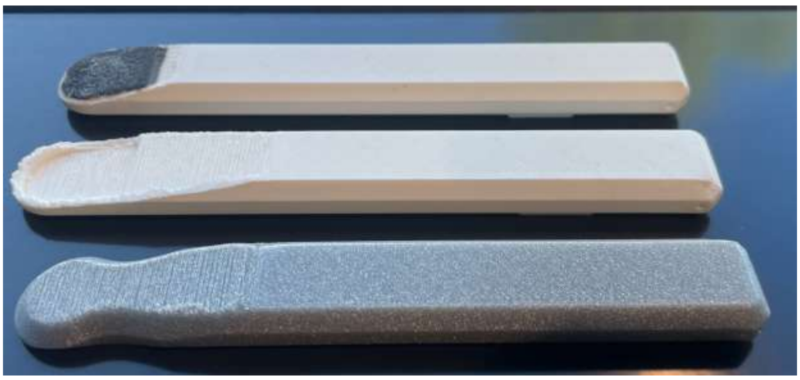


Figure 9.5: Development of grip area for the Squid's arms. **Front:** Version 1. **Middle:** Version 2. **Back:** Version 3.

Figure 9.6: Unfolding affordance with the arms attached to the base unit.

The topside of the arm went through two main iterations. Version 1 followed the same design as the previously presented vector arms, see Fig. 9.7. The main difference is the rounded shape surrounding the LED for pass/fail analysis. This was mostly done for aesthetics, since the arm shape act to accentuate the round LED. However, the squid in this current form did not allow for any input of test parameters and relies on communication from the X2 system, in line with the requirements presented previously in Section 8.2. And so, it was decided against a dedicated LED and the pass/fail feedback was moved to the base unit. This was implemented in version 2. Furthermore, the arms were extended by 10 mm and the screen for numerical readout was move 10 mm away from the base unit. The screen was moved to minimize the chance of the base unit blocking the readout.

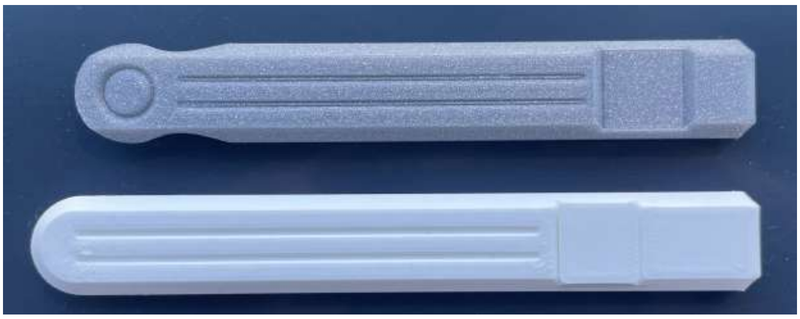


Figure 9.7: Development of arms. **Top:** Version 1. **Botttom:** Version 2

9.2 Squid 2.0

This section describes the use case of the Squid 2.0. The case lid is open, exposing the base with black rubberized inserts in it's side profile, see Fig. 9.8 and Fig. 9.9. The screen on the base unit is turned on when the case lid is open. In this case, the user had previously set test parameters SID to 100 cm and tolerance to 1.00% through the X2 system. These parameters are the ones the user wish to use in the upcoming test as well. The display tells the user that it is ready to perform the QA test with the set parameters.

Figure 9.8: Left: The Squid folded in it's case with open lid. **Right:** Visual feedback on base unit display.

Figure 9.9: Rubberized grip areas that afford easy physical maneuvering

Before interacting with the product, the user has collimated a 20x20 cm light field that will be used during the QA test. When ready, they grab the base unit and removes the squid from it's case, noticing that one arm has gray marking along it's edge. This in combination with the orientation of the text on the base unit, the squid provides clear affordance for how it is intended to be placed in reference to the user. Still holding the base in the same way as when lifting it out of the case, the user places two fingers underneath an arm and a thumb opposite to fold the arm outwards, see Fig. 9.10. There is a slight resistance when the arm is rotated to it's max or min points. When the arm is in either state, it is locked and requires a slight application of force to leave that state.

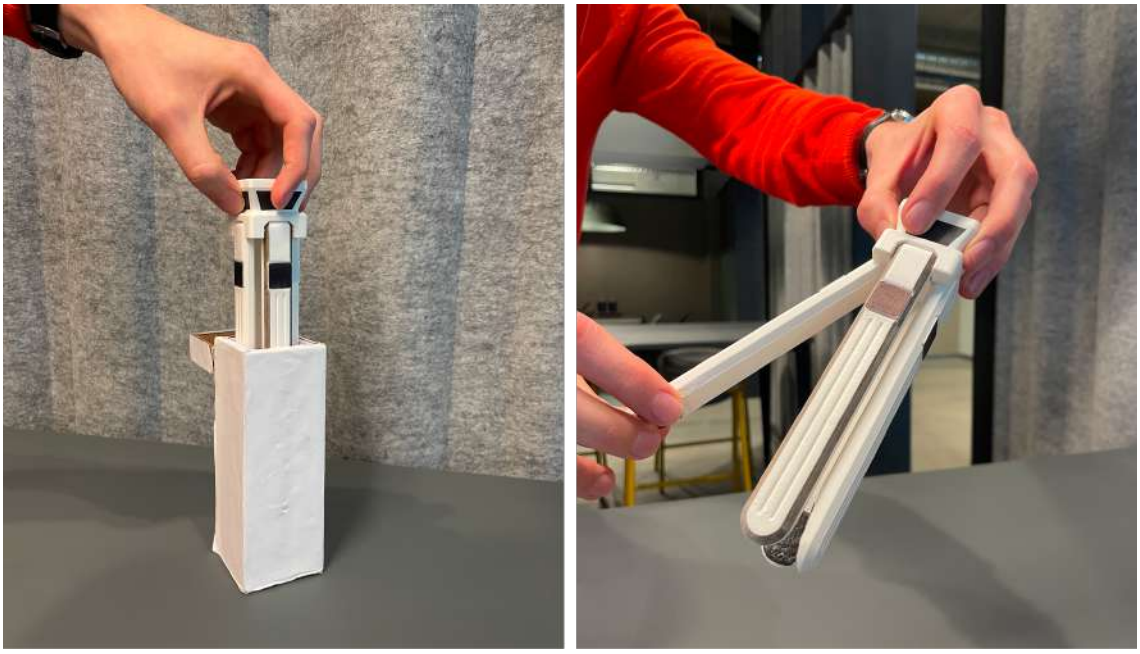


Figure 9.10: Left: A user grabbing the base to remove it from it's case. **Right:** A user grabbing each individual arm and folding them outwards 90 degrees.

The user continues and repeats the process for each arm, unfolding them to a 90 degree angle outwards, making the squid flat at it's base. The squid is then placed flat on the table, with the reference arm, grey markings, oriented towards the users. The squid is now ready to perform a measurement. When all arms are out and the squid is folded flat at it's base, the product enters light edge alignment mode. This changes the visual feedback on the base unit screen. The screen now displays 4 grey boxes, one for each edge, and a text that says "aligning" in the middle, see Fig. 9.11. In this mode, through automatic light edge detection, each arm searches for a light edge. If one is found, then the 1 dimensional position is saved, a line of LEDs turn yellow along the arm out to the identified light edge and the corresponding grey box on the base screen turns yellow, see Fig. 9.12. This keeps the human in the loop at a decent level and increases trust in the automated decision made by the product. When all possible edges are found, the squid enters measuring mode. This is communicated to the users by changing the text on the base unit screen from "aligning" to "ready". The user then walks outside of the room and irradiates.

Walking back in, the secondary blue LED line along the arms is now lit, indicating where the radiation field edge is located. The screens on each arm are now displaying the numerical measurement with a precision of 0.5 mm, see Fig. 9.13. The boxes on the base screen have changed to either green or red, depending on if the measured deviation for each side is within the desired tolerance. The user looks at the base unit and sees that one box is red, meaning that one measured

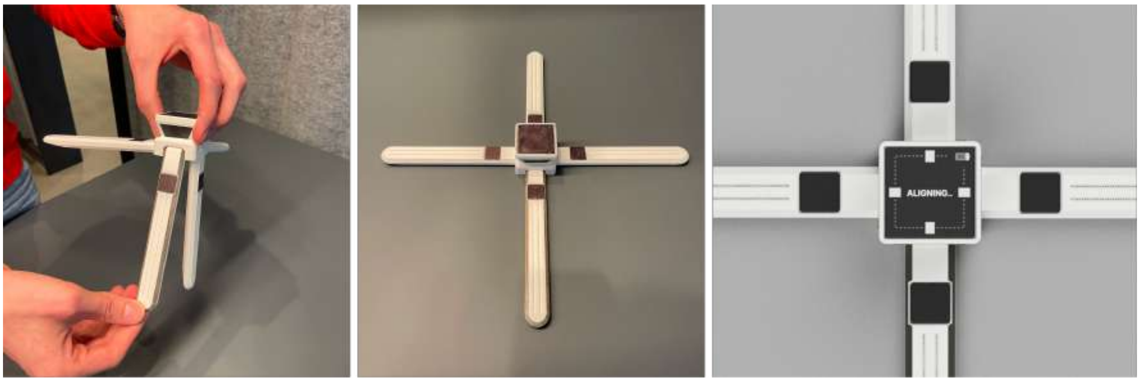


Figure 9.11: Left: A user unfolding reference arm. **Middle:** The Squid placed flat on a table. **Right:** Light edge alignment state with no identified edges.

side is outside of the set tolerance, and so failed the test. This prompts the user to contact technicians at the hospital to further investigate the problem. The measured deviation as well as results from the performed pass/fail analysis is wireless communicated to the X2 system which compiles the data and logs it with date and time, ensuring a clear and consistence record of performed QA tests.

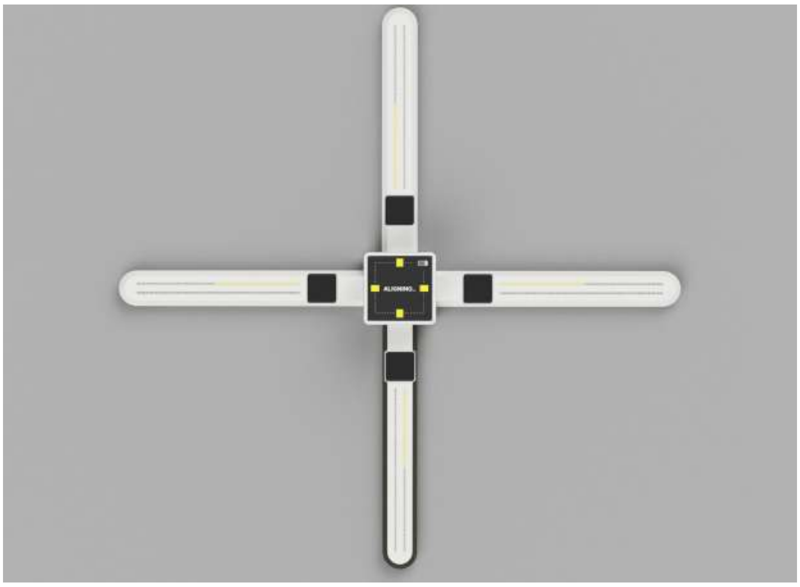


Figure 9.12: The Squid in light edge alignment state with four identified light edges.

Summary

In summary, this phase explored the design space that had been redefined in the previous phase. The segmented design approach meant that individual solutions for design challenges could be generated, tested and iterated upon separately. Leveraging various prototyping techniques such as vector graphics, 3D modeling, digital

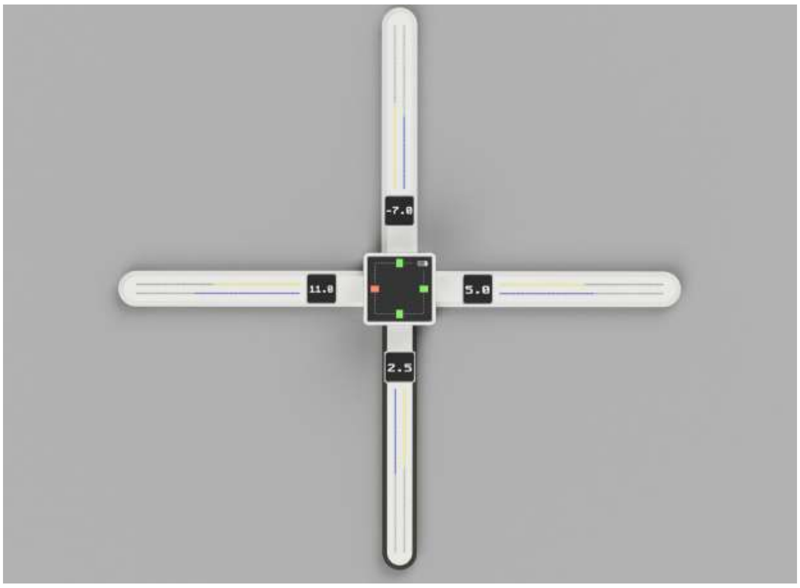


Figure 9.13: The Squid in machine output state.

renderings and 3D printing provided flexibility to the design work. This meant that ideation for a new iteration of the squid concept was quite efficient.

10

Phase 5 - Concept Validation

The final phase of the project aimed to evaluate the latest iteration of the design concept in the eyes of key stakeholders. Doing so had the goal of analyzing the concepts feasibility from a cost and engineering standpoint, and gathering feedback on the concept itself from real world users. These evaluations take two main forms. Engineering and cost aspects will be evaluated through a workshop/presentation with RaySafe's Research and Development (R&D) team. The concept itself will be evaluated in semi-structured interviews with real world users, focusing on the use and functionalities of the concept. Based on the data gathered in this phase, final adjustments to the concept are made, and considerations for future work established.

10.1 Feasibility Considerations

While factors like cost, production and feasibility are outside the scope of this project, there was time to investigate these matters to a degree. Since the overarching goal of the project is to provide a suggestion for how a new DXR+ might be designed, and engineering factors impose limitations on the design, investigating such factors will contribute to the completeness and robustness of the final result. Furthermore, a meeting with R&D was an opportunity to explore more viewpoints on the design and concept itself, opening up for suggestions for improvement.

To evaluate engineering factors related to the design concept, a workshop with RaySafe's R&D group was held. The workshop focused on presenting the work so far, including the previously rejected design concepts, and gathering feedback and ideas on them. A total of 20 members of R&D were present, representing different disciplines and levels of seniority. Open discussions were held, in both smaller groups and with all present members. The discussions explored topics such as sensor technology, size, wireless communication, battery and production costs.

The feedback on the concept itself was very positive. On engineering matters, a few issues were raised. Primarily, production costs for the concepts were estimated to be quite high. The main factor contributing the costs was the complex sensor components required across all four arms. Beyond that, using multiple screens, needing a microprocessor and a rechargeable battery were all pointed out as components increasing production costs over the original DXR+. On the actual feasibility of the concept, whether it was possible to produce, the feedback said it would be possible. The main challenges would likely be shielding vital components from radiation and ensuring lasting quality for the moving parts, i.e. the arm joints, and battery connectivity. However, a participant noted that RaySafe currently offers a product where vital components are located within the light field during irradiation. Indicating technical feasibility. A potential counterweight to production and development cost would be to add functionality to perform related QA tests. However, such related tests will not be discussed here.

10.2 Final User Evaluation

As some time had passed since the last time real world users were involved in the process, an important step towards the end was gathering feedback from them on the final concept. This was done to ensure the concept was in line with the users' expectations and would fit well into their way of working. It was also yet another chance to collect more ideas on how the concept could be developed further.

This final user evaluation was carried out using semi-structured interviews. The method was chosen because only a few users were available, meaning more structured or quantitative methods would likely miss nuance, and because the semi-structured format lends itself well to the more open and exploratory feedback which was sought after. A total of three users were interviewed, focusing on questions regarding their approval of the concept, to which extent they would prefer it over the original DXR+ and what would be the deciding factors in whether their workplace would purchase a product based on the concept.

The feedback received from the users was highly positive. All interviewees expressed a strong interest in the product, and said that it would be a significant improvement over the current DXR+. The following are some quotes from the interviews, translated from Swedish by the authors:

- ”I am slightly floored by the proposition, it was better than I expected”
- ”It is very promising, this is something I hope becomes a product”
- ”I would definitely use this over the DXR+”

Some aspects that were highlighted as strong improvements were the ability to measure all four sides in one irradiation, automatic light field detection, numeric readout, pass/fail analysis and the ability to export results to an external system. Around the concept itself, the two main concerns were the moving parts wearing out, and that the product would be somewhat larger than the current DXR+. In terms of new suggestions, physical distance markings in the arms of the product to allow it to be used like a phantom, and a backup mode using fixed, manual light edge alignment were suggested. Key factors when considering purchasing the product would be time saved, ease of use, accuracy and cost.

10.3 Changes to the Concept

Out of the feedback received from talking to R&D and users, two main items stood out as design suggestions within the scope of the project. The first one is the addition of markings on the arms of the product, allowing it to be used as a phantom, or for visually confirming the size of the light field. These markings can be made in a material visible on X-rays, allowing visual comparisons using the images taken by the X-ray. The second suggestion was a fall-back mode using manual light edge alignment. This would require the use of a set light field size and some sort of input or automatic detection to enter the manual mode.

The ideas of markings on the arms and a fall-back mode with manual alignment were explored through an ideation session. It was concluded that adding extra markings on the arm, whether simply for measuring or for manual alignment, would run the risk of indicating the product requires manual alignment at all time. Furthermore, while a fall-back mode could increase the robustness of the product, there were no indications anywhere in the process that such a mode would actually be needed. As such, neither idea was added to the final concept.

Regarding the feedback on costs for development, components and production, exploring and integrating these aspects is outside the scope of the project. As such, no changes to the design concept are made based on this feedback, and adjusting the concept to be viable from an economical and production standpoint is seen as future work. For the sake of completeness, here are a few of the changes mentioned by R&D that could be explored as part of an effort to go from design concept to viable product, and their impact on the design:

- Reducing the length of the span with sensor components on the arms. The sensors likely do not need to cover the entire length of each arm, and shorter sensors can reduce costs.
- Removing the four small screens on the arms of the product. Instead, the numerical readout can be given on the larger screen in the middle. This would require some redesigning of the information shown on the main screen. There is some risk of creating a cluttered UI, but with careful design this would only be a small downgrade in usability.
- Instead of giving a numerical readout, the product could have a ruler along each arm, and have the user calculate the offset based on the ruler. This would remove the need for extra screens or loading more information onto the main screen. However, it would be a significant setback in usability.

Summary

In summary, this phase aimed to evaluate the Squid 2.0 design concept. It was done through interviews with users and by exploring the concepts feasibility as an actual product. The main takeaways were the highly positive response from users, and that it would be possible to produce the Squid but that work would be needed to adapt the concept to be more production-friendly.

11

Final Design Concept: the Squid 2.0

This chapter will explain the final concept in relation to the various design challenges identified during the design process and relevant requirements. The full description of product use case is presented in Section 9.2 and full description of requirements are presented in Appendix A. Fig. 11.1 shows a rendering of the final design concept.

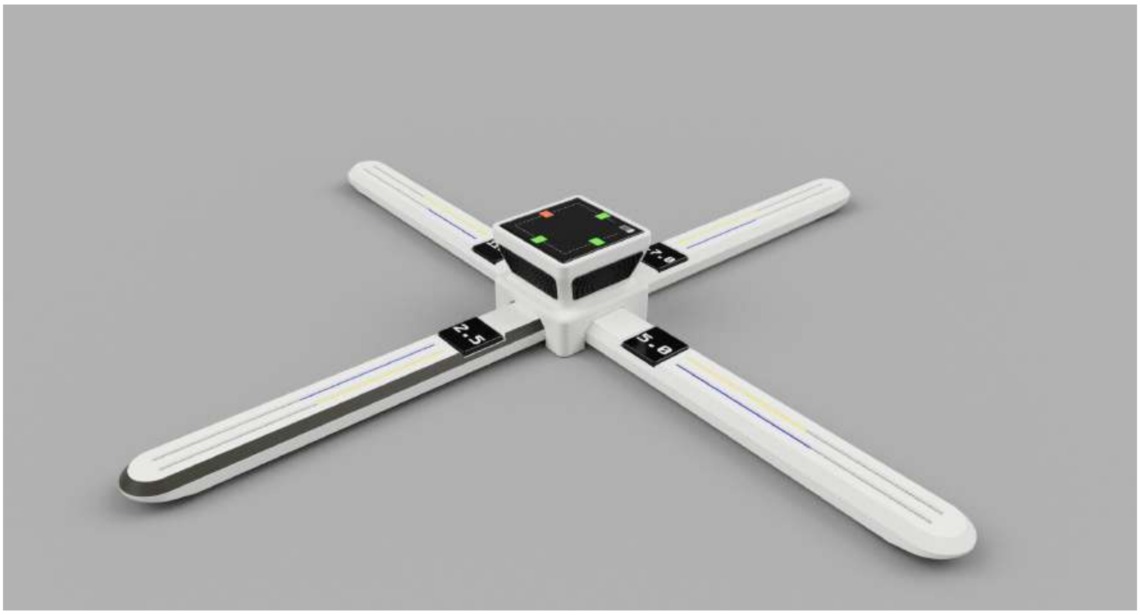


Figure 11.1: Finalized rendering of the Squid after irradiation.

11.1 Automation

A crucial design solution implemented in the squid is automatic light edge detection, fulfilling requirement 71 - *Offer automatic light edge detection.* This provides a whole range of new possibilities in regards to design challenges Alignment and Machine Output which will be discussed in more detail in their respective sections.

In regards to alignment, the user no longer has to align a specific part of the product with a light edge, which was a pain point emphasized by most users in the initial data collection. During alignment, the yellow LED strips along each arm update live where the machine has found a light edge, providing insight into automated decision.

In regards to machine output, the product can provide a numerical readout of the measured deviation with higher accuracy than the current product due to the method used for automated light edge detection. Automating **task 6** *retrieve length of measured deviation*, removes the need to count and multiply amount of pixels. Moreover, numerical readout of the measured deviation provides data in the same format that is used to report measurement in the users internal documentation.

Automated light edge detection in turn also allows for the implementation of pass/fail analysis, assuming test parameters are available. This automates **task 7** check if within tolerance to a degree. In relation to the task "check if light-radioation field alignment is within tolerance", machine output in the format of a simple yes or no is closer to the overall task than a numerical readout.

The squid does not offer a way to input the value of these, instead it relies on the X2 system to communicate these parameters before performing the tests. However, if no new test parameters are provided to the squid it will default to the values used most recently. During the data collection in Phase 1, most users stated that they use the same test parameters most of the time when they perform light-radiation field alignment tests. Relying on the X2 system also removes the need to have input on the product itself, which was shown to increase perceived complexity during the usability testing in Phase 2.

11.2 Reporting

Relevant for this design challenge are three requirements that has evolved from the concept's need to replace the current DXR. It can not be assumed that all users have access to a X2 system when performing QA tasks regarding light-radiation field alignment. And so, fully automating the reporting through such a system would go against all three requirements presented in Table 11.1. The way in which the squid fulfills requirement 31 and 33 is through the numerical readout and pass fail analysis provided on the product itself. This would provide the user with data in the relevant format for reporting. The user has to report the numerical deviation and if it is within tolerances, the squid provides that data directly. It also allows for flexibility when reporting. When possible, the squid also communicates the test data to the X2 system. So if procedural structures change and the automatic logging of data is implemented then the user never has to manually report. They simply check the pass/fail analysis and base their decision on this. If no test parameters are available, in the case of the squid being used without an X2 system, then numerical readout is available, fulfilling requirement 49.

11.3 Geometry and Storage

The geometry of the squid went through various iterations as presented in Section 9.1. However, the general structure of a single base unit with four connected arms has been the same since the creation of the concept. A few key features have

Table 11.1: Requirements relevant for reporting.

nr	**Relevant requirements**
31	*Offer manual reporting*
33	*Offer machine output that is compatible with the hospitals internal documentation processes*
49	*Offer utility without any external systems*

been iterated upon and changed during the course of Phase 4. Requirements relevant for this design challenge are presented in Table 11.2.

Table 11.2: Requirements relevant for geometry.

nr	**Relevant requirements**
27	Allow for easy transportation and storage through small form factor
66	Offer machine output that is compatible with the hospitals internal documentation processes
75	Offer one distinct unfolded state
80	Allow for physical maneuvering though grip
81	Offer dedicated grip for unfolding
85	Moving parts should feel sturdy

How the arms are folded for storage was developed further and went from folding from the top to folding from the bottom, see Fig. 11.2. This design decision was made due to a clear preference of users in the usability study to unfold the squid in their hands. This design would allow for picking up the squid and unfolding it, without changing grip of the base unit. This design also allow the base to act as a stop, limiting the rotation of each arm only between 0 and 90 degrees. It also hides the rotating mechanism from the user, and so hopefully minimizing the perceived fragility of moving parts, fulfilling requirements 27, 66, 75 and 85. Furthermore, it allows the base unit to offer clear affordance regarding pick up and unfolding. Placement of the arms in the Phase 2 prototype in its folded state made it so the user had to grab it from the bottom and then change grip when aligning or pick it up. Now the base unit is grabbed when removing it from it's case and allows physical maneuvering during it's entire use case. Fulfilling requirements 80 and 81.

Placing the hinges inside the base unit also dramatically reduced the footprint of the product. Now defined by the width and depth of the base unit and length of the arms instead of base unit dimensions plus 2 times arm thickness as in the Phase 2 prototype.

11.4 Alignment

As mentioned previously, design solutions regarding alignment are influenced by steps taken to automate certain tasks. Automatic light field detection allows the overall alignment to be simplified. Placing the squid only requires one alignment in order to gather data from all four sides. This assumes two things. Firstly, that

Figure 11.2: Geometry comparison between first and last iteration of Squid. **Left:** Prototype used in Phase 3. **Right:** Final prototype rendering.

automatic light edge detection is possible and cost effective to implement. Secondly, that necessary sensors that allow for this function is placed correctly along the length of each arm. The requirements for this design challenge are presented in Table 11.3.

Table 11.3: Requirements relevant for alignment.

nr	Relevant requirements
29	Allow for measurement of 20x20 cm light field
69	Aid in orthogonal placement of product in relation to light field edges
70	Offer visual span for alignment with light edge

Regarding the first assumption, it has been established that automatic light edge detection is technically possible and the technology exists. There are however uncertainties regarding what type of size requirements this technology would place upon the geometry of the squid. Furthermore, the cost of implementing these sensors are unknown and would require insight into RaySafe procedures regarding acquisition and production. However, implementing this technology would increase usability value tremendously, as shown in Section 10.2.

The second assumption somewhat ties into the cost aspect. As currently presented, the squid has sensors placed along most of the arm length. This allows for automatic alignment for field sizes between 15x15 to 25x25 centimeters. However, requirement 29 was synthesized based on the facts that most users collimated a 20x20 light field for this type of QA task. And so, placement of sensors could be optimized for this size of light field. This would decrease the size of sensor needed and so minimize production cost without affecting usability.

In regards to affordance for correct placement and subsequent alignment there are two requirements that are relevant. Requirement 69 - *Aid in orthogonal place-*

ment of product in relation to light field edges is fulfilled by aligning four arms with their corresponding edges at one time. This in combination with the base unit sat in the middle provides the user with 5 separate reference points to ensure correct orthogonal placement. Requirement 70 - *Offer visual span for alignment with light edge* is fulfilled through clearly showing where the sensor and LED are placed along the arm. Furthermore, the LED strip indicating where the machine has identified a light edge provides visual clarity for alignment and improved trust in the automation.

11.5 Value-Side Relationship

As described in Section 8.2, in order for a data point to have value in relation to the QA task "*Ensure light-radiation field alignment is within tolerance*" it needs two corresponding attributes. Firstly, what side of the light field it belongs to and secondly the orientation of that specific side to a known reference point. The relevant requirements for this design challenge are presented in Table 11.4.

Table 11.4: Requirements relevant for value-side relationship.

nr	Relevant requirements
73	Aid the user in deciding which sides have been measured
91	Offer reference point for value-side relationship
93	Keep value-side relationship intact during transportation

The first aspect is fulfilled through grey markings along the side of one arm. This in combination with text orientation on the base unit provides clear affordance for how the Squid is to be placed. Subsequently, the geometry allows for each arm to be related to a specific side of the light field. As long as the product is place with the grey marking towards the user when machine output is retrieved, then the value-side relationship will be kept intact during transportation or any physical maneuvering of the product. Fulfilling requirements 91 and 93. Furthermore, this relationship allows for the tests results to be communicated and documented through external systems. Where each data point will be presented with a similar structure as on the product itself. Requirement 73 is fulfilled mainly through presenting machine output in relation to a specific side. Furthermore, measuring all sides of the light field at once leaves little room for confusion regarding which sides have been measured or not.

11.6 Machine Output

Solutions regarding design challenge Machine Output are presented in three categories, numerical deviation, visual representation of distance and visual representation on base unit, as shown in in Fig. 11.3. These are the main avenues in which the machine provides some form of output that the user can perceive. Relevant requirements are presented in Table 11.5.

Table 11.5: Requirements relevant for machine output.

nr	Relevant requirements
64	Offer one correct way to place the product when aligning with light field
72	Communicate when the machine is ready to be irradiated
77	Offer visual representation of deviation through visual distance
84	Offer measure-mode where test parameters are locked and displayed as confirmed
86	Offer accuracy higher than 2.5 mm

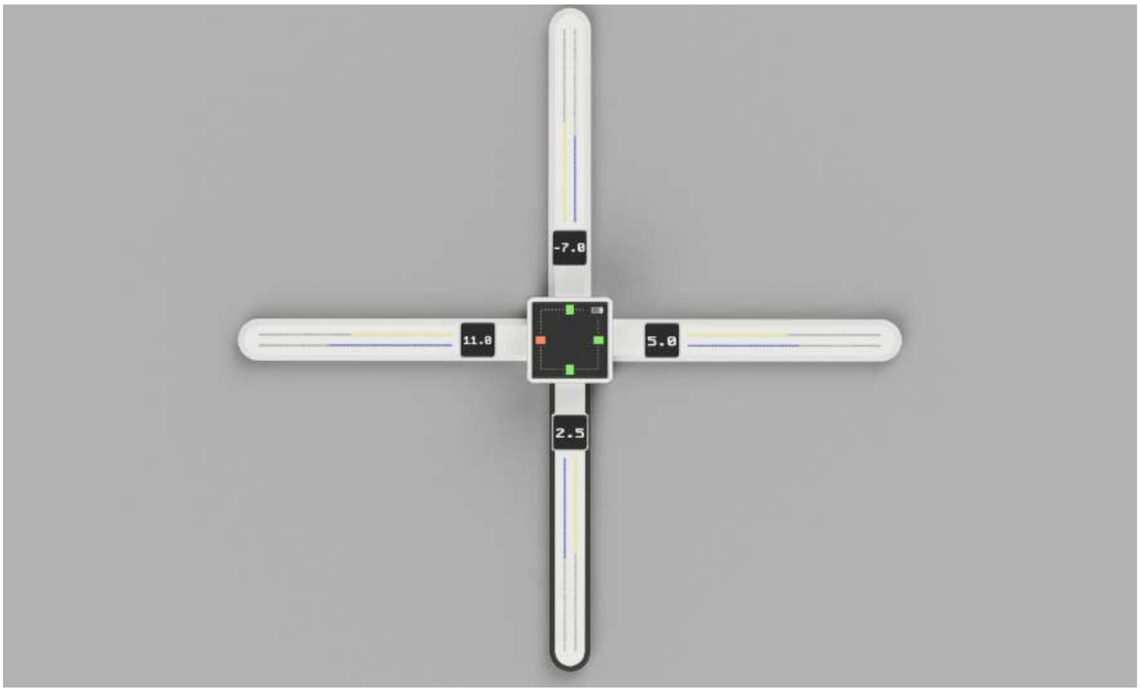


Figure 11.3: Finalized rendering of the Squid after irradiation.

Numerical deviation As discussed previously, the squid can provide visual feedback in the format of 3 digit numerical values on each arm. This numerical deviation is placed on the arm that performed the measurement. Another possible placement of this feedback is on the base unit screen. However, presenting the values on the specific arm that performed the measurement was deemed to have a better result in ensuring a strong perceived value-side relationship.

Measured deviation is presented in millimeters with a possible accuracy of +-0.1 millimeters, fulfilling requirement 86. Negative values, when the light field extends beyond the radiation field, are presented with a minus sign, without it's assumed positive. The orientation of the output is based on that of the grey arm and fulfills requirement 64.

This data is always presented, whether or not the Squid is connected to the X2 system. This ensures that the products core functionalities are always available. Numerical readout can be offered through various technical solutions, the presented concept employs small digital LED screens.

Visual representation of deviation A crucial part of performing the task

"Ensure that measured deviation is within tolerance" is to form an understanding of how both fields are placed relative to each other. The geometry of the Squid allows it to visually represent the alignment for all sides simultaneously. This is done through 2 individual lines, blue representing radiation and yellow representing light. The lines light up from the base outwards until the identified edge, fulfilling requirement 77. The accuracy of this visual representation won't be as high as the numerical output, but it provides the user with further detail into the automated processes performed by the machine. In the case of a negative numerical readout, the user could verify this by checking the visual representation. If the yellow line extends further from the base than the blue one, then both visual and numerical readout are in agreement and the automated process will be perceived as more reliable.

Visual representation on base unit The base unit acts a way to provide the user with both pass/fail analysis as well as feedback regarding machine state for automated tasks, see Fig. 11.4 for full description of machine state progression. For cases where no X2 system is integrated in performing the task, visual representation on the base unit does not include the last two states.

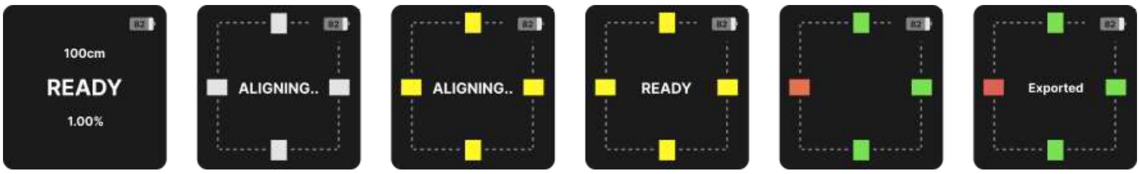


Figure 11.4: Visual feedback on base unit to communicate state. In order from left, where product is removed from it's case to right, where pass/fail results are displayed and communicated to an X2 system.

The visual representation relies on four squares placed on each side of a dashed square. These have 4 different possible states representing each side of the light field in relation to the task "*Ensure light-radiation field alignment is within tolerance*", see Fig. 11.5. The output on the base unit is then complimented with a descriptive word, either indicating a task is being performed, completed or that the machine is ready to proceed to the next task, fulfilling requirements 72 and 84.

11.7 Longevity

Relevant for this design challenge are mainly three requirements presented in Table 11.6. Requirements 82 and 85 are fulfilled through solutions relevant for design challenge Geometry, specifically through how requirement 66 - *There should be one way to unfolding the product* and requirement 75 - *Offer one distinct unfolded state* are fulfilled. Minimizing the possible way the product can be handled through only allowing the user to fold each arm from 0 to 90 degrees, as well as locking each arm when in it's extreme point (0 or 90 degrees) is how the squid fulfills requirement 82 and 85. However, fulfilling requirement 82 with specific production requirements is outside the project scope. The types of hinges and connectors that are used to produce the squid will affect how well the product fulfills requirement 82.

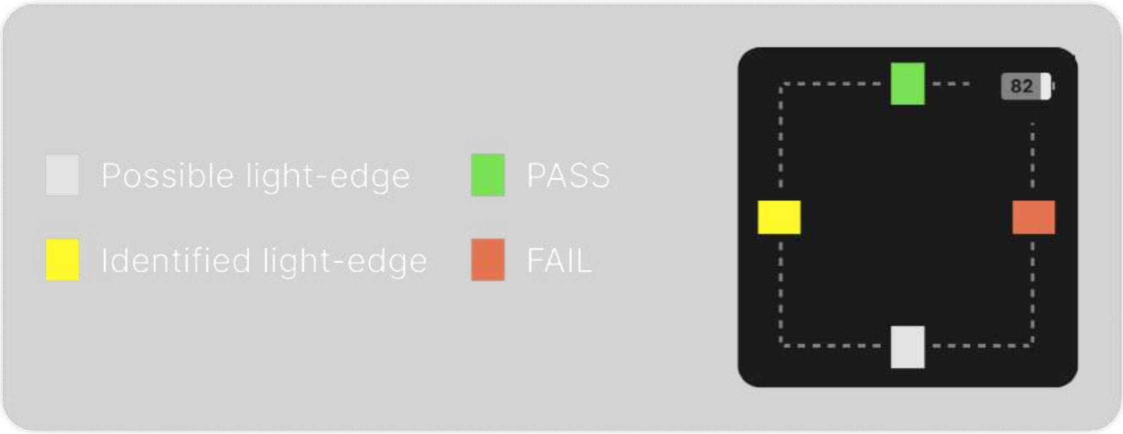


Figure 11.5: Indications of machine decisions for specific sides.

Table 11.6: Requirements relevant for longevity.

nr	Relevant requirements
82	Movable parts should not deteriorate due to normal usage
85	Moving parts should feel sturdy
90	Allow for battery service without specialty competence

Requirement 90 is fulfilled through implementing a USB type C charging port inside the product case and allowing the squid to charge while placed inside. The proposed concept is charged through magnetic connectors placed at the bottom of the base unit. This is then connected to a raised charge point inside the case, see Fig. 11.6

Summary

In summary, the Squid 2.0 provides a set of specific functions required for light-radiation field alignment. This is done through automating changes in machine state to comply with sequential task completion. There is very little direct interaction on the squid itself, and so it allows the user to perform light-radiation field alignment without drastic changes to current workflow.

Overall, the design process produced a concept that is attuned to the task "*Ensure light-radiation field alignment is within tolerance*". The main interaction, unfolding, has clear affordance and high guessability. Machine output is side and task specific. Alignment is automated and machine state is updated live. Geometry allows for four measurements per irradiation. Reporting and input of test parameters relies on an external system already present in the use case.

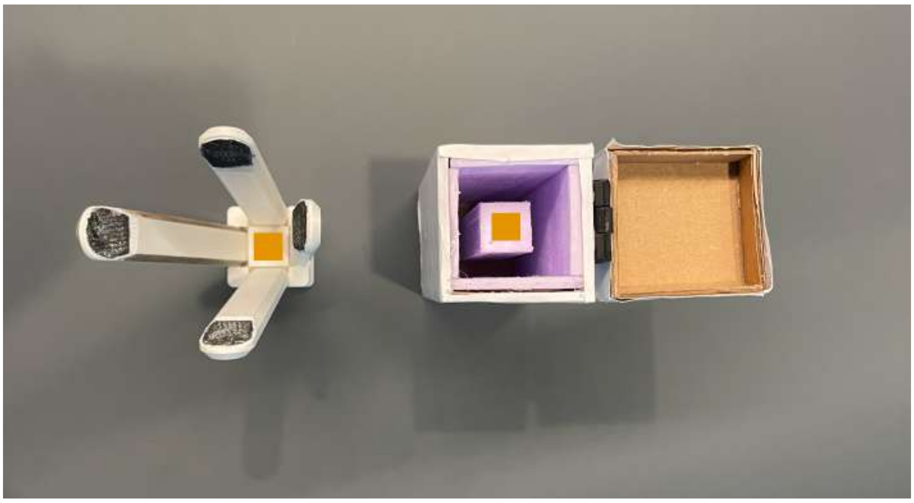


Figure 11.6: Placement of magnetic connectors for charging, indicated with orange boxes.

12 Discussion

This chapter will critically reflect on the process and results to investigate to what extent the RQ's were truly answered. Further more, it will cover potential future work, reflections on the the methodology and theory applied and more.

12.1 Purpose and Scope

Overall, the results indicate that the project was successful in relation to its purpose. The purpose of this work was to develop a design concept for the next generation DXR+ product for the Swedish market, from a User-Centered Design perspective, which has been done. The final design concept has been designed with users involved, and received highly positive feedback. The concept was demonstrated to RaySafe's R&D, and they clearly indicated that it was a solid concept with the ability to inform decisions for a full product. However, since the development of the actual product has not begun, the true value of the design concept cannot yet be evaluated.

There are some details that are not yet fully finished, such as interaction with the product when it connects to and communicates with external systems. However, the purpose was to develop a detailed concept for *the next generation DXR+*, not for the systems it interacts with. The scope was also quite limited, but considering the time frame, resources and contacts available, the delimitation were appropriate. A broader scope would have required more data gathering, potentially shifting the work more towards data gathering and less towards producing a design concept, which was the purpose of this project. This all indicates that the purpose and scope of the project were appropriately formulated, and that the methods and process applied was sufficient in fulfilling them.

12.2 Methods and Validity

The methods used in this project lead to a verifiable conclusion. However, no methodology is perfect. This section aims to critically reflect on the choice and application of methods used in the project, and to what extent they led to valid results.

12.2.1 User Involvement

A recurring theme in this project was the difficulty in involving a variation of users. If a user in this context is defined as someone working in a role that performs light-radiation field alignment, the total number was five. Eleven proxy users were involved through the usability study, but the strong indicated learning effect discovered in Section 8.1.4, indicates that the proxies were likely quite distant proxies.

How many users to involve in a usability study is a highly debated topic (Alroobaea & Mayhew, 2014; Hwang & Salvendy, 2010; Woolrych & Cockton, 2001). Estimates vary from 3 to 20 participants depending on context and methods, but most studies indicate that more than four users are needed to uncover a significant majority of issues. Studies on this mostly cover usability studies and not "how many users to involve in general", but they can be seen as indicative of how many users are needed to provide representative results with good coverage.

The results from the steps involving users in this project, whether real world or proxy ones, converge to similar contents. That is to say, as more interviews or usability tests were held, the results started to repeat themselves and less and less new information, ideas and issues were uncovered. This can be seen as an indication that the amount of user involvement was sufficient and that most important insights were captured. Still, the low amount of real world users put the validity of the results into question. When finding users to involve, the strategy was to primarily find current users of the DXR+. The search could have been widened to include more potential users, such as clinical physicist and medical engineers that perform light-radiation field alignment using other tools than the DXR+. Doing so could potentially have revealed more possible improvements to the DXR+, and increased the validity of the results.

In a similar fashion, the real world user that were involved were only involved in limited parts of the project. This was due to logistic and scheduling reasons, and it would have been unreasonable to expect hospital staff to dedicate more of their time to a project like this one. It does however mean that many steps and design decisions were made based on insights from users, but not together with users. Applying methods of co-creation or participatory design could have been very valuable if there would have been resources to do so.

12.2.2 The Usability Study

Some aspects of the usability study performed in Section 8.1 deserve scrutiny. The final result quite clearly favored one specific concept, and did so with such significance that it is possible that changes to the method itself would not have changed the outcome. However, parts of the methodology could have lead to unfair comparisons between the concepts. One of the main principles behind the usability test was testing and comparing aspects of the concepts, not the whole concepts themselves. This is reflected for example in asking participants to rank the concepts' geometries and readouts separately. The drawback of this approach is that it cannot be clearly established that aspects in a concept did not influence the participants' experience of the concept's other aspects.

One example where this issue is highlighted is in comparing concepts that featured inputs during the usability study with those that did not. The concepts with inputs, i.e. the Four Cheeses and the Extender, could have functioned without their inputs, and the concepts that did not require input, the Squid and the Butterfly, could have had some sort of input modalities added to them. This means the inputs where not inherent to the concepts themselves, but rather added on top of them. When test participants rated the concepts they likely did so taking the experience of the input into account, whether consciously or not. Since the Four Cheeses and the Extender performed worse overall than the other two concepts, it is highly possible that participants rated them lower because of the need for input, not because of aspects inherent to the concepts. Possible ways of mitigating this effect could have been asking more targeted questions about aspects of the concept or having some participants test all four concepts with input, and some without. The same issue exists with machine output, where the overall impression of a prototype might have affected the rating its readout.

A similar issue exists with the prototypes themselves, specifically those requiring user input. Because of their low fidelity, a test facilitator needed to manage a digital prototype in sync with the actions participants performed on the physical prototype to show the screen content, as described in Section 8.1.3. The digital and physical prototypes were hard to keep in sync, and many participants expressed confusion over the connection. This issue did not exist on the prototypes without user input. While this is quite clearly an issue with the prototypes, it is possible participants rated the concepts lower because of the confusion and lack of perfect sync. More flexible digital prototypes or physical prototypes of higher fidelity could have mitigated this effect.

Regarding the statistical validity of the quantitative data gathered during the usability study, it is reasonable to conclude that the sample size was enough for the results to be valid. A number of the metrics were shown to be statistically significant, and most of the other metrics trended towards significance. More statistical methods could have been applied, both to check the validity of the data and to further explore correlations. However, the simple methods applied showed a clear enough result to draw conclusions on, and the low sample size would likely have lead to more detailed-focused statistical tests not giving significant results.

12.2.3 Prototype Fidelity

Central to any design process is iterative development, and this requires one to evaluate current design solutions and redeveloping them based on collected and analyzed data. In the context of this project, developing a small quite simple hand-held QA device, producing a high fidelity prototype was initially assumed to be possible and necessary.

However, a decision had to be made in Phase 2 regarding functional prototypes and if it would be worthwhile endeavor. The design solution automatic light edge detection would require specialized sensors that no one in the project group had previous experience with. It would also set restrictions on how well certain design challenges could be prototyped. For example, a functional prototype would require sensors, an Arduino, power supply and breadboard or any other type of connectors. This would affect the ability of design solutions regarding geometry to be tested. In the context of Phase 2 and the type of data to be collected in Phase 3, it was decided to not develop a functional prototype and instead follow a segmented approach. Meaning individual design solutions were prototyped, instead of any complete whole concepts. This led to some validity questions in regards to what was actually being testing during the usability study, as mentioned previously in this chapter. If functional prototypes were developed, Phase 2 would have taken a lot more time and this might have limited the amount of subsequent iterations that would be possible to perform within the time frame of this project. However, it would result in less ambiguity regarding usability study results in Phase 3.

12.2.4 Final Validation

The initial plan for Phase 5 included another iteration of data collection, analysis and requirement synthesis leading into another iteration of design. However, due to time constraints and limitations with the fidelity of final prototype, the phase was limited to validating the concept generated in Phase 4 and synthesizing the collected data into possible avenues for future work.

The validation of the final concept took a very simple form through semi-structured interviews with three users across two occasions. This was the result of a combination of the time constraints mentioned above and the low access to real world users. While the response from the users was clear and positive, the method used to gather the response was quite weak. As mentioned in Section 12.2.1, it would have been possible to contact more users to gather more feedback. Interviewing users that had not previously been part of the study would also have been highly relevant, as their answers could be seen as a measurement of how generalizable the result is to users. Even considering just the three users that were interviewed, a more rigorous evaluation more centered around the identified requirements and system performance metrics would have provided a more robust evaluation.

12.3 Generalizability, Requirements and Application of ACD^3

Using the ACD^3 framework as a basis to shape procedure and defining input/output for each phase provided clarity and structure to an iterative design process. Since starting point and end goal was already defined when entering a new phase, it became quite easy to structure the necessary work in a detailed manner and systematically reduce the design space based on user needs.

In some aspects the requirement synthesis succeeded in following the ACD^3 framework. As the project progressed, set restrictions on the design space followed the design and requirement levels as detailed in ACD^3. Quite broad and high level functional requirements and generalized usability guidelines were reworked into specific requirement for each identified design challenge. Each decision of reducing the design space is clearly motivated by analysis and each requirement has a clear history. However, the requirements were generally synthesized as quite direct and implicit reductions in the design space even initially. Leading the requirement list to resemble a justification for the final design concept instead of a generalized framework for the next generation direct X-ray ruler. This became most apparent during the requirement rework in Phase 3. Synthesized requirements acted as a way to structure aspects of improvement specifically for the squid concept. How well individual design solutions performed guided the rework of corresponding requirements, sorted by design challenge. Which means that entirely new solutions were not explored in Phase 4.

12.4 Ethics and Sustainability

Through out all dedicated data collection sessions participant data was handled in accordance with GDPR and each participants own preferences. However, during concept evaluation with stakeholders in Phase 5, the session was planned as a pitch followed by a quite informal Q&A session. Aspects raised by participants in the Q&A session were written down and used in the project. The GDPR form employed previously in the project was not used for this instance of data collection. The group was large and time was limited, and so participant were informed that notes would be taken and all data collection was kept anonymous. In terms of sustainability, Phase 2 and 4 produced various iterations of each 3D printed design, resulting in quite a bit of waste. However, this is hard to completely eliminate since tolerances and fittings for 3D parts does require some trial and error. And so, the project relied on specialized waste bins for 3D printed material. Two times during the course of the project a car was used to travel from RaySafe headquarters in Hovås to Kungälvssjukhus in Kungälv. This was not strictly necessary since there are public transportation connections between the two points. However, driving by car allowed more time at each location and allowed the project team to schedule two meetings in two distant locations in one day. Generally the work in this project kept to the outlined ethics and sustainability goals. Some aspects regarding plastic waste and choosing public transportation could have been more consistent with the set sustainability goals.

12.5 Resolution, Dose Range and Exposure Time

Very little data was gathered on users' wants in terms of resolution, dose range and exposure time for the product. The only synthesized requirement regarding these aspects was requirement 86 - *Offer accuracy higher than 2.5 mm*, which in itself is quite vague and resolution is dependant on type of sensors used. However, specifying a certain resolution would require synthesizing requirements on design level element, which is beyond the process scope. These are technical aspects and results of engineering, but they still play a vital role in the usability and user experience. A product with high resolution might give a reliable impression and proper dose range and exposure time allows for easier adjustment of settings on the X-ray machine and potentially compatibility with more machines. Not gathering this data can be seen as a significant flaw of this work. Asking the already participating users about their preferences on these matters would have required very little extra work, and would have provided distinct value. Doing so could have been an easy addition to the user study held in Phase 1.

12.6 Compatibility with Computed Tomographs

Early on in the process, the ability to measure the dose profile on CT machines was discussed as a potential improvement, primarily based on the request of RaySafe. However, the final concept does not include any designated CT compatibility features. This can be seen as a consequence of the geometry of the Squid not lending itself well to analyzing dose profiles, but whether the decision to not explore CT compatibility further was a conscious, well-supported decision or not could be supported further.

The data gathered on CT compatibility came exclusively from the user interviews in Phase 1. All participants indicated that the ability to measure dose profile would be a valuable addition to the DXR+, with one stating that it would drastically improve their view of the product. In relation to the strong indications from the users, the process of investigating and finally discarding CT compatibility was fairly fast and simple. While it is true that the ability to measure dose profile would add complexity to the product, and potentially clash with its geometry, more attention could have been paid to the feature by doing more research on what requirements on the product CT compatibility would pose on the product. This would have lead to better grounds for the decision on whether CT compatibility should be incorporated into the final design concept.

12.7 Future Work

This project had a focused scope. As such, considerable future work is needed to create an actual product based on the final design concept. Parts of this future work are entirely matters of engineering, and will not be discussed here. Instead, this section focuses on design and concept related aspects of future work.

12.7.1 Cost-Friendly Design

As mentioned in Section 10.1, implementing the final design concept is technically possible, but requires expensive components. To become a viable product, the next generation DXR+ will need a viable price. As such, changes to the design concept are likely necessary in order to bring down production and engineering costs. Such changes should be carried out in collaboration between a design team and R&D to ensure that the user-centered design is not lost and important features for interaction are not removed, while also developing the inner workings and components of the product.

Some potential cost-saving changes to the design are discussed in Section 10.3. Which ones of these are good options in the balance of cost to value is difficult to say. Sensor architecture and component selection for cost optimization is also identified as future engineering work.

12.7.2 External System Integration

Parts of the final design concept are based around communication with external systems. What these systems are, how the integration works and, most importantly for this project, how the UCD perspective of the external systems and their integration with the design concept work are not defined. Instead, these external systems are mostly viewed as black boxes. Meaning only relevant aspects of these systems, such as automated documentation and input possibilities, were considered.

Since the external systems would be important parts of the overall usage of the product, designing their interfaces, workflows and integrations to the product should be considered part of the design needed in the future. It is important to not just consider the external systems themselves, but also how they work together with the new product. This includes in which way they communicate (wired, Bluetooth, WiFi, etc), how the task of connecting them is performed and how the user is kept in the loop about their communication.

12.7.3 Detailed Product and UI Design

The final design concept and the design process primarily focus on UCD and workflow. Initial versions of the UI design and form, material and color are incorporated into the design concept. However, they have not been directly verified or developed through a proper user-centered process. This means there is likely room for improvement in these areas. Future work could consist of an iterative user-centered design process exploring different suggestions for form, material, color and UI.

12.7.4 Adaptation to International Users

Users from different countries and regions are likely to have different preferences for a product like the DXR+. For example, as mentioned in Section 3.5, different regulations and requirements apply depending on country or region. Users from different places might also have different workflows, conditions and use different units of measurements (i.e. metric or imperial). These factors have not been taken into account in the final design concept. An attempt was made to contact users outside Europe, but no interviews could take place.

Some predicted consequences to the design when adapting it to international users include a way of changing between metric and imperial units and geometrical changes to allow for measurement of fields of different sizes. It is also possible that regional regulations influence the design by imposing requirements on batteries, material or connectivity. Furthermore, the types of X-ray machines used in a region can come with design implications, or engineering requirements that in turn lead to design implications. All in all, for the product to appeal to an international market, more work is needed to understand users, regulations and overall context internationally.

13
Conclusion

The goal of this project was to deliver a detailed design concept for a new version of the DXR+, covering directives on workflow, interaction, UI and physical product design. Through a user-centered design process, a concept matching that description was created. Throughout the process, validated methods and quantitative data informed design decisions. The final concept was shown to stakeholders, including users of the current DXR+, and received highly positive feedback. Due to the scope of project, the concept does not cover all aspects needed to create a complete product. There is also some potential for improvement in the choice and application of methods, as discussed in Chapter 12. However, because of the verifiable, user-centered process and the highly positive final evaluations, it can be concluded that the project was successful. Two research questions were formulated for the project.

RQ1, ”What usability and utility requirements exist on the interaction between a DXR and its user?”, has been answered through the list of requirements built as part of the process outlined in this report and covered in Appendix A. In order to synthesize these requirements, a number of both guidelines and requirements were created on lower design levels. As is the nature of requirements in a design-oriented work, objectively establishing that a list of requirements contains all and only all valid requirements is not possible. However, the list has been produced as part of work using validated methods, and the product matching the requirements received highly positive feedback. As such, it can be concluded that the list in Appendix A is a valid answer to RQ1.

RQ2, ”How can the requirements from RQ1 be implemented in a new iteration of the DXR+?” is answered through the design concept described in Chapter 11. All requirements formulated as an answer to RQ1 can be mapped to features of the design concept. This means the design concept is one possible answer to RQ2. Considering the highly positive feedback it received, it can be concluded that the concept is a good answer to RQ2, given the scope of the project.

References

Alroobaea, R., & Mayhew, P. J. (2014). How many participants are really enough for usability studies? *2014 Science and Information Conference*, 48–56. https://doi.org/10.1109/SAI.2014.6918171

Bligård, Lars-Ola. (2015). *Acd3: Utvecklingsprocessen ur ett människa-maskinperspektiv.* Chalmers University of Technology.

Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2012). *The essential physics of medical imaging* (3rd). Lippincott Williams & Wilkins.

CENELEC. (2024). *Evaluation and routine testing in medical imaging departments - part 3-8: Acceptance and constancy tests - imaging performance of x-ray equipment for radiography and radioscopy* (European Standard No. EN IEC 61223-3-8:2024). European Committee for Electrotechnical Standardization (CENELEC). Brussels, Belgium.

Coulentianos, M. J., Rodriguez-Calero, I., Daly, S. R., & Sienko, K. H. (2020, April). *Stakeholder engagement with prototypes during front-end medical device design: Who is engaged with what prototype?* (Vol. 2020 Design of Medical Devices Conference). https://doi.org/10.1115/DMD2020-9020

Endsley, M. R. (2004). *Designing for situation awareness: An approach to user-centered design* (2nd ed.). CRC Press. https://doi.org/10.1201/b11371

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics*, *42*(3), 462–492. https://doi.org/10.1080/001401399185595

Gauntt, D. M., Ranger, N. T., Willis, C. E., Al-Senan, R., Bercha, I. H., Dave, J. K., Fang, Y., Gingold, E. L., Goldman, L. W., Jones, A. K., Peck, D. J., Ranallo, F. N., Rutel, I. B., Schueler, B. A., Uzenoff, R. A., Walz-Flannigan, A. I., Weiser, J. C., Yorkston, J., Apgar, B., & Meyer, S. W. (2024). *Acceptance testing and quality control of digital radiographic imaging systems* (AAPM Report No. 150). American Association of Physicists in Medicine (AAPM). Alexandria, VA. https://www.aapm.org/pubs/reports/TG-150_final.pdf

Gibson, J. J. (2014). *The ecological approach to visual perception: Classic edition.* Psychology press.

Hart, S. (2006). Nasa-task load index (nasa-tlx); 20 years later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *50*. https://doi.org/10.1177/154193120605000909

Hart, S. G., & Staveland, L. E. (1988). Development of nasa-tlx (task load index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 139–183, Vol. 52). North-Holland. https://doi.org/https://doi.org/10.1016/S0166-4115(08)62386-9

Hwang, W., & Salvendy, G. (2010). Number of people required for usability evaluation: The 10±2 rule. *Communications of the ACM*, *53*(5), 130–133.

International Electrotechnical Commission. (2024). *Evaluation and routine testing in medical imaging departments - part 3-8: Acceptance and constancy tests - imaging performance of x-ray equipment for radiography and radioscopy* (International Standard No. IEC 61223-3-8:2024). International Electrotechnical Commission. Geneva, Switzerland. https://webstore.iec.ch/en/publication/64680

Islind, A. S., Lundin, J., Cerna, K., Lindroth, T., Åkeflo, L., & Steineck, G. (2023). Proxy design: A method for involving proxy users to speak on behalf of vulnerable or unreachable users in co-design. *Information Technology & People*, *38*(1), 531–552. https://doi.org/10.1108/ITP-07-2021-0539

Ivanov, S. H. (2023). Automated decision-making. *foresight*, *25*(1), 4–19.

Jones, A. K., Heintz, P., Geiser, W., Goldman, L., Jerjian, K., Martin, M., Peck, D., Pfeiffer, D., Ranger, N., & Yorkston, J. (2015). Ongoing quality control in digital radiography: Report of AAPM imaging physics committee task group 151. *Medical Physics*, *42*(11), 6658. https://doi.org/10.1118/1.4932623

Kron, T., & Ferguson, S. (2000). Where is the light field edge: Perception of different operators on different surfaces. *Medical Dosimetry*, *25*(2), 99–103. https://doi.org/10.1016/S0958-3947(00)00036-4

Kutcher, G. J., Coia, L., Gillin, M., Hanson, W. F., Leibel, S., Morton, R. J., Palta, J. R., Purdy, J. A., Reinstein, L. E., Svensson, G. K., Weller, M., & Wingfield, L. (1994). Comprehensive qa for radiation oncology: Report of aapm radiation therapy committee task group 40. *Medical Physics*, *21*(4), 581–618. https://doi.org/https://doi.org/10.1118/1.597316

Kylén, J. (2004). *Att få svar: Intervju, enkät, observation* (1st ed.). Bonnier Utbildning.

Läkemedelsverket. (2021). *Is it a medical device?* [Accessed: 2026-02-12]. Läkemedelsverket. https://www.lakemedelsverket.se/en/medical-devices/manufacture/is-it-a-medical-device#hmainbody1

Lewis, C., & Rieman, J. (1993). *Task-centered user interface design: A practical introduction*. University of Colorado, Boulder, Department of Computer Science. https://hcibib.org/tcuid/

Lindström, J., Hulthén, M., Sandborg, M., & Carlsson-Tedgren, Å. (2020). Development and assessment of a quality assurance device for radiation field–light field congruence testing in diagnostic radiology. *Journal of Medical Imaging*, *7*(6), 063501. https://doi.org/10.1117/1.JMI.7.6.063501

Martin, J. L., Clark, D. J., Morgan, S. P., Crowe, J. A., & Murphy, E. (2012). A user-centred approach to requirements elicitation in medical device development: A case study from an industry perspective. *Applied Ergonomics*, *43*(1), 184–190. https://doi.org/https://doi.org/10.1016/j.apergo.2011.05.002

Martin, J. L., Norris, B. J., Murphy, E., & Crowe, J. A. (2008). Medical device development: The challenge for ergonomics. *Applied Ergonomics*, *39*(3), 271–283. https://doi.org/https://doi.org/10.1016/j.apergo.2007.10.002

Menold, J., Jablokow, K. W., & Simpson, T. W. (2019). Prototyping for context: Exploring stakeholder feedback based on prototype type, stakeholder group and question type. *Research in Engineering Design*, *30*, 453–471. https://doi.org/10.1007/s00163-019-00317-5

Nielsen, J. (1994). Enhancing the explanatory power of usability heuristics. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 152–158. https://doi.org/10.1145/191666.191729

Norman, D. A. (1999). Affordance, conventions, and design. *interactions*, *6*(3), 38–43.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*(2), 230–253. https://doi.org/10.1518/001872097778543886

QUART. (2026). *Quart nonius product page* [Accessed: 2026-02-05]. https://quart.de/en/products/meters-instruments/x-ray-rulers/quart-nonius

Rasmussen, J., & Vicente, K. J. (1989). Coping with human errors through system design: Implications for ecological interface design. *International Journal of Man-Machine Studies*, *31*(5), 517–534. https://doi.org/10.1016/0020-7373(89)90014-X

RaySafe. (2026). *Raysafe dxr+ product page* [Accessed: 2026-02-05]. https://www.raysafe.com/products/x-ray-test-equipment/raysafe-dxr

Rodríguez-Calero, I., Coulentianos, M., Daly, S. R., & Sienko, K. H. (2020, April). *Single versus multiple prototypes: Medical device design practitioners' rationale for varying prototype quantities to engage stakeholders during front-end design* (Vol. 2020 Design of Medical Devices Conference). https://doi.org/10.1115/DMD2020-9046

RTI Group. (2026). *Rad-digix-4 product page* [Accessed: 2026-02-05]. https://rtigroup.com/products/phantoms/radiography-phantom/

Sandom, Carl, Harvey, Roger S. (2004). *5.3 hierarchical task analysis (hta)*. https://app.knovel.com/hotlink/pdf/id:kt00C7TTHH/human-factors-engineers/hierarchical-task-analysis

Scupin, R. (1997). The kj method: A technique for analyzing data derived from japanese ethnology. *Human Organization*, *56*(2), 233–237. https://doi.org/10.17730/humo.56.2.x335923511444655

Sharp, H., Preece, J., & Rogers, Y. (2019). *Interaction design: Beyond human-computer interaction* (5th ed.). John Wiley & Sons.

Swedish Institute for Standards (SIS). (2024). *Evaluation and routine testing in medical imaging departments - part 3-8: Acceptance and constancy tests - imaging performance of x-ray equipment for radiography and radioscopy* (Swedish Standard No. SS-EN IEC 61223-3-8:2024). Swedish Institute for Standards (SIS). Stockholm, Sweden. https://www.sis.se/produkter/halso-och-sjukvard/medicinsk-utrustning/rontgen-och-annan-diagnostikutrustning/iec-61223-3-82024/

Walsh, C., Larkin, A., Dennan, S., & O'Reilly, G. (2004). Exposure variations under error conditions in automatic exposure controlled film–screen projection radiography. *British Journal of Radiology*, *77*(923), 931–933. https://doi.org/10.1259/bjr/62185486

Woolrych, A., & Cockton, G. (2001). Why and when five test users aren't enough. *Proceedings of IHM-HCI 2001 conference*, *2*, 105–108.

You, H.-c., & Chen, K. (2007). Applications of affordance and semantics in product design. *Design studies*, *28*(1), 23–38.

A

Appendix A - Requirement List

In this appendix the full requirement list is presented. This has been iterated upon through the project to create a structured way of defining the design space in which design work is conducted. Requirements and guidelines are presented with corresponding design challenge and source description. Further more the right most column describes either how the final concept fulfills that specific requirement or if it was reworked into another requirement. Data follows on the next page.

1	Automatisk identifikation av ljuskant	Fysiker 1	Utökad funktionalitet, Automatisering	Användarvänlighetsönske	Resulterade i krav 71, 94
2	Möjliggör att produkten kan placeras åt båda hållen	Fysiker 1	Alignment, Geoemtri	Användarvänlighetsönske	Blev ej krav. Går emot krav 91 och 93
3	Erbjud användaren möjlighet att själv bestämma när mätvärdet slutar visas	Fysiker 1	Geoemtri	Användarvänlighetsönske	Resulterade i krav 72
4	Spara mätvärdet automatiskt	Fysiker 1	Rapportering	Användarvänlighetsönske	resulterade i krav 91, 93
5	Erbjud överföring av mätvärden till X2	Fysiker 1	Rapportering	Användarvänlighetsönske	Resulterade i krav 88¨
6	Visa resultat på högre nivå, pass/fail eller % av SID	Fysiker 1	Avläsning	Användarvänlighetsönske	Resulterade i krav 74 och 87
7	Mäta flera sidor på en gång	Fysiker 2	Geoemtri, Alignment	Användarvänlighetsönske	Resulterade i krav 63
8	Gör mätvärdet pålitligt även om röntgenfältets kanter är snea	Fysiker 2		Användarvänlighetsönske	Blev ej krav, kunde inte bygga upp
9	Möjliggör att användare kan byta batteri	Sjuksköterska 1	Utökad funktionalitet	Användarvänlighetsönske	Resulterade i krav 90
10	Erbjuda att spara mätvärde hos maskinen	Sjuksköterska 1		Användarvänlighetsönske	Blev ej krav. Mätvärde sparas via externt system. Sparas lokalt en förbestämd tidsintervall som nuvarande.
11	Erbjuda överblick av mätvärde-sida relation	Sjuksköterska 1	Avläsning, Geoemtri, Mv/S-Relation	Användarvänlighetsönske	resulterade i krav 64, 91, 93
12	Erbjud enkel översikt på huruvida avvikelse är inom tolerans	Fysiker 3		Användarvänlighetsönske	Erbjuder pass/fail tillsammans med externa system
13	Erbjud självförklarande användning trots oregelbunden användning	Fysiker 3		Användarvänlighetsönske	
14	Hjälp användaren hålla koll på vilka sidor som mätts	Fysiker 3	Geoemtri, Avläsning, Mv/S-Relation	Användarvänlighetsönske	Resulterade i krav 73
15	Låt användaren själv bestämma över pass/fail-parametrar	Fysiker 3	Utökad funktionalitet, Automatisat beslutfattan	Användarvänlighetsönske	Resulterade i krav 74
16	Minimera tillfällen för use-error	Fokus Grupp	Avläsning, Alignment, Automatisat beslutfattan	Användarvänlighetsönske	Resulteade i krav 64, 65, 66
17	Möjliggör mätning av storlek på ljusfält	Fokus Grupp	Geoemtri	Användarvänlighetsönske	resulterade i krav 78
18	Möjliggör uträkning av storlek på strålfält	Fokus Grupp	Geoemtri	Användarvänlighetsönske	resultearade i krav 78
19	Visa mätvärde med högre upplösning än 2,5 mm	Fokus Grupp	Avläsning	Användarvänlighetsönske	resulterade i krav 86
20	Erbjud automatiskt mått av SID	Fokus Grupp	Utökad funktionalitet, Automatisering	Användarvänlighetsönske	Blev ej krav på grunda av tekniska svårigheter som identiferades vid diskussion med teknisk kunnug intressent på RaySafe
21	Förbättrad skärm med färg/siffror	Fokus Grupp		Användarvänlighetsönske	
22	Möjliggör att användaren själv bestämmer när mätvärdet försvinner	Ingenjör 1		Användarvänlighetsönske	Resulterade i krav 92
23	Erbjud ökad tillit till maskin-beslut	Ingenjör 1	Automatisering, Avläsning	Användarvänlighetsönske	Resulterade i krav 64,69
24	Erbjuda tydlig affordance för placering av produkt vid ljuskant	Flera användare	Alignment	Användningskrav	geoemtrin inger att basen skall placeras i mitten. Ljusindikatorerna updateras live vid alignment. resulterade i krav 70
25	Erbjud alltid numerisk avläsning av avvikelse	Fysiker 1	Avläsning	Användningskrav	Numerisk avläsning ges oberoende av PASS/FAIL. Resulterade i krav 76
26	Erbjud avläsning direkt från produkt	Fysiker 1	Geoemtri, Avläsning	Användningskrav	Numerisk avläsning på armarna samt PASS/FAIL på basenhet
27	Möjliggör enkel transportering och förvaring genom liten formfaktor	Fysiker 1	Geoemtri, Förvaring	Användningskrav	Med koppling i basenhet så sätter baseneheten måttet. nuvarande 40x40x170 [Bas,Djup,Höjd]
28	Visa resultat och process såpass tydligt att användaren känner sig trygg med resultat	Fysiker 1		Användningskrav	
29	Möjliggöra mätning av 20x20 (cm) ljusfält	Fysiker 1	Geoemtri	Användningskrav	20x20 ligger inom 15x15-25x25 spann
30	Möjliggör mätning av ljusfält av olika storlekar	Flera användare	Geoemtri	Användningskrav	Kan mäta 4 sidor på 15x15 till 25x25 ljusfält. 2 sidor på alla andra storlekar
31	Erbjuda manuel rapportering	Sjuksköterska 1	Avläsning, Rapportering, Automatisering	Användningskrav	Användare kan läsa av numerisk avläsning och sedan manuellt rapportera in i sjukhusets mall
32	Erbjud funktionalitet vid behov	Sjuksköterska 1	Geoemtri	Användningskrav	Produkten behöver endast fällas ut för att erbjuda funktionalitet. Annars är den förvarad i X2 väskan (i sitt case)
33	Output behöver vara kompatibel med sjukhusets egna rapporteringsmallar	Sjuksköterska 1	Avläsning, Rapportering	Användningskrav	Numerisk avläsning är kompatibel med alla mallar vi sett
34	Erbjud upplösning på minst 2,5 mm	Sjuksköterska 1	Avläsning	Användningskrav	Se krav 86
35	Möjliggör SID mätning med röntgensmaskins måtband	Sjuksköterska 1	Geoemtri	Användningskrav	Likt nuvarande DXR
36	Möjliggör förvaring i X2 väskan	Sjuksköterska 1	Förvaring, Geoemtri	Användarvänlighetsönske	Inget krav. Kan sätta krav på X2 väska
37	Låt användaren själv kunna besluta om avvikelse är inom tolerans	Fysiker 3		Användningskrav	
38	Erbjud enkel toleranstabell för dos	Fysiker 3		Användningskrav	
39	Erbjuda funktionalitet direkt, utan förarbete med produkten	Ingenjör 1	Geoemtri	Användningskrav	Kräver inte INPUT för att erbjuda funktionalitet
40	Möjliggör enkel användning 10-12 gånger per år	Ingenjör 1	Alignment, Avläsning, Förvaring	Användningskrav	Intuitiv användning och maskinen ger feedback gällande vilket state den är i
41	Erbjud "lagom" noggranhet	Ingenjör 1		Användningskrav	
42	Erbjud mätning av dosprofil i CT	Fysiker 1		Användningsönskemål	
43	Möjliggöra mätning av 30x30 (cm) ljusfält	Sjuksköterska 1	Geoemtri	Användningsönskemål	Kan utföra mätning av 30x30 ljusfält men då endast 2 sidor per exponering
44	Spara 1-dimensionell position av kant på ljusfält	Nuvarande Produkt		Funktionskrav	Vid alignment så tänds lampor från centrum fram till ljuskant. Resulterade i krav 95

45	Spara 1-dimensionell position av kant på röntgenfält	Nuvarande Produkt			Funktionskrav	Vid exponering så tänds lampor från centrum fram till röntgenkant
46	Erbjuda avläsning av distans mellan ljus och röntgenfält	Nuvarande Produkt			Funktionskrav	Se krav 76, 77
47	Möjliggör placering oavsett position och storlek av skuggkors	Nuvarande Produkt			Funktionskrav	För 20x20 ljusfält så har produkten över 5 cm tillgodo på varje arm. Så produkten kan placeras lite offset och ändå erbjuda funktionalitet.
48	Möjliggör avläsning av linjalelement i röntgenbild	Fysiker 2			Funktionskrav	Svarar inte till
49	Möjliggör att DXR används helt självständigt	Fysiker 3	Rapportering, Avläsning, Automatisering		Funktionskrav	Kräver inga externa system för att visa numerisk och visuell avvikelse.
50	Erbjuda noggranhet utefter lagkrav (IEC)	Product Manager	Alignment, Avläsning, Rapportering		Intressentkrav	Erbjuder noggranhet så avvikelse < 1-2% av SID kan säkerställas.
51	Erbjuda funktionalitet utan externa system	Product Manager			Intressentkrav	Se krav 49
52	Behöver ersätta den nuvarande DXR+	Product Manager			Intressentkrav	Utan externa system erbjuder den mer målinriktad funktionalitet än nuvarande DXR
53	Ökad funktionalitet ska inte påverka användarvänlighet	Product Manager	Utökad funktionalitet, Automatisering		Intressentkrav	Resulterade krav 89, 95
54	Erbjuda maximal output baserat på minimal användar-input	Product Manager	Automatisering, Avläsning, Rapportering		Intressentkrav	Resulterade krav 87, 89
55	Produkten behöver vara antingen "dum" eller "flexibel"	Product Manager			Intressentönskemål	Resulterade i krav 83, 87
56	Möjliggöra integrerat rapportingsflöde med X2	Product Manager	Rapportering		Intressentönskemål	Resulterade krav, 88
57	Erbjuda mätningsresultat i röntgenbild	Product Manager			Intressentönskemål	Svarar inte till, men inget krav då vi inte kunde bygga upp detta
58	Minimera vitala komponenters utsättning för strålning	Product Manager			Intressentönskemål	Svarar inte till, men inget krav då vi inte kunde bygga upp detta
59	Erbjuda ökad värde vid användning tillsammans med externa RaySafe system (X2)	Product Manager			Intressentönskemål	Resulterade i krav 87, 89
60	Utöka dosomfång för att fungera med fler maskiner	Fokus Grupp			Intressentönskemål	Typ av sensorer
61	Säkerställ tolerans inom 2% av SID	IEC			Regelmässigakrav	Automatisk ljus och röntgenigenkänning med 0.5mm noggranhet
62	Erbjud snabb och enkel användning	Flera användare			Användarvänlighetskrav	kräver endast förarbete ifall PASS/FAIL parametrar önskas av användaren.
63	Mäta flera sidor på en gång	User_studie_fas3	Geoemtri	7	Användningskrav	Mäter 4 sidor samtidigt.
64	Ska finnas ett rätt sätt att placera produkten	User_studie_fas3	Alignment, Geoemtri	11,16, 23	Användningskrav	Referens arm ska placeras emot användaren. den har färg markering samt text orientering på skrärmen.
65	Ska erbjuda funktionalitet även om placering sker fel	User_studie_fas3	Geoemtri, Avläsning	16	Användarvänlighetskrav	Om placering sker "fel" så kommer avvikelse mätas för de sidor där ljuskanten har lyckats identifierats.
66	Ska finnas ett tänkt sätt att fälla ut produkten på	User_studie_fas3	Geoemtri	16	Användarvänlighetskrav	Kan endast fälla ut armarna i den tänkta riktningen. Alignment går inte att göra om inte alla armar är utfällda
67	En alignment per mätning	User_studie_fas3	Alignment	62	Användarvänlighetskrav	Armarna sitter ihop och alignment sker via fysisk manövrering av basenhet via greppyta
68	4 sidor per mätning	User_studie_fas3	Avläsning, Geoemtri	62	Användarvänlighetskrav	4 armar som fälls ut för mätning
69	Underlätta bedömning av ortogonal placering av produkt emot ljuskant	User_studie_fas3	Alignment	62, 23	Användarvänlighetskrav	Alignment av alla 4 sidor samtidigt
70	Erbjud visuellt spann för alignment med ljuskant	User_studie_fas3	Alignment	24	Användarvänlighetskrav	Affordance för placering med 2 linjer som visar ljus och röntgenfält
71	Automatisk identifikation av ljuskant	User_studie_fas3	Automatisering, Utökad funktionalitet	1	Användarvänlighetskrav	Array med ljussensorer längs med armen. Resulterar i krav 94
72	Signalera när maskinen är redo för exponering	User_studie_fas3	Avläsning	3	Användarvänlighetskrav	Visuell feedback på basenehet. Resulterade i krav 92
73	Hjälp användaren hålla koll på vilka sidor som har mätts	User_studie_fas3	Mv/S-Relation, Avläsning	14	Användarvänlighetskrav	Alla sidor mäts samtidigt. De sidor som kommer mätas visas via visuell feedback på baseneheten. resulterar i krav 93
74	Låt användaren bestämma över SID och Tol.%	User_studie_fas3	Automatisering	6	Användarvänlighetskrav	Sker via externt system
75	Ska finnas ett distinkt utfällt läge	User_studie_fas3	Geoemtri		Användarvänlighetskrav	Armarna går bara att fälla ut i en riktning. Går inte att fälla ut mer än 90 grader
76	Numerisk representation av avvikelse via digital skärm med 3 siffror	Nuvarande Produkt	Avläsning	25, 46	Funktionskrav	Skärm finns på armarna
77	Visuell representation av avvikelse via längd	Nuvarande Produkt	Avläsning	46	Funktionskrav	Linje för röntgen och ljus visas i blått respektive gult brevid varandra
78		Fokus Grupp	Utökad funktionalitet		Användarvänlighetskrav	
79	Dedikerad interaktion för varje paramter input	User_studie_fas3	Automatisering		Användningskrav	Interaktion för input parametrar sker via externt system
80	Erbjuda greppyta för upplockning	User_studie_fas3	Geoemtri		Användningskrav	Basenheten är formad för grepp från toppen.
81	Erbjuda greppyta för utfällning	User_studie_fas3	Geoemtri		Användningskrav	Botten av armarna har vinkel samt grepp yta med "mjuk" plast/gummi.
82	Rörliga delar ska inte försämras vid normal användning	User_studie_fas2	Geoemtri, Underhåll		Användningskrav	Produktions aspekt
83	Erbjuda funktionalitet utan trådlös uppkoppling	User_studie_fas2			Användningskrav	Produkten erbjuder mätning av avvikelse utan input parametrar. PASS/FAIL finns inte tillgängligt utan externa system.

84	Erbjud mät-läge där parametrar är låsta och visas som bekräftade.	User_studie_fas2	Avläsning		Användningskrav	Ready state när produkten tas ut ur case
85	Inge gedien känsla av rörliga delar	User_studie_fas3	Geoemtri, Undehåll		Användarvänlighetskrav	Rörlig del är "gömd" i basenehet. Armarnas rotation är låst mellan 90 och 0 grader. Snap vi 90 eller 0 grader.
86	Erbjud mätvärde med högre noggranhet än 2,5 mm	User_studie_fas3	Avläsning	19	Användarvänlighetskrav	Numerisk avvikelse med noggranhet till 0.5 mm. Ljus och röntgen linje visar med 1 mm noggranhet.
87	Erbjud PASS/FAIL beslut om test parametrar är tillgängliga via X2 system	User_studie_fas3	Automatisering	6	Användarvänlighetskrav	Visar pass fail via visuell feedback på basenhet
88	Kommunicera mätdata till X2 system (eller ekvivalent)	User_studie_fas3	Rapportering	56,59	Användarvänlighetskrav	Skickar mätt avvikelse samt PASS/FAIL till X2 system.
89	Mottag av test parameter input från X2 system (eller ekvivalent)	User_studie_fas3	Automatisering	59	Användarvänlighetskrav	När produkt ligger i sitt case kan den ta emot test parametrar. Dessa visas när caset öppnas.
90	Möjliggör batteriunderhåll utan specifik kompetens	Sjuksköterska 1	Undehåll	9	Funktionskrav	Laddning via case. Case laddas med USB-c
91	Erbjud referenspunkt för mätvärde-sida relation	Flera användare	Mv/S-Relation, Geoemtri, Avläsning	4,11	Användarvänlighetskrav	Armen som placeras vid kl 6 har färgad kant runt armen för att stå ut i jämförelse med de andra armarna.
92	Utför ny mätning vid ny exponering	User_studie_fas3		72	Användarvänlighetskrav	Produkten känner av när det utsätts för strålning. Har en alignment skett innan så beräknas avvikelse och presenteras till användaren.
93	Spara mätvärde-sida relation under flytt av produkten	Flera användare	Avläsning, Geoemtri, Mv/S-Relation	4,11	Användarvänlighetskrav	Mätvärden är placerade på armarna. tillsammans med referens arm och text riktning så bibehålls Mv/s relation under flytt.
94	Erbjuda visuell feedback för identifierad ljuskant	Tidigare krav/önskemål		71	Användarvänlighetskrav	Linje för ljusfält (gul) updateras vid alignment.
95	Möjliggör PASS/FAIL beslut utan distinkt plats för feedback	Tidigare krav/önskemål		44	Användarvänlighetskrav	PASS/FAIL beslut ges via basenhetens skärm. Var en dedikerad LED, men pga krav 49 så togs den bort

B

Appendix B - Usability Questionnaire

For the usability study in Phase 3 a questionaire was produced in order to have consistency in regards to data collected. For each individual prototype, the following was asked, in Swedish:

- På en skala från 1 till 100, där 100 är största möjliga, hur stor var den mentala belastningen av uppgiften? Hur mycket mental och perceptuell aktivitet krävdes? Var uppgiften lätt eller krävande, enkel eller komplex, krävande eller förlåtande?
- På en skala från 1 till 100, där 100 är största möjliga, hur stor var den fysiska och motoriska belastningen av uppgiften? Hur mycket fysisk aktivitet och finmotorik krävdes? Var uppgiften lätt eller krävande? Långsam eller rask? Pillig eller smidig?
- På en skala från 1 till 100, där 100 är största möjliga, hur stor var den tidsmässiga belastningen av uppgiften? Hur mycket tidspress kände du på grund av den takt eller det tempo i vilket uppgifterna eller uppgiftselementen utfördes? Var tempot långsamt och avslappnat eller snabbt och hektiskt?
- På en skala från 1 till 100, där 100 är största möjliga, hur frustrerande var uppgiften? Hur osäker, modfälld, irriterad, stressad och irriterad kontra trygg, tillfredsställd, nöjd, avslappnad och självbelåten kände du dig under uppgiften?
- På en skala från 1 till 100, där 100 är största möjliga, hur ansträngande var uppgiften? Hur hårt var du tvungen att arbeta (mentalt och fysiskt) för att uppnå din prestationsnivå?
- På en skala från 1 till 100, där 100 är bästa möjliga, hur väl upplevde du att du presterade i uppgiften? Hur framgångsrik tror du att du var med att uppnå målen för uppgiften som försöksledaren (eller dig själv) satte upp? Hur nöjd är du? *For this question, the answer was noted as 100 - [the participants answer] to be consistent with the method but easy to understand for the participant*
- På en skala från 1 till 7, där 7 är högsta möjliga grad, i hur stor grad upplevde du att prototypen hjälpte dig att hålla koll på vilket mätvärde som hörde till vilken sida

- På en skala från 1 till 7 där 1 är portabel och 7 är stationär, var skulle du placera prototypen?
- På en skala från 1 till 7 där 1 är enkel och 7 är komplicerad, var skulle du placera prototypen?
- På en skala från 1 till 7 där 1 är smidig och 7 är klumpig, var skulle du placera prototypen?

After all prototypes had been tested, the following was asked:

- Rangordna de 4 prototyperna baserat på hur mycket du gillade deras geometri.
- Förklara varför du rangordnade som du gjorde.
- Rangordna de 4 prototyperna baserat på hur mycket du gillade deras avläsning.
- Förklara varför du rangordnade som du gjorde.

C

Appendix C - Usability Results

The results from the quantitative analysis are presented in this chapter. Each participant performed testing with each concept, and so results from each test is presented. Results follow on the next page.

Deltagare	Prototyp	Ordning	Tid	Mental belastning, 1-100	Fysisk belastning, 1-100	Tidsmässig belastning, 1-100
Student 1	Extendo	1	03:44	35	1	20
Student 1	Fyra Ostar	2	02:24	10	5	10
Student 1	Butterfly	3	01:49	10	10	20
Student 1	Bläckfisken	4	01:31	1	1	1
Student 2	Butterfly	1	01:44	20	10	1
Student 2	Extendo	2	02:23	75	20	1
Student 2	Fyra Ostar	3	02:07	20	5	1
Student 2	Bläckfisken	4	01:17	10	10	10
Student 3	Fyra Ostar	1	03:41	20	1	1
Student 3	Extendo	2	04:00	50	10	20
Student 3	Butterfly	3	04:14	30	1	1
Student 3	Bläckfisken	4	01:47	1	1	1
Student 4	Bläckfisken	1	04:58	70	25	20
Student 4	Fyra Ostar	2	06:15	75	10	50
Student 4	Butterfly	3	04:55	20	15	5
Student 4	Extendo	4	03:05	1	20	1
Student 5	Extendo	1	03:51	55	10	40
Student 5	Bläckfisken	2	01:33	20	5	20
Student 5	Fyra Ostar	3	01:58	40	30	15
Student 5	Butterfly	4	01:41	40	45	10
Student 6	Fyra Ostar	1	06:34	60	30	30
Student 6	Bläckfisken	2	03:54	40	20	20
Student 6	Extendo	3	03:33	40	30	20
Student 6	Butterfly	4	02:42	50	60	40
Student 7	Bläckfisken	1	01:59	10	10	20
Student 7	Butterfly	2	02:00	10	15	20
Student 7	Fyra Ostar	3	01:57	5	15	10
Student 7	Extendo	4	02:48	40	25	20
Student 8	Butterfly	1	01:48	15	20	5
Student 8	Bläckfisken	2	01:17	20	20	25
Student 8	Extendo	3	02:01	50	28	15
Student 8	Fyra Ostar	4	01:41	60	10	15
Ingenjör 1	Bläckfisken	1	NA	40	20	20
Ingenjör 1	Extendo	2	NA	60	60	60
Ingenjör 1	Butterfly	3	NA	40	30	40
Ingenjör 1	Fyra Ostar	4	NA	40	60	50
Ingenjör 2	Fyra Ostar	1	NA	30	35	40
Ingenjör 2	Bläckfisken	2	NA	20	20	20
Ingenjör 2	Butterfly	3	NA	20	20	40
Ingenjör 2	Extendo	4	NA	20	45	50
Ingenjör 3	Butterfly	1	NA	30	10	30
Ingenjör 3	Extendo	2	NA	30	20	20
Ingenjör 3	Bläckfisken	3	NA	20	20	10
Ingenjör 3	Fyra Ostar	4	NA	30	20	15

Deltagare	Prototyp	Frustration, 1-100	Ansträngning, 1-100	Prestation, 1-100, lägre är bättre
Student 1	Extendo	35	20	70
Student 1	Fyra Ostar	5	20	30
Student 1	Butterfly	5	5	25
Student 1	Bläckfisken	1	1	1
Student 2	Butterfly	5	5	5
Student 2	Extendo	25	20	50
Student 2	Fyra Ostar	1	5	25
Student 2	Bläckfisken	1	1	25
Student 3	Fyra Ostar	20	1	20
Student 3	Extendo	60	55	70
Student 3	Butterfly	65	45	45
Student 3	Bläckfisken	1	1	1
Student 4	Bläckfisken	10	5	70
Student 4	Fyra Ostar	60	65	75
Student 4	Butterfly	10	20	15
Student 4	Extendo	1	25	10
Student 5	Extendo	15	35	23
Student 5	Bläckfisken	5	15	15
Student 5	Fyra Ostar	15	20	15
Student 5	Butterfly	20	10	40
Student 6	Fyra Ostar	40	30	30
Student 6	Bläckfisken	20	20	20
Student 6	Extendo	20	20	10
Student 6	Butterfly	30	40	25
Student 7	Bläckfisken	20	25	20
Student 7	Butterfly	15	10	15
Student 7	Fyra Ostar	1	5	10
Student 7	Extendo	25	40	15
Student 8	Butterfly	35	20	20
Student 8	Bläckfisken	30	10	15
Student 8	Extendo	30	35	30
Student 8	Fyra Ostar	70	50	80
Ingenjör 1	Bläckfisken	27	30	10
Ingenjör 1	Extendo	50	60	40
Ingenjör 1	Butterfly	30	30	20
Ingenjör 1	Fyra Ostar	40	50	30
Ingenjör 2	Fyra Ostar	65	20	50
Ingenjör 2	Bläckfisken	20	20	25
Ingenjör 2	Butterfly	20	25	25
Ingenjör 2	Extendo	20	35	25
Ingenjör 3	Butterfly	30	20	40
Ingenjör 3	Extendo	30	20	40
Ingenjör 3	Bläckfisken	15	10	30
Ingenjör 3	Fyra Ostar	25	30	50

Deltagare	Prototyp	Märvärde-sida-relation, 1-7	1 Portabel - 7 Stationär	1 Enkel - 7 Komplicerad
Student 1	Extendo	1	1	4
Student 1	Fyra Ostar	7	1	2
Student 1	Butterfly	2	3	1
Student 1	Bläckfisken	4	2	1
Student 2	Butterfly	5	1	3
Student 2	Extendo	5	1	4
Student 2	Fyra Ostar	7	1	2
Student 2	Bläckfisken	4	1	3
Student 3	Fyra Ostar	7	1	3
Student 3	Extendo	3	1	5
Student 3	Butterfly	5	1	5
Student 3	Bläckfisken	7	1	1
Student 4	Bläckfisken	6	3	2
Student 4	Fyra Ostar	6	2	5
Student 4	Butterfly	6	1	1
Student 4	Extendo	7	1	2
Student 5	Extendo	7	2	4
Student 5	Bläckfisken	7	2	1
Student 5	Fyra Ostar	4	2	3
Student 5	Butterfly	6	1	1
Student 6	Fyra Ostar	7	1	3
Student 6	Bläckfisken	6	1	2
Student 6	Extendo	6	1	3
Student 6	Butterfly	6	1	3
Student 7	Bläckfisken	6	2	2
Student 7	Butterfly	6	1	2
Student 7	Fyra Ostar	7	2	3
Student 7	Extendo	6	1	5
Student 8	Butterfly	6	1	2
Student 8	Bläckfisken	5	1	3
Student 8	Extendo	4	1	5
Student 8	Fyra Ostar	1	5	5
Ingenjör 1	Bläckfisken	5	3	3
Ingenjör 1	Extendo	2	5	4
Ingenjör 1	Butterfly	4	2	2
Ingenjör 1	Fyra Ostar	5	3	3
Ingenjör 2	Fyra Ostar	5	3	5
Ingenjör 2	Bläckfisken	6	2	2
Ingenjör 2	Butterfly	3	1	3
Ingenjör 2	Extendo	5	2	4
Ingenjör 3	Butterfly	2	2	2
Ingenjör 3	Extendo	4	2	2
Ingenjör 3	Bläckfisken	6	5	2
Ingenjör 3	Fyra Ostar	3	2	4

Deltagare	Prototyp	1 Smidig - 7 Klumpig	Rank, geometri	Rank, avläsning
Student 1	Extendo	3	4	3
Student 1	Fyra Ostar	2	2	4
Student 1	Butterfly	2	3	1
Student 1	Bläckfisken	1	1	2
Student 2	Butterfly	2	2	3
Student 2	Extendo	3	4	2
Student 2	Fyra Ostar	2	1	1
Student 2	Bläckfisken	4	3	4
Student 3	Fyra Ostar	1	2	4
Student 3	Extendo	4	3	3
Student 3	Butterfly	4	4	1
Student 3	Bläckfisken	2	1	2
Student 4	Bläckfisken	1	3	2
Student 4	Fyra Ostar	3	4	4
Student 4	Butterfly	2	2	3
Student 4	Extendo	1	1	1
Student 5	Extendo	4	4	1
Student 5	Bläckfisken	2	1	3
Student 5	Fyra Ostar	1	3	2
Student 5	Butterfly	1	2	4
Student 6	Fyra Ostar	2	2	1
Student 6	Bläckfisken	2	1	4
Student 6	Extendo	1	3	2
Student 6	Butterfly	1	4	3
Student 7	Bläckfisken	3	2	1
Student 7	Butterfly	2	3	2
Student 7	Fyra Ostar	3	1	4
Student 7	Extendo	4	4	3
Student 8	Butterfly	3	2	1
Student 8	Bläckfisken	4	1	2
Student 8	Extendo	1	3	3
Student 8	Fyra Ostar	3	4	4
Ingenjör 1	Bläckfisken	3	1	2
Ingenjör 1	Extendo	3	4	3
Ingenjör 1	Butterfly	2	2	1
Ingenjör 1	Fyra Ostar	3	3	4
Ingenjör 2	Fyra Ostar	4	4	4
Ingenjör 2	Bläckfisken	2	3	1
Ingenjör 2	Butterfly	1	1	2
Ingenjör 2	Extendo	2	2	3
Ingenjör 3	Butterfly	2	4	2
Ingenjör 3	Extendo	3	3	4
Ingenjör 3	Bläckfisken	3	1	1
Ingenjör 3	Fyra Ostar	3	2	3

D

Appendix D - User Profiles

For each performed data collection in Phase 1, a user profiles was created. This profile included perceived system goal, task description, work title, what tools they use and a collection of comments regarding current DXR+ usage. The data from five users and one stakeholder was synthesized as user profiles.

Ingenjör 1

Röntgeningenjör | Konventionella, CT & C-båge | DXR & Kopparplattor | Ansvar ● ● ○

Mål: Kontrollmätning av strålfält

Uppgift: Kontrollmätning av strålfält

Kontakt: Kan kontakta igen

Gillar verktyg man bara kan ta fram och använda
(Om verktyg) Enkel och snabb är bra, avancerade krångliga är inte bra
Bra att man inte behöver koppla upp DXR på något vis
Om något gjorts som kan påverka stråldos → kontakta fysiker
DXR används 10-12 ggr per år
Jobbigt att behöva göra flera exponeringar
20×20 fält för mätningar
Rapporterar vanligtvis endast OK eller EJ OK, inte inidividuella mätvärden
"Känner maskinerna väl"
Gör man allt noga så fastnar man i det
Arbetar själv men tar kontakt med kollega vid åtgärdsbehov
Nöjd ifall resultatet av mätningen är 0 avvikelse
Har hänt att man lagt den på fel håll
Hade uppskattat att själv bestämma när mätvärdet försvinner o DXR är redo för ny exponering
"Det är lite synd att man inte kan byta batteri på den"
Svårt att lita på en direkt PASS/FAIL analys från maskinen

Sjuksköterska 1

Onkologisjuksköterska | Konventionella | DXR & X2 | Ansvar ● ● ○

Mål: Fältet ska ligger inom tolerans

Kontakt: Kan kontakta i april för vidare frågor och funderingar

- Ställer in 30×30 ljusfält för all kalibrering [X2 och DXR]
- Sätter SID till 1 meter
- manuell input till rapporteringsmall är bra
- Vill inte ha automatisk input från DXR till rapporterings mall, de blir bökigt
- RaySafe view kan krångla med GDPR, säkerhet etc.
- Är nöjd med mätvärdet ligger inom gränsen (1% av SID)
- Mätningen ska inte ta för lång tid
- Mätning tar från patient tid
- Förväntar sig att DXR funkar när det är dags
- Använde fluorescerande skärm - 4 mätningar direkt - avläsning i mörker - inte bra
- Tekniker får alltid resultat av uppgiften
- Går alltid tillsammans med fysiker när man gör mätningar igen - innan någon annan kontaktas
- Kontaktar alltid först fysiker ifall något är fel
- 2 parametrar: SID och mätning av sidor
- Använder sjukhusets egna rapportmallar
- Riktningsberoende kan vara ett problem
- Att mätvärdet försvinner antyder att produkten är redo för nästa exponering
- Mätvärden i 0.25, mer exakt behövs inte
- Hade varit bra att få en siffra direkt vid avläsning

- Användning vid årskontroll, kontroll efter service
- SID avläses med ett måttband (på maskinen)
- Använder 2 DXR för att minska antal mätningar
- Kan stoppa i X2 väskan
- 2 mätningar samtidigt hade varit bra
- Mäter mot-bort och vänster-höger
- Använder sjukhusets uppsättning produkter (X2 och DXR)
- Kontroller utstritt över året
- Planerar mätning 2 månader i förväg
- Avläsa batteritid hade varit bra
- Byta batteri själv hade varit bra
- Tidsfönster för avläsning är OK
- Jobbigt att springa fram och tillbaka mellan avläsningar
- Alignment fungerar bra [Sätter den i ljusfältet och skjuter utåt för att hitta kanten]
- Mätvärde kan vara najs att de sparas, men vitkigt att veta vilket värde som tillhör vilken sida
- Vill kunna benämna vilka sida som är vilken, frihet att bestämma ordning av mätning
- CT mätning görs bara vid leverans

Gå in → Tänd ljusfält → Mät SID → Lägg DXR på plats → Align nollställe → Gå ut → Gör exponering → Gå in → Läs av värde → Kom ihåg värde och sida → Gå ut → Dokumentera mätvärde i excel

x2 (Lägg DXR på plats – Align nollställe)

x2 (Gå in – Dokumentera mätvärde i excel)

Product Manager

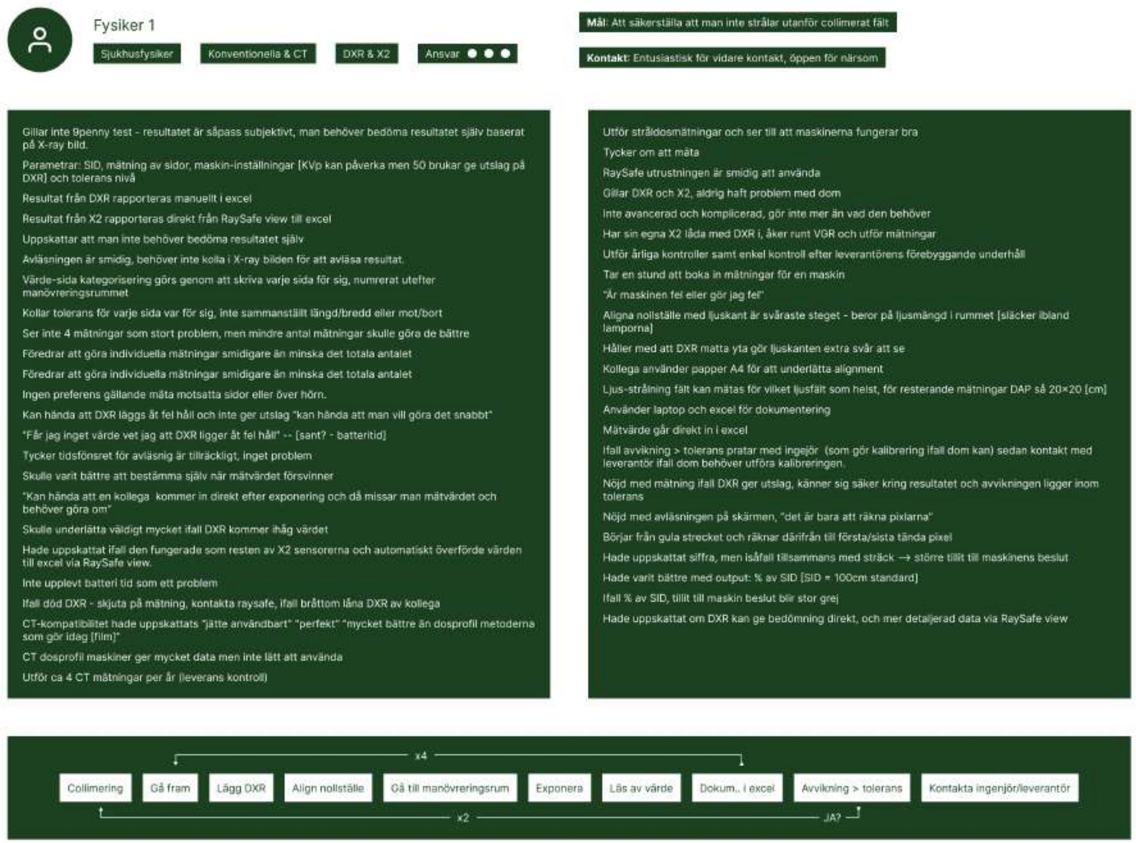
Säkerhetsanalys | Kvalitetsfrågor | Applikations- och produktspecialist

Mål: ????

Kontakt: Kan kontakta igen

- Ljus-och röntgenfält mätning är ett viktigt test
- RaySafe måste erbjuda en produkt med den funktionaliteten för att vara ledande aktör i QA marknaden
- DXR är gammal och ser potential att förbättra den utifrån ett användarperspektiv
- DXR har en viktigt roll i QA aktiviteten som användarna utför
- DXR måste erbjuda ljus-röntgenfält mätning standalone
- Hade varit bra ifall användningen fick högre värde när DXR används tillsammans med X2
- Implementera DXR med X2 och dess rapporteringsflöde hade underlättat för användarna
- Ska säljas till nya kunder samt till existerande kunder som uppgradering
- Bättre implementering med X2 kan skapa bättre argument för existerande DXR kunder att uppdatera
- En ny DXR behöver ersätta den gamla
- En produkt som "fungerar" i Sverige kommer antagligen fungera på internationell marknad
- Användargrupp är personer som arbetar utefter lagkrav, inte fysiker som vill göra det exakt för sakens skull
- Användarvänlighet har prio över utökad funktionalitet
- Utökad funktionalitet är intressant, så länge ökad belastning på användningen är inom rimliga gränser
- Ge användaren maximal output baserat på minimal input
- Låsa fast DXR till fasta input (SID & tolerans) inte ett alternativt
- Produkten behöver vara "dum" eller flexibel

- Behöver erbjuda funktionalitet för användare med imperial och metric enheter.
- Enhet kan variera beroende på maskin som används
- Vissa kunder skickar in DXR på eget bevåg, RaySafe gör mkt enkla funktions tester
- X2 systemet behöver skickas in på kalibrering (kan va interessant vid högre implementerings grav av DXR i X2 systemet)
- Möjliggör batteribyte/underhåll utan att öppna upp produkten
- RaySafe säljer till serviceingenjör kopplade till leverantör eller oberoende serviceorganisation
- Snea sidor är inte ett problem, goda toleranser svarar för detta
- CT - erbjuda mätning av dosprofil från roterande källa
- CT - högre upplösning på mätning [CT dosprofil kan vara nere vid 1-2cm bred]
- C-båge lurigt - behöver veta mer kring krav från kliniskt perspektiv.
- Möjliggöra resultat synliga på röntgenbild ?
- Säkerställa att vitala komponenter inte kontinuerligt utsätts för stora mängder strålning.


Fysiker 1
Sjukhusfysiker
Konventionella & CT
DXR & X2
Ansvar
Mål: Att säkerställa att man inte strålar utanför collimerat fält
Kontakt: Entusiastisk för vidare kontakt, öppen för närsom
Gillar inte 9penny test - resultatet är såpass subjektivt, man behöver bedöma resultatet själv baserat på X-ray bild.
Parametrar: SID, mätning av sidor, maskin-inställningar [KVp kan påverka men 50 brukar ge utslag på DXR] och tolerans nivå
Resultat från DXR rapporteras manuellt i excel
Resultat från X2 rapporteras direkt från RaySafe view till excel
Uppskattar att man inte behöver bedöma resultatet själv
Avläsningen är smidig, behöver inte kolla i X-ray bilden för att avläsa resultat.
Värde-sida kategorisering görs genom att skriva varje sida för sig, numrerat utefter manövreringsrummet
Kollar tolerans för varje sida var för sig, inte sammanställt längd/bredd eller mot/bort
Ser inte 4 mätningar som stort problem, men mindre antal mätningar skulle göra de bättre
Föredrar att göra individuella mätningar smidigare än minska det totala antalet
Föredrar att göra individuella mätningar smidigare än minska det totala antalet
Ingen preferens gällande mäta motsatta sidor eller över hörn.
Kan hända att DXR läggs åt fel håll och inte ger utslag "kan hända att man vill göra det snabbt"
"Får jag inget värde vet jag att DXR ligger åt fel håll" -- [sant? - batteritid]
Tycker tidsfönsret för avläsnig är tillräckligt, inget problem
Skulle varit bättre att bestämma själv när mätvärdet försvinner
"Kan hända att en kollega kommer in direkt efter exponering och då missar man mätvärdet och behöver göra om"
Skulle underlätta väldigt mycket ifall DXR kommer ihåg värdet
Hade uppskattat ifall den fungerade som resten av X2 sensorerna och automatiskt överförde värden till excel via RaySafe view.
Inte upplevt batteri tid som ett problem
Ifall död DXR - skjuta på mätning, kontakta raysafe, ifall bråttom låna DXR av kollega
CT-kompatibilitet hade uppskattats "jätte användbart" "perfekt" "mycket bättre än dosprofil metoderna som gör idag [film]"
CT dosprofil maskiner ger mycket data men inte lätt att använda
Utför ca 4 CT mätningar per år (leverans kontroll)
Utför stråldosmätningar och ser till att maskinerna fungerar bra
Tycker om att mäta
RaySafe utrustningen är smidig att använda
Gillar DXR och X2, aldrig haft problem med dom
Inte avancerad och komplicerad, gör inte mer än vad den behöver
Har sin egna X2 låda med DXR i, åker runt VGR och utför mätningar
Utför årliga kontroller samt enkel kontroll efter leverantörens förebyggande underhåll
Tar en stund att boka in mätningar för en maskin
"Är maskinen fel eller gör jag fel"
Aligna nollställe med ljuskant är svåraste steget - beror på ljusmängd i rummet [släcker ibland lamporna]
Håller med att DXR matta yta gör ljuskanten extra svår att se
Kollega använder papper A4 för att underlätta alignment
Ljus-strålning fält kan mätas för vilket ljusfält som helst, för resterande mätningar DAP så 20×20 [cm]
Använder laptop och excel för dokumentering
Mätvärde går direkt in i excel
Ifall avvikning > tolerans pratar med ingejör (som gör kalibrering ifall dom kan) sedan kontakt med leverantör ifall dom behöver utföra kalibreringen.
Nöjd med mätning ifall DXR ger utslag, känner sig säker kring resultatet och avvikningen ligger inom tolerans
Nöjd med avläsningen på skärmen, "det är bara att räkna pixlarna"
Börjar från gula strecket och räknar därifrån till första/sista tända pixel
Hade uppskattat siffra, men isåfall tillsammans med sträck → större tillit till maskinens beslut
Hade varit bättre med output: % av SID [SID = 100cm standard]
Ifall % av SID, tillit till maskin beslut blir stor grej
Hade uppskattat om DXR kan ge bedömning direkt, och mer detaljerad data via RaySafe view
x4
Collimering
Gå fram
Lägg DXR
Align nollställe
Gå till manövreringsrum
Exponera
Läs av värde
Dokum.. i excel
Avvikning > tolerans
Kontakta ingenjör/leverantör
x2
JA?

Fysiker 2

Sjukhusfysiker | Konventionella, CT & C-båge | Fantom | Ansvar ● ● ●

Mål: Att säkerställa att man inte strålar utanför collimerat fält

Kontakt: Oklart, ingenjörerna va down att prata igen

- Fantom är bättre för det ger mycket information på en exponering
- Tycker informationen på fantomen är tillräcklig
- Svårt att aligna fantom med ljuskant
- hade uppskattat om DXR var CT-kompatibel
- CT kan vara upp till 16 cm bred
- Bökigt att mäta CT idag
- C-båge har inget ljusfält - DXR går ej att använda
- Ifall DXR resultatet går att se i röntgenbilden - C-båge kompatibel??
- Ljusfältet är inte alltid aktivt under exponering
- Föredrar visuell uppskattning över numerisk exakthet. Ifall visuell uppskattning indikerar fel → gör exakt mätning med linjal
- DXR är bara kompatibel med konventionella maskiner
- Konventionella maskiner används mindre o mindre
- Litar inte på DXR "punkt"-mätning
- Tyckte fantomen är smidig att bära med sig
- Jobbar med fantom för andra mätningar, så den är smidigt att göra ljus/röntgen-fält mätningar med också

- Kontrollverksamhet är en lite del av arbetet
- Tycker inte det är jätte kul med kontroll
- Gillar mätprober, dom mäter mycket i samma veva
- Använder gemensamma verktyg
- Årskontroller + vid behov
- Börjar mer och mer förlita sig på leverantörens kontroller
- Ljusfält 20×20
- Antecknar avvikelsen i internt produktspecifict program, rapporterar ifall det ligger utanför tolerans.
- Upplever att det sällan ligger utanför tolerans
- Gillar inte att man behöver göra 4 exponeringar med DXR
- Föredrar att se resultat i röntgenbilden
- Röntgenbild, röntgenfält, ljusfält som är relevanta.
- Röntgenfältet kan ligga utanför röntgenbilden
- Vill se ifall kanterna är snea

Collimering → Placera fantom → Align med ljusfält → Gå till manövreringsrum → Exponera → Avläs röntgen bild → Bedöm avvikelse visuellt → Avvikning > tolerans → JA? → Utför mer exakt mätningsekvens

Sjukhusfysiker 3

Sjukhusfysiker | Konventionella | DXR & X2 | Ansvar ● ● ●

Mål: Kolla så maskinen står emot IEC standard, om inte mer noggrant

Uppgift: Kontrollmätning av strålfält

Kontakt: Kan kontakta igen: fredrik.wellman@regionblekinge.se

DXR ger bra indikation om något är knasigt
DXR är viktigast vid leveranskontroll
Laptop är det främsta verktygen man har
DXR ger värden med rimlig upplösning
DXR utgör en liten roll av allt det man undersöker
DXR har liten formfaktor så den följer med
DXR används 10-12 gånger per år
DXR används max en gång per år helt själv
Tycker IEC standard är för generös, godtar sällan om det över 1%
Använt 2 DXR, tyckte det var super
Jobbigt att aligna DXR med ljuskant - SVÅRT ATT VARA EXAKT
Jobbigt att behöva göra flera exponeringar
Kollar på skuggan på skärmen för att aligna
20×20 fält för mätningar, använder samma fält som för andra mätningar
Rapporterar inte alltid alla mätvärden, ibland säger bara "inom tolerans"
Vill ha central roll i beslutsfattande gällande OK eller EJ OK avvikelse
"Känner maskinerna väl"

Arbetar själv men tar kontakt med kollega vid åtgärdsbehov
Mycket resultatorienterad när det kommer till nöjdhet
DXR har smiley i detektorn ?
SID - är det toleranser är satt efter
Exponeringstabell - för att ställa in rätt dos så DXR ger utslag.
Tar hellre fler sidor per exponering om formfaktor bibehålls
Nice om DXR håller koll på vilka sidor som mäts
Har hänt att man lagt den på fel håll
Tiden är generellt generös memn hade varit najs att kunna spara värdet
Hade varit najs att programmera själv när mätvärdet försvinner
Behöver ibland tänka för att få ut mätvärde, 2,5 + 2,5
"Visste inte att RaySafe kunde byta batterier"
Aldrig varit med om batteriproblem men nice om man kunde byta själv
Svårt att lita på en direkt PASS/FAIL analys från maskinen
Bestämma över PASS/FAIL parametrar
Behöver känsla av kontrokll för att lita på PASS/FAIL samt insikt i processen (exakt mätvärden etcc)
CT kanske användbart, men osäker
Viktigt att DXR biubehåller sin stand-alone funktion
Det kan finnas extra funktionalitet men som som inte behöver använda

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY