Design of an oral surgery simulator

Human-centered design study and implementation on a surgery simulator.

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Alexander Jonsson, Martin Husell
Abstract

The company Forsslund Systems has developed a simulator for oral surgery training. The simulator, named Kobra, uses detailed virtual models of surgical situations, spatial haptics and a co-located stereoscopic display to provide an environment in which students can practice surgical techniques. Four years after the introduction of the Kobra a need was recognized for a new hardware design that satisfies the customers expectations on visual appearance and hardware refinement and that aims to improve the experience for the end users. This report describes the design development process of the new enclosure, that had a focus on human-centered design, brand management and small-scale manufacturing. Inspired by findings from a comprehensive user study, conducted at a teaching hospital in Riga and relevant literature, as well as the results of prototyping and testing, the new design of the Kobra aims to improve the usability and market attractiveness of the product offering. This while being tailored to utilize the manufacturing technologies available to a small-scale in-house or out-sourced production team. A full-scale functioning prototype of the concept was built in-house, using the proposed means of manufacture, demonstrating a design that is close to ready for production.

Keywords: surgery simulator, spatial haptics, co-located display
Sammanfattning


Nyckelord: kirurgisimulator, 3D-haptik, samlokaliserad skärm
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Alexander Jonsson & Martin Husell
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ambidexterity is the state of being equally adapted in the use of both the left and the right hand.

colocation matching the physical space with a visual representation to create an immersible environment.

elevator A surgical instrument used to luxate and remove teeth and roots that cannot be engaged by the beaks of forceps, or to loosen teeth and roots before forceps application.

forceps An instrument resembling a pair of pincers or tongs, used for grasping, manipulating, or extracting, especially such an instrument used by a surgeon.

haptic (often referred to as 'haptic feedback') is a technology that allows users to 'feel' something has been done in an interface because of some mechanical feedback.

immersion state of being deeply engaged or involved; absorption.

manipulandum something that is manipulated physically. -the physical instrument the user holds with their hand and which is connected to the haptic device, i.e. its 'handle'

maxillofacial Pertaining to the jaws and face, particularly with reference to specialized surgery of this region.

mesioangular (dentistry) Angled fully 90 degrees sideways. A mesioangular impacted tooth.

mesiodens A supernumerary tooth located in the midline of the anterior maxillae, between the maxillary central incisor teeth.

spatial relating to, occupying, or having the character of space.

stereoscopy is a technique for creating or enhancing the illusion of depth in an image by means of stereopsis for binocular vision.
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Chapter 1

Introduction

New simulator technologies are being developed, with the aim of solving some of the problems and limitations associated with the practices of traditional medical education. One such effort, directed at improving oral surgery training, has been made by the small research and development company Forsslund Systems [1], that is based in Stockholm, Sweden. Their oral surgery simulator, named Kobra, features state-of-the-art computer models of surgical situations, a co-located stereoscopic display and a haptic feedback interface, that combine to enable its users to practice advanced surgical techniques, in a realistic and immersive virtual environment.

As of the start of this project, the company has produced a total of five units, four of which have been sold to Rīga Stradiņš University (RSU), a teaching hospital in Riga, Latvia. The systems technical backbone supports a high level of functionality, but a redesign of the enclosure could be made to better reflect the maturity of the technology inside. The outer enclosure, of the original Kobra, consists of a wooden cabinet built by a furniture maker, see Figure 1.1 on page 2.

After the product having been on the market and in use for four years, a need was recognized for an upgraded enclosure, to meet the expectations on visual appearance and hardware refinement, that the most demanding university hospital customers have of a modern high-end medical device. Following from this need, as a master’s thesis project, conducted by two students from the Royal Institute of Technology in Stockholm, a redesigned enclosure for the simulator was developed.
Chapter 1. Introduction

1.1 Background

Historically, learning the practices of medicine have required extensive hands-on experience in clinical training. The dominating method for transferring the trade skills of surgery, specifically, to aspiring practitioners has been and continue to be real-world practice on actual patients. This method carries unwanted side effects, such as an increased risk of harming the patient and a dependency on a supply of patients with specific afflictions. New tools, combining spatial haptic interaction technology with virtual reality components, are being developed to solve some of those issues and to advance the medical education system.

Today, surgery simulators are increasingly utilized [2] as tools for educating students and training practicing surgeons. These types of simulators relies on specialized software and hardware to provide safe virtual environments, where the users can experience scenarios, that closely resembles the real-world conditions of surgical procedures, without requiring the resources and involving the risks associated with real operations.
The surgery simulator produced by Forsslund Systems gives its users an opportunity to immersively engage as a surgeon in realistic representations of surgical procedures. While viewing an anatomically detailed model of the patient in 3D, through a high definition stereoscopic display, the user can simultaneously experience a convincing tactile response, closely resembling that of using the surgeons tools in real life. Manipulating the tool in their hand moves both an on-screen representation of the tool and the articulated arm of a haptic device. In the same time, the handle, known as the manipulandum, mounted on a haptic device, provides real-time force-feedback, to simulate the feeling of using the tool on the patient. The user is not looking directly at the monitor, but instead downwards through a mirror. This extends the focal plane from the tilted monitor above, so as to align the graphical interface with the physical counterparts underneath the mirror. The effect is called co-location and is one of the key concepts implemented to create the immersive simulation.

In research conducted during his PhD studies Jonas Forsslund found that the best results were achieved when a student conducted the exercises together with a practicing surgeon, who could give live feedback and guide the students to a successful procedure. Often the teacher would use his own body, to aid in showing where and how the patient would be positioned in an equivalent real-life scenario. In some cases, where some contextual information about the patient case was missing from the exercise, the student and teacher would make up a background scenario to make the simulation as vivid as possible. These reifying practices, conducted around the simulator, creates a state of immersion, that can improve the students learning.

An effort to commercialize the extensive knowledge acquired in the PhD studies of Jonas Forsslund lead to a series of simulators called Kobra. Four of which were sold to RSU. Since then, the company has continued to develop and improve the different subsystems of the machine, mainly focusing on the software and creating new exercises, but some work has also been directed at developing new haptic hardware. The encapsulation of the machine, a painted wooden cabinet created by a local furniture maker, remains largely unchanged since the first release of the simulator. The 2013 edition of the Kobra, in use at RSU, lacks the ability to adjust the elevation of the workspace, which entails that shorter students need to stand on a small step stool to reach the appropriate height needed to operate the machine. However, this was solved in a redesigned version in 2016, by the introduction of a height-adjustable stand.

In early conversations with some potential customers, the visual appearance of the enclosure was proven to be a determining factor in the effort of selling the product. The outdated styling, rough finish and crude materials of the original simulator failed on occasion to inspire confidence towards the product in the most demanding university hospital clients, who expect a high emphasis on visual appearance and hardware refinement in any modern high-end medical device. A need was recognized for a new hardware design that could provide a visual appearance that communicates a level of refinement that matches that of the advanced software inside and that is appropriate for a product of the high price point of the Kobra. Further, an effort in developing new hardware
would be an opportunity to improve the experience for the end user, that would in the end increase the value of the product.

1.2 Purpose

The thesis was grounded in a real-world product development case, where the solution was dependent on aspects from human-centered design, brand management and small scale manufacturing.

The first purpose of the study was to research if and how established design strategies and solutions, from the field of human factors in the development of medical equipment, can be implemented in the design process of a surgery simulator. Also any relevant insights acquired from a user study, evaluating the design of the current version of the simulator and identifying properties of the simulator that are important to the users, was to be considered in the development of the new design. To build on the work that has lead up to the latest iteration of the simulator, the aim of the user study was to gain understanding of how the current version of the simulator was used in a learning environment and what possibilities there were to improve the user experience and learning process. This to build a human-centered starting point for the subsequent design development. Another aim was to compare the Kobra to the Moog Simodont dental simulator [3], a competitor that was also used at the university, as well as mechanical alternatives, that uses disposable prosthetic teeth.

The end goal was to propose a design solution that applies elements from existing human factors research to improve the learning experience of the end user and that meets the user-derived requirements, while integrating the technologies already existing in the current version of the simulator or components that are found to be superior.

Secondly, the purpose was also to identify what manufacturing solutions are most suitable for a small series production of the new version of the simulator and test how well the suggested production methods would suit the new design by building a full scale functioning prototype.

Finally, the purpose was also to investigate how to use brand management in the product development process to strategically highlight key features of the offering in both the design and, if time permitted, the marketing language. The solution was to display a distinct and appealing design that aims to strengthen the Forsslund Systems brand and differentiate the product, so as to provide a competitive advantage on the market. This should be done by using industrial design to improve the visual appeal of the product, in terms of better representing the advanced technology inside and the value of the product as a learning tool, in the eyes of both end users and potential customers.
1.3 Delimitations

The thesis will not take into consideration producing complete technical drawings needed to manufacture the product in the future. It will not deliver any detailed information regarding production methods for the different parts. It will however supply the reader with suggestions as to how these parts could be manufactured without the use of high-cost toolmaking for injection molding etc. The haptic device intended for the final concept will not be designed as a part of this thesis, a CAD mock-up will however be used in order to avoid conflicting parts when the new haptic device is realized. The final design was not to be evaluated, by another user study, as part of the project.

1.4 Methodology

A crucial first step in the development process of the new design solution for the Kobra simulator, was to perform a pre-study, that could build a foundation for the design with detailed knowledge linked to the product in the concept development phase. The pre-study consisted of searching through research articles within the fields of spatial haptic simulators and medical aesthetics and ergonomics. The findings were condensed to the most important insights so that they could be considered during the design process.

An initial study of the previously published research by Jonas Forsslund [2] was performed, to gain knowledge about the research and development process that lead to the current version of the Kobra simulator. This was a way of gaining understanding of the core technologies of the Kobra simulator and the competing solutions.

After the pre-study phase of the project an interview guide for the user studies was produced with consideration to the gained insights. The process used for the entire entity of the project will be defined as a "Double Diamond" design process, starting with information gathering about the market and users, a ideation phase starting with clustering and sorting to converge followed by divergent concept generation to create a broad starting field and throughout the project work with converging methods to evaluate the different solutions and arrive at a final concept, rendering the best functions and qualities from all of the different ideas into one single product.

1.4.1 User Studies

With the essential knowledge of the Kobra simulator, a user study was prepared and conducted at the Riga Stradinš University (RSU) in Latvia, aimed to uncover new information about how the simulator was used that could be used to aid the design process of the new simulator. The user study included performing semi-structured interviews with both students, that had operated the Kobra, as well as their instructors. The studies in RSU also included observations of students and instructors using the
simulator, with the intent of revealing non-cognitive user patterns in the everyday use and practical limitations that might have existed along with the current version of the device, beyond that of the interviews. The university also uses mechanical simulators and simulators from the competitor Moog, which opened the question of why they were using three different systems and if they filled different purposes. The interviews would also serve as step in evaluating the current design of the Kobra simulator. If possible it would also be of great value to visit and observe real oral surgeries on live patients to map out the different similarities and differences between real surgery and simulations in order to bring another depth to the study.

1.4.2 Concept Development

In the concept development phase, the knowledge gained through the pre-study and user study was implemented to inform the design decisions that constituted the final concept.

The concept development process started with a divergent concept generation phase, where a number of distinct concepts were produced, that tried out different design paths and had potential of fulfilling the functional requirements. After the initial phase, the convergent development phase was initiated, where a few concepts, considered to have the best potential for satisfying both the requirements and desired attributes, were selected for further development. These concepts were refined to sufficient resolution so as to reveal any major inherent problems and served as accurate representations of what the final product would look like, for the purpose of being evaluated in cooperation the client.

A final concept was chosen based, in part, on response from the client and the thesis supervisor and was then further refined. The final design was presented as a full-scale functional prototype along with a Computer Aided Design (CAD) model of the product. Additionally, a investigation into the possible production techniques for a small series of the product was made.

1.5 Timeframe and Risk Assessment

The project took place over a 20-week period. With holidays like easter and the student event 'Quarnevalen' taken into account. See Appendix A for a detailed gantt-schedule. The project was aimed at presenting a complete report and conducting the presentation before the midsummer of 2017 but was delayed until the beginning of September that year.

A risk assessment was made in the initial phase of the project and can be viewed in Appendix B.
Chapter 2

Frame of Reference

The nature of the thesis project was heavily defined and influenced by medical technology, an area which was a new and rather unfamiliar field. With help from the client, the major competitors in the market were mapped out and saved for future reference. It became clear that Forsslund Systems, with their surgery simulator named Kobra, could possibly fill an existing gap in the market. The biggest competitor VoxelMan \[4\] which had a product setup with similar properties, had replaced it with a more basic configuration. The other big competitor, Moog \[3\] had a product with similar properties on the market but with a small monitor that limited the ability for trainers to take part in the simulation alongside the student to give advice, something that had proved to be a popular feature in the Kobra. These features that set the Kobra apart from the rest of the market needed to be pushed further, and highlighted in the Forsslund Systems brand identity in order to take a leading position in the market. From the research papers it was discovered that better results were accomplished in the simulations when the students and teachers played out scenarios alongside the simulation in order to build on the realism, like putting on scrubs, washing down and prepping like it would have been done for a real surgery. It was therefore considered important to make the simulator a part of the background in order to further push on the immersion of the simulation. After meeting with the client and supervisor it became apparent that the company also was in need of a manufacturing strategy suitable for smaller series of production. The project was therefore divided into three main parts;

1. Improving the design through user-centered design methods.
2. Developing a design that can strengthen the brand of the company.
3. Research manufacturing methods for small scale production runs.

Another aspect that arose during the background study was the fact that the company’s preference for open-source could be shaped into one of the features of the simulator. Even though features like audible feedback or tactile vibratory feedback was not supported by
the existing software, it could possibly be built into the device in order to prepare it for future software updates or even customer additions.

2.1 Research Articles

The focus of the three week long initial research phase was to gain understanding of how simulators are used in medical education and what established design strategies and rules of thumb, from the fields of interaction design and human factors design, could be worth considering in the subsequent design process. Further, an aim was to find out what integrating spatial haptics implies to the design of a simulator and another was to find appropriate methods that could be used in a user study involving the original Kobra simulator.

2.1.1 Simulators in Medical Education

The medical industry has in the last century made significant advancements in developing and implementing new technology, not lest in medical training. Medical simulators have in recent years been developed to meet the needs from health care institutions for reduced educational cost, to avoid certain ethical issues associated with traditional medical training procedures and to improve patient safety. Several specialized simulator systems have been developed to benefit the education of medical students and the training of medical personnel in new procedures. For example, simulators are used to train suturing and stapling techniques, minimally invasive surgeries and anesthesiology. Complex scenarios can be reenacted with the help of specially designed simulators to practice teamwork in emergency care situations and operating room procedures.

Traditionally a mentor-apprentice method has been used to teach surgical skills. The adage “See one, do one, teach one” is sometimes used to summarize the process. This approach requires extensive input from the surgeon as well as a supply of patients with a specific medical problem, who are often limited in numbers. Incorporating students in the treatment of real patients always involves an additional risk to patient safety. Further, the teaching may require animals or cadavers to train on, associated with both ethical and economical issues. It is argued that the use of simulators is not intended to substitute traditional training, but to supplement the classical curriculum, to increase efficiency and effectiveness of the education, and to reduce the burdens that results from conventional training practice.

The repeatability, that the simulators offer, opens up the opportunity to, at any given time, practice particular techniques with a great number of repetitions. This allows the student to practice basic techniques in a low risk environment, before applying their knowledge in real-world situations. As a result, during the clinical training, a student can focus on more complex aspects of patient interaction and get more experience out of
the precious exercises in contact with real patients. Some simulators also offer a platform for objective evaluation of surgical skills, by providing direct feedback in the form of a summarized score, that is a measure of the students performance.

Additionally, including patient specific data in the simulations can enable surgeons and nurses to meticulously plan procedures in advance. Other applications of medical simulators include standardizing educational experiences, training practicing surgeons in new techniques, evoking interest in surgery among students and marketing new procedures at medical conferences.

In the book Situating simulators from 2004 [5] researcher Ericka Johnson expresses a social and behavioral science perspective on simulators in medical education. She recognizes that knowledge is constructed in practice and that the knowledge acquired is strongly tied to the context where the learning is situated. She sees teaching using simulators not as merely a transfer of discrete elements of ability and knowledge to the student, but considers the wider knowledge created in the social context around the interaction with the machine a central part of any implementation of simulators in teaching hospitals. A great number of contextual elements are distilled away, when designing a medical simulator, in order to make a manageable model. Johnson emphasizes the significant role that the instructor has in filling in what is left out from the simulation, in terms of medical practices and physical environment.

In her study, Johnson observed and analyzed numerous simulator teaching sessions at a large teaching hospital in Sweden. Using observations, interviews and videotaping she surveyed the activities around a minimally invasive surgery simulator and a full patient anesthesiology simulator, focusing on the practices enacted by the participants and their interaction. She gives examples in her analysis of when she noticed the instructor using surgical terms to describe the activities that the team were performing and when he was using his own body to illustrate the patients body. The surgeon might play out an imitated dialogue with the patient or point to his own knee, when clarifying how the patient is positioned in the simulated procedure.

She explains how these activities, that she calls reconstituting practices, are what recreates medical practices out of the practices and understandings that are reified in the simulator. As she puts it, "This process ... creates a patient’s body out of the simulator and medical practitioners out of the students" (Johnson, 2004).

Despite most simulators being technically advanced machines and containing realistic models of the human body and medical practice, it is only when the simulator allows for the social context to be reconstituted by the participators, that it attains its full potential as an educational tool.
2.1.2 Designing an Intuitive Interface

The design of medical devices has been an area where great advancements in human factors and usability engineering have been made, as a result of the high demand for error-resistant equipment from hospitals and caregivers. In critical-care environments, where a myriad of specialized devices have essential status, a high quality user interface can have life-saving potential. The strong competition among medical equipment producers has led to a mature market, where the user interface quality has become a prominent factor in product differentiation. As a result an extensive bank of design knowledge has been accumulated over the years.

What makes a device, built of a complex system of esoteric technologies, easy to use from the very first interaction with the machine, is the careful and deliberate effort of the user interface designer. The goal of designing any human machine interface is to maximize the usability of the device and to create the best possible user experience. A successful user interface enables the user to accomplish tasks effectively, efficiently, safely, and with satisfaction.

For a device to be intuitive, means that it should be easy to use from the start. Key to a user operating a device correctly the first time is that the product enables the user to draw upon their existing knowledge and skills. A good user interface needs to be clear and consistent to assure a proper operational sequence.

Wiklund [6] notes that the same design characteristics that aim to increase intuitiveness tend to both reduce the potential for use error and enhance the product appeal. He also states the importance of high user-interface quality on the commercial success of most medical devices. More effective sales presentations and reduced customer service expenses, he mentions to be some of the direct benefits of employing human factors in the design process.

The intuitiveness of a device is essential to achieving high usability. However, a pursuit of initial ease of use can often come at a cost in operational efficiency, if a careful balance of features is not considered during the design process. As Wiklund points out, in many examples of products implementing a minimalistic design, the device can often seem easy to use on first impression, but when more advanced tasks are to be performed the fail at delivering the function. The designer should instead eliminate the extraneous information, according to Wiklund, to not overwhelm the user.

Among the measures that can be applied in creating a good user interface, Wiklund mentions providing a large display and making important features and information prominent as well as clearly indicating the device’s purpose, proper operation and operational status.
2.1.3 Challenges with Spatial Haptics in Interaction Design

The thesis supervisor at Forsslund System has published a PhD dissertation at the Royal Institute of Technology in Stockholm containing research in the fields of both stand-alone haptic devices and complete setups of surgery simulators [2]. Looking at the research that has been done in the field of haptic devices it is clear that, although a wide variety of devices are available on the market they either are more expensive than the rest of the components of the surgery simulator combined or fail to meet the three main criteria set by Massie and Salisbury. [7]

First: *free space must feel free.* Which boils down to minimizing the internal friction and inertia of the haptic device in order to minimize the force needed to move the manipulandum in the virtual free space.

Second: *solid virtual objects must feel stiff.* Which states that in order to avoid hard objects to feel soft or rubbery the motors which gives the force feedback must be able to render the appropriate stiffness.

Third: *virtual constraints must not be easily saturated,* which translates to not being able to push through visual objects with the manipulandum. The commercial models mentioned in the dissertation, seen in Figure 2.1 on page 11 also fall short when it comes to certain design features since they are firstly made for stand-alone use. This means that they are difficult to incorporate into the complete simulator setup.

![Figure 2.1. An arrangement of commercially available spatial haptic devices.](image)

Another design feature mentioned in the dissertation is the use of a co-located stereoscopic display. The display presents offset images displayed separately to the left and right eye to convey a depth perception to the user. With the help of an angled display hanging on top of the simulator and then mirrored to the user it extends the focal distance to the displayed environment to the same distance and angle as the users hands and manipulandum, seen in Figure 2.2 on page 12. This creates a feeling of manipulating the haptic device in the same physical space as the visual environment.

One of the competitors, Voxel-Man, produces a solution like this but has since 2015 [4] decided to promote a simulator with a conventional display setup instead of co-location.
This decision would certainly cut engineering and production costs since it does not require the design and manufacturing of an aesthetically pleasing and lightweight enclosure for the simulator. Two criteria which could have a big impact on making the product attractive to the customers.

**Figure 2.2.** Illustration of a co-location arrangement of a 3D-monitor and haptic device from an old patent.

During his design and development process, Jonas touches on the importance of a professional and appealing design of the enclosure for the Kobra simulator. During a feedback event with the faculty of a dental school that had shown interest in the Kobra, pictures of the prototype in an early stage had been presented, seen in Figure 2.3 on page 13. Even though the primary focus of the session was further development of the software, the crude looks of the enclosure was too distracting and shifted the focus away from the software. It is an excellent example of how the visual traits of a product must be considered of the same user value as the functionality of the product itself.
Forsslund observed that the key element to a beneficial use of the simulator, was not in providing a highly realistic portrayal of a surgical scenario, but rather in the representation being linked to real practice and in supporting the live tutoring between instructor and student.

Despite providing no torque feedback, Forsslund argues that the significance of supporting Six Degrees of Freedom (6-DoF) haptic feedback for the educational purpose is offset by both the complexity and cost [2].

2.1.4 Human Factors in Medical Devices

In the article *Do it By Design, An Introduction to Human Factors in Medical Devices* [8], the author writes about how human errors can be correlated to improper design of the user interface and also how to reduce them by changing the design of the equipment. This is critical, especially in medical devices, where errors can have a huge impact on
the safety of the patient. However this might not be an issue when it comes to surgical simulators, it is important to note that the user experience could be improved and the perceived quality of the machine could gain from designing the user interface with these rules of thumb in mind.

In order to understand how the user interface can be improved one must first look at the interaction of the user and the operating environment. A medical device can only be used effectively if the interaction between the operating environment, user capabilities, stress levels and device design is considered during the design of the device. To understand the human factors in design, the human capability can be divided into these basic dimensions.

Physical and Sensory Capacity
The most basic capabilities including vision, hearing, strength, dexterity and reach. Related design factors that can interact with them to influence the human performance can be: the readability and distinguishably of displayed symbols, audibility and distinctiveness of alarms and notations, the strength required to operate the machine and requirements for reaching controls on the machine.

Perceptual and Cognitive Abilities
The ability to detect, identify and recognize sensory input makes up the human perception. It is crucial to recognize the human strengths and limitations in this area to make a successful design, specially when it comes to control arrangement, keypads, displays, alarms, and presentation of information. In order to make a successful design when it comes to big databases of information is to use well established semantics and pictograms for screen and menu designs to avoid the user from feeling overwhelmed with information.

Expectations
When reacting to new situations, humans are predisposed to react according to older, established habits. This can be taken into account and used as an advantage when designing devices. Like the existing convention that the color red means stop, or danger and green means go, or safe. If the design is in line with established conventions the learning time will be reduced and the performance increased. If the design conflicts with these it can result in errors instead.

Mental Models
When faced with complex phenomena, humans can form abstract concepts about how they actually work based on previous experience. As mentioned in the article, anesthesiologist can form mental representations of the patients status based on information about the bodily processes like heart rate, oxygen levels etc. It is therefore important that this information is presented in a manner that allows and enables this mental model to be made. This should be considered when designing a simulator in which the users play out scenarios around the simulator itself and create a mental image of the patient and what's happening around them.
2.1. Research Articles

While it can be considered impossible to design out all issues related to human factors, striving for a design with the user in mind will result in a device that requires less training and is less prone to user error. Keeping the human limitations and strengths in mind during the design phase will help to conceal the machine from the user and improve the immersion of the simulation. Although the article brings up several rules of thumb for designing medical equipment, here follows some of the most applicable points to be considered when designing a surgical simulator.

- Make the overall design as consistent with user expectations as possible. Consider well established conventions and previous user experience.
- Ensure that the design has obvious associations between controls and display.
- Consider the typical viewing angles and distances when designing labels and displays so that they can be easily read while operating the device.
- Utilize color and shape to provide rapid identification of controls and displays.
- All cables, connectors, and other hardware should be designed to ensure an easy installation and make incorrect installations impossible, difficult or easy to detect.

The article suggest two methods for studying medical equipment design. The first being observations of the actual device in use. Where non-intrusive and systematic observations are rated best. It is recommended that the sessions should be videotaped using narrative from the user to further explain the process, what they are doing and why to give a clear image of the usage. The other method for gaining knowledge about the device is from interviews. It is described as a flexible way of obtaining opinions about the device, possible issues, user preferences and possible improvement ideas. The interview is suggested to be containing the following:

- Walk-through of the operational steps.
- Compare relative strengths and weaknesses of different models.
- Description of incidents involving the device.
- Recommendation of changes to the device.
- Assess a new device concept.

It also points out that it is important to use pictorial drawings, mock-ups or images of existing models when conducting the interviews since the interviewee usually will not be able to visualize design concepts in the abstract. Allowing the interviewee to react to trigger material will provide a wealth of ideas that could be difficult to obtain through only questions. It is also mentioned that interviews of supervisors or trainers can be of great value since they will most likely have a broader view of the devices strengths and weaknesses. Training staff usually have a detailed knowledge of how the design can affect the training time.
When utilizing focus group sessions it is recommended that the group consists of six to eight health-care practitioners or lay-users. The individuals should also be prospective users of the new device that is being designed. The sessions are best conducted by experienced moderators following a script prepared by the design team. It is important to remember that the users often have limited knowledge about design alternatives or principles, so the best result is gained from weighing subjective data against known interface characteristics and knowledge in human factors. A well executed focus group session can result in several ideas and insights about user interface design and user requirements.

2.2 Competition

There is a limited number of competitors worth mentioning that are specialized in the field of oral surgery simulators. They all share some common features, all simulators use haptic devices with manipulandum tools, some more developed than others but all systems differ from each other in their own way.

2.2.1 Voxel-Man Dental

The Germany-based company Voxel-Man offers a wide range of simulators, not limited to oral or dental surgery. Looking at the simulators throughout the company’s history they started out with a similar setup that Forsslund Systems are now pursuing with a top mounted screen and mirror setup, see Figure 2.4, that creates a co-location with the haptic device mounted underneath the mirror. The design was very crude and prototype-like with only the bare minimum design features. Monitor and mirror is held up by a square tube metal frame and the Phantom Omni haptic device mounted on a table underneath the framework.

By the year 2005, Voxel-Man had kept the same setup of the dental simulator but refined it. The monitor had been replaced by a 3D stereo monitor and the entire device had been encapsulated in a cabinet that although square and boxy, see Figure 2.5 on page 17, gave a more professional look to the simulator. The simulator was still equipped with a mirror for co-location and utilized the same model of the Phantom Omni. Even though it looked like they would continue on the path of co-location and further develop the technology somewhere along the line they seem to have made the decision to scrap that concept entirely and continue with a tabletop model consisting of a haptic device and a flat screen 3D-monitor. This strategy is further discussed in Forsslunds dissertation [2].
The choice to move away from the co-location gives the Kobra an advantage of offering a greater level of immersion to the user. One key feature that changed in the latest model
is the use of dual Phantom Omni devices, seen in 2.6 on page 18. This feature gives the user the opportunity to wield dual tools in the simulation and enables the use of mirrors to further mimic real world situations.

![Figure 2.6. Latest iteration of the Voxel-Man Dental simulator.](image)

### 2.2.2 VirTeaSy

The French company HRV develops simulators for both oral- and general surgery applications [9]. The oral surgery branch of the company features a well designed and professional looking simulator called VirTeaSy. It utilizes two monitors, one in 3D, aimed for the student and placed at an angle over the Phantom Desktop haptic device. The other monitor is placed on top of the simulator facing forward. This can be used either to display additional information or to mirror the simulation to a teacher without the need for 3D-glasses. In front of the haptic device, closest to the user a 3D-mouse is placed, this gives the user an easy way to manipulate the 3D environment in all degrees of freedom, see Figure 2.7 on page 19. It would be interesting to interview users in order to see if this feature adds value to the simulator or if it is redundant. One possible method to use as a work around the 3D-mouse could be to add an arrangement of predefined positions for the virtual mannequin.
One interesting feature of the VirTeaSy is that it is designed for ambidexterity, it can be adapted to all morphologies. Instead of using a plastic mouth for support it uses a simple plastic puck since it can be used for both left- and right-handed users. The design is the result of a competition launched in 2015, won by the French design bureau Desind [10]. The resulting design is a futuristic combination of color and form, which resembles something related to video game consoles. The designer mentions that he deliberately decided to throw away all established norms and codes from the medical sector, as can be seen in Figure 2.8 on page 20. As can be seen when comparing the design proposal with the design that HRV chose to go forward with, seen in Figure 2.7 on page 19, the choking blue panels have been replaced by more neutral off-white that correlates more to the established design codes in medical technology. But to give it some more life, the doors for the computer cabinet has been given a vibrant green color that makes it a bit more interesting to the eye.
2.2.3 Moog Simodont

The multi-faceted corporation Moog has been around for over fifty years and produce a wide variety of products ranging from missile components to motorsport suspensions. They are also the creator of the Moog Simodont [3]. The Simodont features a slim design, similar to the VirTeaSy in the sense that they both are build around a center column where the computer is held. The Simodont utilizes a small projected 3D-monitor which the user sees through a mirror, creating a co-location effect. The design is distinct and unique to the market, see Figure 2.9 on page 21.
Similar to the VirTeaSy it features a 3D-mouse in the front and a separate monitor for extra information. The 3D-monitor which the student uses is however so small that there is no possibility for a teacher to monitor the students progress and aid in the training. Also similar to the VirTeaSy, the Simodont is adapted for a sitting position. Unique for the Simodont is the integrated haptic device which adds to the uniform appearance of the simulator and also can cut down the manufacturing cost drastically. It also features an extra, passive tool which can be used for simulated mirrors etc, see Figure 2.10 on page 22.
2.2.4 Mechanical Mannequins

A substitute for digital simulators is the mechanical dental training mannequins see Figure 2.11 on page 23. They are greatly available from several suppliers and manufacturers, including Frasaco [11] which manufacture and sell a wide variety of dental mannequins. The mannequin works as an analog to a real patient, the student in some cases has to buy plastic teeth from a type of vending machine and prep the head before the simulation. The dental operation is then carried out with real dental tools like drills and scrapers. The used disposable teeth has to be removed after the simulation and then thrown away. An additional use for the mannequins is to practice X-ray to expose dental cavities, something which can not be done with other types of simulators.
An advantage to using these types of simulators is that the student gets a realistic environment in the sense that the head and mouth placement resembles a real patient and real tools are used. The student can therefore learn how to position themselves while operating, see Figure 2.12 on page 24. A downside is that the teeth has to be replaced between every usage and they are strictly limited to dental work, meaning that for instance jaw surgery is out of the question.

Although mechanical mannequins might not be a competitor for virtual simulators it might be of interest to study the use of them. They both have advantages and disadvantages and should not be considered obsolete but rather a good complement to dental surgery training.
2.2.5 Older Configurations

The Kobra simulator is a product of a research project in human-computer interaction by Jonas Forslund at Royal Institute of Technology (KTH). The current version of the dental surgery simulator is being actively used in education by dental students at the Rīga Stradiņš University (RSU) in Latvia and the University of Erlangen in Germany.

Throughout his research the Kobra has undergone several iterations, arriving at the present design configuration. The early prototype was strictly based on functionality, with a metal frame supporting a monitor and mirror, as seen in Figure 2.13.a on page 25. This could be placed on a tabletop with the haptic device standing on the table underneath the mirror. This early design has a great resemblance to the early Voxel-Man simulators as seen in Figure 2.4 on page 17. Although functional it does not give the impression of being a medtech device but rather some sort of experimental device.

The next model seen in Figure 2.13.b the Kobra featured a integrated design with components built into a wooden box to give a more unified impression. This was used to evaluate the software with focus groups, but it proved too crude for the purpose since the focus group got stuck with the notion that it looked so home built and unprofessional.

In the next design seen in Figure 2.13.c the Kobra kept most of the form features of the previous model but in a more refined quality. The whole simulator got a white paint and as seen in the picture a secondary monitor was added on the side to display application menus and additional information like x-ray images and instructions.
2.2. Competition

The last image shows the present day design with a more finished look, a touchscreen monitor for the extra display and the 3D-monitor has been replaced by a flat screen, resulting in a more slimmed down design. The overall form still inherits the boxy outline of the early prototypes but is starting to look more like a med-tech device. The workspace features a patient head for which the student can get support from and the rest of the area is covered with green cloth to resemble a real patient operation, which improves on the overall immersion. The primary monitor and mirror is big enough so that a teacher can overlook the simulation and give oral feedback to the student. The drilling operation is controlled with a footpad placed on the floor. The present design has a lot of empty space built into it, this enables the next design to be more slim with no sacrifice to functionality.

Figure 2.13. The different stages of the Kobra design process.

The haptic device is used to render an immersible interaction with virtual objects through
the hand of the user. In the current version of the simulator, the haptic device used is a Phantom Desktop, a commercial unit from 3D Systems. The device provides 6-DoF positioning input as well Three Degrees of Freedom (3-DoF) force feedback. This means that the tool in the hand of the user can be freely moved around within the workspace, while the synchronized movement of a virtual representation of the tool is visual on the display in front of the user.

What constitutes the ability to freely move the manipulandum, the tool handle, within the hand-scale workspace is a mechanical system of serially joined links. The system is actuated by three electrical motors. Six encoders are used together to track the position and rotation of the manipulandum in space. The positional data is then used to determine the appropriate output force. This control approach is called impedance control. Forsslund observed that the key element to a beneficial use of the simulator, was not in providing a highly realistic portrayal of a surgical scenario, but rather in the representation being linked to real practice and in supporting the live tutoring between instructor and student. Despite providing no torque feedback, Forsslund argues that the significance of supporting 6-DoF haptic feedback for the educational purpose is offset by both the complexity and cost [2]. Through user studies he found that a less complex and cheaper 3-DoF system would be fully sufficient for the intended use.
Chapter 3

The Design Process

3.1 Preparing User Studies

Early on in the project it was decided that the design work would be grounded in a user-centered perspective. A user-centered design process taps into humans intuitive ability and pattern recognition. The goal is to construct ideas that are emotionally and functionally meaningful, inspired by behavior rather than demographics. The user centered design process can be described in three main stages. It starts out with the Discovery phase where the designer goes out to learn from the users. The next phase is Ideation, where all the information is narrowed down, translated and sorted into different themes and patterns. Lastly comes the Prototyping phase where the ideas rapidly transforms into tangible designs and evaluated with user feedback. This process can be seen illustrated in Figure 3.1 on page 27.

![Figure 3.1. The user-centered design process.](image-url)
3.1.1 Interview Guidelines

In order to conduct repeatable interviews an interview guideline was produced. Since the interviewees would consist of three separate groups, with different experience of the simulators (Kobra students, Moog students, and instructors) it was decided to create three different interview guides. They were all presented with the purpose of the interview, and asked for permission to publish their answers as part of the thesis report.

**Kobra students**
The students using the Kobra were asked about their general experience with the simulator, when they were first introduced to it and how much they have used it since. They were asked about the general user experience, good and bad. How they interact with the simulator when instructors are around, what they felt that they had learned from it and if they saw any areas for improvement.

**Instructors**
The instructors got questions that were more centered towards the educational content of the simulations and their role as teachers in that setting. If they see any repeating patterns in how the students use the simulators. The differences and similarities between real life surgery and simulations.

**Moog students**
The students using the Moog simulator were asked similar questions to those using the Kobra although the focus was shifted towards how they perceived and used the model specific design features linked to the Moog Simodont.

All interviewees were also asked questions regarding design choices and areas of improvement in general, regardless of the simulator they used. The interview guideline can be read in its entirety in Appendix D

3.1.2 Trigger Material

Since four of the Kobra simulators were installed at RSU, it was arranged so that one session with students was observed and documented. How they used the simulator was monitored and they where prompted to call out if they felt uncertain of anything.

Since they where first time users, the Kobra itself could act as a sort of trigger material. Capturing issues that the students would possibly learn to adapt to, and forget after long use. After the lab session they were gathered with the instructor and got the chance to evaluate the simulator in a group. This turned in to a brainstorming session resulting in many ideas for improving the simulator. This session, along with the lab was later analyzed and a full transcript can be read in Appendix E
3.2 The User Studies in Riga

In order to get the users perspective on the design of the Kobra and other methods for dental practice, a field trip to RSU with the intention to observe and interview the students and surgeons using the simulators. The department for oral surgery had placed the four Kobras in the middle of a small room where the students could use them, see Figure 3.2 on page 30.

3.2.1 The Kobra Session

The observations began with a simulation exercise with a class of third year students, with no clinical experience, and a surgeon instructor. The entire exercise was recorded on video and audio and the participants were urged to talk out loud if they encountered anything that made them stop or think. The students directly formed pairs of two and started using the simulators together, where one student acted as the surgeon and the other aided. The surgeon instructor walked around the classroom and gave the students advice on how to solve the cases, and often drew parallels to real life scenarios, explaining how the simulation differed to real-life and how he would perform the procedure if it was an actual patient lying there. The majority of the feedback was how he would rather have used another tool for that specific task, mostly referring to different drill heads.
When watching the video recording afterwards it was clear that the students learned the most when directly interacting with the surgeon trainer, since he could recite real life scenarios and often made comments that added another level of education to the simulation. The students often gathered around him to see how he would go about solving the different cases as seen in Figure 3.3 on page 31. For instance in one case he stated that if the patient was young and healthy he might be urged to go for a more invasive path, that would give a better end result, since the flaps would be able to heal better than if the patient was over 50 years old with general health problems, where he would be more cautious. The students also requested more information in the case description since the simulators would mostly be used for self studies without a teacher.

Suggestions were made that the cases could include a short instruction video and higher resolution X-ray images to improve this. The surgeon even suggested adding real-life footage of the same procedure as the case information.

Something that also was discovered while inspecting the recordings was that some students tended to grip the manipulandum in awkward ways, often with their entire hand, as if it would have been a chisel or a skewer, while the surgeon held it in a precision grip, not unlike that of a pencil. This could very well be connected to their statement that the manipulandum felt too light and that it did not resemble a real drill hand piece.
3.2. The User Studies in Riga

3.2.2 Interviews

In an interview on the visit to RSU a practicing surgeon and teacher there (Referred to as 'Surgeon A'), expressed his thoughts and opinions on the Kobra simulator.

At RSU the Kobras are not used for any formal evaluation of the students performance, according to Surgeon A. They are solely used as a tool for teaching and to give the students an opportunity to practice surgical techniques, before moving on to the clinical part of their education. Although, Surgeon A points out, the Kobra affords the teacher to notice some incorrect techniques of the students, during the assisted exercises, such as if the student wrongly drills into a neighboring tooth or surrounding bone and to correct the students technique, before they attempt a flawed practice on a living patient.

In teaching his students using the Kobra, Surgeon A, much like Surgeon B, describe every action he does in detail, while a small group of two to three students stand around and observe him perform the simulated operation. While first being introduced to the Kobra, Surgeon A started to learn how to operate the simulator on his own. He stated that he found the exercises self explanatory, with the help of the written directions apparent on
When asked to call out any deficiencies of the Kobra, he, as an instructor, has recognized, Surgeon A acknowledged the lack of some specific exercises. He gave examples of surgery cases that he thought would be useful for the students to practice on in the simulator, such as extraction of upper jaw molars, separation of upper jaw molars, extraction of upper jaw wisdom teeth (preferably a challenging placement of the tooth, such as mesioangular or horizontal), root extractions, mesiodens extractions, implants, and flap design. He highlighted wisdom tooth extraction as possibly the most important exercise for the students to practice, since this is as common procedure in real-life practice. During his time using the Kobra, Surgeon A states that, he has never encountered any issues or difficulties operating the simulator. Although he mentioned that he would like to be able to rotate the manikin head for better reach and visibility.

Further, he also commented on the realism of some of the existing representations of dental tools in the current version of the simulation. The way drilling in bone and tooth material feels in the model is similar to reality, although the tactile feedback is not as strong as it would be under real-life conditions, according to Surgeon A. Also the dental elevator lacks the some of the mechanics involved in real-life extraction, which makes it hard for the students to learn how to hold the tool. He also requested some additional tools, that he would use in some of the operations that are currently represented in the simulations and in exercises yet to be implemented. He specifically mentioned a conical drill and a scalpel, which is used for flap design.

During an assisted exercise, some of the teaching also happens beyond the on-screen activity of the Kobra. For example, when instructing in the simulation exercises, Surgeon A teaches the students how to hold the jaw correctly, in order to reduce the risk of damaging the tissue surrounding the tooth. He does this by showing the correct grip, that he would use in real-life, on the manikin head of the Kobra. But when questioned about incorporating any reenactment of preparatory tasks, as part of his simulation exercises, Surgeon A stated that he might once go through how to properly clean his hands and use a coat, a surgical mask and a cap, but that these trivial tasks generally are of too low priority in the time constrained exercise occasions to be performed.

At the time of the observation of the Kobra class, taught by Surgeon B, it was noted that some of the shorter participants where forced to stand on makeshift steps or on their toes, in order to see down though the mirror of the Kobra. This because of the fixed height of the simulators, when placed on top of the tables in the center of the class room. When prompted about the steps, Surgeon A explained that the surgeon and the assistant always stand during an operation and if one person in the team is sufficiently shorter than the other, they will be using similar steps.

The opportunity the teacher has to influence the content of the exercises for the Kobra is valued by Surgeon A. He states that if he comes upon a real-life surgery case in the clinic, that he finds of particular relevance to his teachings, he can recommend it to be modeled as a simulation exercise. Through internal channels of the faculty, namely speaking to
the head of the oral and maxillofacial department or to his colleague that is responsible for the Kobras, he can make the request. His colleagues, in turn, have direct contact with the content designers of the Kobra and can make an order for a new simulation exercise, based on a detailed description of the case accompanied by X-ray images. The full interview transcript can be read in Appendix F.

3.2.3 Results from the User Study

After the lab exercise the participants were gathered and got a chance to give feedback on the user experience. They came up with many different ideas on how to improve the design and experience. Together with the recorded session and the interviews the user studies could later be boiled down to the following most important changes:

- The ability to move the head/view or use head tracking on the user to change the view is a needed feature.
- Ability to change the tools in the simulation.
- The addition of forceps.
- A more realistic manipulandum with more weight.
- A bigger side monitor with higher resolution.
- 30-second instructions and/or video of real scenario with additional and better quality x-ray images.
- Improved realism with better anatomy.
- The elevator needs to be calibrated.
- Vibrations and sound to improve the realism.

3.3 Implementation

After the literature review and user study had been conducted the ideation phase of the design process could begin. Different concepts of the full setup and individual subsystems were developed, with the aim of solving the problems that had been brought to attention in the background study. A known feature for all possible concepts would be to have a height adjustment. Instead of designing a mechanical solution for this it was decided to buy an existing product for office tables and build the rest of the simulator around this product, the chosen stand can therefore be seen throughout all the design sketches and renderings. A more detailed description of this choice and the product itself can be found in chapter 4.1, Standard Components.
Chapter 3. The Design Process

3.3.1 Ideation

The first order in the ideation process was to examine the brand identity of Forsslund Systems and create a moodboard that could be applied for both lifting the brand itself but also serve as a visual guideline when designing products in order to keep the general theme consistent. The main triggers for the moodboard were the current version of the Kobra, with clean white surfaces. The Forsslund Systems logotype, see Figure 3.4, featuring a FS monogram in green and blue colors.

![Figure 3.4. The Forsslund Systems logo featuring a monogram.](image)

A teal color was added to the moodboard since it was coherent with details on the Kobra and also gave some resemblance to the color used on scrubs and other fabrics used in hospital environments. Since the Kobra rely on both high tech software and hardware some elements relating to this was added to the mood board in order to make it a more prominent statement. The moodboard can be seen in Figure 3.5 on page 35.
Several efforts to design solutions for particular subsystems were initially made in the same time as the main design of the enclosure was developed.

**Manipulandum**

In order to meet the demand of forceps in the simulation it was deemed necessary to include a manipulandum add-on which could simulate the pinching action and link that to the simulation. A set of dental extraction forceps were acquired in order to modify them into a haptic device. To enable the use of different manipulandums a quick change tool-holder needed to be designed. An early idea was to use neodymium magnets to hold the manipulandum in place and either a switch or electrical contacts to indicate what kind of tool that is in use. When using forceps some kind of switch is needed in order to simulate the pinching action. This could be solved with a micro-switch that is activated when one of the jaws presses down on it, as can be seen in Figure 3.6 on page 36.
The other user feedback related to the manipulandum was regarding the shape and weight. The plastic straight manipulandum on the Phantom Desktop was considered too light and felt wrong to grip like a drill. In order to increase the user experience it was decided to use a modified dental drill hand piece as the drilling manipulandum, similar to the one used in the Moog Simodont. Something that also came up in the user studies was the fact that the Moog Simodont used built in vibrations and sound effects to increase the user experience. However some users stated that the monotonous sound effects was not used to its full potential. In real life the sound would change based on the type of tissue that was being drilled into, the Moog only featured one continuous sound that did not feel real. This resulted in the sound being perceived as more annoying than helpful, therefore if it is to be a feature it is important to make sure the frequency of the sound changes with the different materials in the simulation. Also, from analyzing the video footage it was observed that the users did not find it obvious where to place manipulandum when letting go of the handle. A holder for the for the tool to rest in could solve this issue. Adding these features can be considered a simple task when it comes to the hardware while the software needs more work that is not covered by this project. Therefore the hardware will be prepared so that they can be added in future development.

Display
The key feature, that would predominately affect the general design of the simulator, was the display solution. Several distinct solutions for displaying the virtual environment were found. The four most promising solutions were; a co-located stereoscopic display
3.3. Implementation

(found in the previous version of the Kobra), a system based on an LED projector, a conventionally implemented (no co-location) stereoscopic display and a head-mounted display. To aid in the choice of solution, the most important characteristics of the four solutions were structured in a decision matrix. The matrix listed the most important advantages and disadvantages of each solution and an estimated cost of the components involved to more easily compare the alternatives. The decision matrix can be found in Appendix G.

It was decided that the co-located solution, found in the old design, was the most appropriate solution. This primarily since it was shown in the user studies to enable the dynamic interaction between student and instructor, an important characteristic supported by the literature and observations made in Riga. Although, possibly being the most expensive of the solutions, it also came with the advantage of the existing knowledge in how to implement it and therefore had the highest likelihood of a successful implementation.

Other technical solutions such as the head-mounted display (virtual reality) and projector solutions were discarded, since the decision matrix revealed that they were not, at the time, the best alternative. But the solutions might become needed in the future, since the stereo displays are becoming more difficult to acquire, as their primary consumers, on the gaming market, is switching to head-mounted displays.

During the initial concept ideation, a few different illustrative design concepts were presented to the customer, in order to spark a conversation about the alternative design paths. The concepts were kept a white base color with teal details to tie them to the established mood board. All ideas were built around the co-located stereo display system and a height-adjustable stand, which strongly characterizes all the designs. Further, the concept of using bent acrylic panels, to introduce a premium material suitable for low-scale production, was explored in several of the concepts. For example, one of the concepts was strongly inspired by how influential Finish designer Alvar Aalto bent laminated wood in his furniture designs [12].

As can be seen in Figure 3.7 on page 38, one of the initial ideas was to slim down and refine the original design of the Kobra. Another idea was to build the simulator around a central column and go for a more open 'skeleton' design, bringing forth the supporting structure instead of trying to hide it. One thing that all designs had in common was the adjustable floor pedestal which due to its modularity and modern design fit very well for the project.
Figure 3.7. The initial rough sketches of different design concepts.

Shortly after the sketches, rough CAD-models were generated to further explore possible designs. The focus was on the skeleton design, since it was the most well received from both the client and the tutor. But in order to keep an open mind, other designs were rendered as well. When evaluating the different concepts, they were judged based on how well they translated to the mood board and how difficult and expensive they would be to manufacture. In Figure 3.8 on page 39 the first and fourth concepts, which are roughly based on similar designs, where chosen due to the fact that they had a slim and pleasing design, with a back piece that can shield off reflections of light armature or other things that might distract the user, without feeling too bulky. At this step, CAD was the main tool for design ideation since it was an easy way to test out general proportions and discover design issues early in the process.
Several of the first design concepts included a hinged mirror frame, that would allow the mirror to be folded up towards the display, where it would be protected from dust accumulating on its surface. The design included a gas spring that was to be installed so as to allow the mirror to be folded up and down effortlessly. The foldable mirror feature was later determined to be unnecessary and needlessly complicated, while also placing unwanted constraints on the design. A static support for the mirror was instead proposed.

### 3.3.2 Prototype Development

To get an quick feeling of the measurements and general dimensions a wooden mock-up was built, roughly based on the concept design and built around measurements derived from the Kobra, as seen in Figure 3.9. The mock-up was built from scrap plywood and mounted on the height adjustable pedestal. Even before mounting the monitor and mirror it became apparent that the dimensions from the Kobra did not translate well to the concept design and the need for adjustments demanded for a more refined build. The initial intention was to mount the mirror and haptic device ledge at an appropriate position while running the simulation, and find the "sweet spot". This was based on the hypotheses that a 45 degree monitor angle would be optimal, since that was the angle used in the Kobra. After reading two publications [13] [14] touching on the subject of co-location geometry and finding that the proposed optimal angle of the monitor to
be closer to 70 degrees or even horizontal, see Figure 3.10 rather than the 45 degrees previously used on the Kobra.

Figure 3.9. A rough mock-up of the dimensions and angles for the monitor.
The next mock-up was built using aluminum profiles, similar to those that were going to be used for the final prototype. The advantage of using the aluminum profiles is the ability to quickly change between different angles and distances between the mirror and monitor. A mounting plate for the base and a monitor adapter plate was water cut in order to mount everything to the pedestal and test run the simulation application, see Figure 3.11.
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Figure 3.11. An adjustable mock-up of the dimensions and angles for the monitor made from aluminum profiles and scavenged Kobra parts.

The size of the stereoscopic display and of the mirror of the previous version of the Kobra, were concluded, from both the user studies and the designers own judgments, to be well suited for the new simulator. The other key dimensions and relations of the new simulator were determined using the adjustable prototype.

Firstly, the tilt of the screen and mirror was determined, by iterating between configurations with different inclinations and positions of the two components, both in relation to each other and to the vertical axis, until a satisfactory result was found. By viewing the virtual environment through the full stereoscopy set-up while operating the haptic
device, the configurations were judged based upon a set of deciding factors. Firstly, the active workspace should be situated at an elevation and distance from the users face comfortable for the user. Secondly, the user should not make contact with their head on the top border of the frame in front of the stereoscopic display. Moreover a dark shadow, an unwanted artifact from the alignment of the polarizing elements, that occurred on the lower part of the screen at a certain range of angles, was to be avoided. A tilt of 60 degrees for the display in combination with the mirror being horizontal proved to be the optimal set up. The angle was measured from the base of the central pillar to the profile holding the monitor, as seen in Figure 3.12

![Figure 3.12. The measured angle between the vertical frame to the monitor mount.](image)

When a suitable configuration had been achieved, the placement of the mirror in its own plane was set, so that the virtual model on the display could be viewed in its entirety.

The placement of the manikin head was chosen so as to align the cavity of the mouth with the mirrored plane of the stereoscopic display, while at an angle that is representable of the real world conditions of a surgical procedure. By using the CAD environment, the focal plane could be precisely determined, as seen in Figure 3.13. The positions of the two haptic devices were subsequently determined, so that the mouth of the manikin
would be within the work-space, while also allowing the articulated arms to move freely under the mirror support above. The elevation of the table top could then be determined by where the haptic devices would be recessed at an appropriate height.

Both designers, conducting the experiment, despite being of different height (representative of a wide range of users), agreed on the resulting configuration.

The most practical placement for the main electronic components were determined to be underneath the manikin head, that could rest on a panel that would conceal the electronics well. That panel, referred to as the table top, would extend so far as to fully incorporate the haptic devices, so that they could be built into the body of the simulator. The elevation of the table top could then be determined by where the haptic devices would be recessed at an appropriate height. The electronics enclosure underneath was to be as shallow as possible, while still allowing for sufficient freedom to later vary the dimensions of the components that were to be housed inside. One of the motors of the new haptic devices, in a recessed state, was determined, through the CAD environment, to be the component that would need the greatest height. Other components that required significant space were the motherboard, the graphics card and the power supply.
The aluminum profile proved to be rigid enough to support the weight of the monitor and mirror, as well as additional load which was promising for the final prototype. However, the base plate and monitor brackets were too thin to support the construction steady. An increase in thickness from 2 mm to 8 mm should help stiffen the frame.

Two types of plane mirrors were compared. The first mirror was of a conventional back-silvered type, but with an exceptionally thin glass panel. This to reduce the optical aberration caused by the secondary reflection of the front surface of the glass panel. The second mirror was of a first surface type, from which that type of aberration is absent in the image. The two mirrors were mounted side by side in the full stereoscopic setup of the prototype and the two resulting images were viewed and compared by the observer. The image from the first surface mirror was notably sharper and brighter compared to the image from the back-silvered mirror, see Figure 3.14.

![Figure 3.14. A comparison test between two different mirrors.](image)

The first surface mirror was significantly more expensive than the conventional mirror, but the elevated cost was outweighed by the value of the improved image quality.

Two types of half-wave retarders were mounted side by side in the test rig to evaluate the difference between retarders laminated on different substrates and produced by different manufacturers. The half-wave retarder is an optical element that is necessary to alter the polarization of the light coming of the monitor in order to compensate for the phase shift that occurs when the light is mirrored. In terms of their optical performance, the two types were indistinguishable by the observer. The comparison can be seen in Figure 3.15, where two retarders are held side by side. (The black area in the image has no retarder and the blue area is the overlap between the two retarders.)
The difference in price was significant, the glass retarder being over two times as expensive as the acrylic retarder, so the acrylic type was decided to be used.

During the prototyping phase many more minor choices were made about the final design, for example that steel plates, more rigid than the aluminum ones, were to be used on a couple of the sides of the lower electronics enclosure, so as to eliminate any noticeable deflection of the panel, when engaging the buttons on the right side or connecting a cable on the back side. Moreover, several test samples of white acrylic were studied and compared to aid in the choice of tint to be used on the new simulator.

3.3.3 Final Concept

The new generation Kobra simulator takes design inspiration from its predecessor, but embodies an updated view of the end user and a heightened attention for the customers’ expectations. Some of the thoughts behind the styling of the simulator are described hereinafter.

Beyond promoting the function and usability of the machine, the new simulator required a design that is appropriate for the high price point and that honors the great development effort manifested in the advanced technology inside. The wooden construction of the old Kobra served its base functions well, providing mechanical structure and concealing the internals, but failed on occasion to inspire confidence towards the product in the most demanding of potential clients.

The high emphasis on visual appearance, that is expected of modern medical technology, is achieved through the thoughtful and deliberate styling of the new Kobra and through the implementation of premium materials, such as died acrylic and anodized aluminum. Nevertheless, the design is tailored to take advantage of the narrow set of processes available to a small manufacturing team, appropriate to the low scale production.

The design is grounded in the constraints set by the key components, supporting the main function of the simulator, such as the stereoscopic monitor, the mirror and the
haptics and utilizes the characteristic system level geometry that they form, as can be seen in Figure 3.16

![Image](image.jpg)

**Figure 3.16.** The styling of the new Kobra follows the function of the components and subsystems.

The most prominent styling feature of the redesigned Kobra may be the turquoise acrylic panel, framing the stereoscopic monitor, seen in Figure 3.17. The panel draws upon a heritage from the old simulator, that is it could be interpreted to resemble the spread hood on the neck of a rearing Kobra. Where the colored acrylic panel curves, it also tapers down, to a form thin waistline. In doing so, it ties the tilted display to the vertical backbone of the simulator, where it extends the upright centerline, that starts from the stand.
The overall shape of the new simulator resembles a rearing Kobra.

The theme of the tapering form is carried over in several other components of the simulator. The shape can be seen in the outline of the white acrylic frame in front of the monitor, where it merges with the dark panel, that is the infrared cover, through a curved section. It can also be found in the sheet metal support for the mirror and in the back portion of the mirror frame. A mirrored version of the tapering curves can be seen on the upright panel underneath the mirror, tying down the vertical waistline to the lower enclosure, as the original shape does with the monitor and the vertical backbone, as can be observed in Figure 3.18.
A similar theme of form is the V-shape, that is present on the front edge of the work space panel (also referred to as the table top) and on the bottom edge of the acrylic frame of the side monitor. The inverted shape can be found in the inner cutout of the colored acrylic panel.

The extra thick acrylic sheet, used to form the work space panel and the mirror frame, was chosen for the property of being able to express sturdiness, both perceived and genuine. In order to invite the user to work with the equipment underneath the mirror, the front overhang of the work space panel was bent down, exposing a surface for the user to rest their hands on.

To give the electronics enclosure, underneath the work space panel, a slender appearance, as can be seen in Figure 3.19, the flat sides were set to slope inwards, forming a truncated pyramid. A shape that is mirrored by the top hood, covering the stereoscopic monitor. The rounded aluminum profiles, that forms the corners of both enclosures, were set in relief to give the enclosures an ornate presence.
Chapter 3. The Design Process

Figure 3.19. The slanting sides gives the top and bottom enclosures a slender appearance.

Inherited from the Forsslund Systems brand is also the turquoise color of the semi-translucent acrylic, seen in Figure 3.20, as it originates in a blend of the blue and green in the company’s logo and graphic profile. The turquoise color is suitable in the medical environment, where the simulator is to be placed, as the color is commonly implemented in operating theaters. The satin finish of the colored acrylic panel was chosen to give contrast to the high gloss finish of the white acrylic panels and as an attempt to produce a sophisticated implementation of bright color, that is in line with the desired premium look of the product. As an effort to achieve a refined and elegant interpretation of the sterile surfaces in an operating room, the glossy white surfaces of the rest of the acrylic panels were chosen.

The objective of the color choice was also to create an eye catching and distinctive style, in an effort to grab the attention of potential buyers at exhibitions and conferences, that still holds an appearance that remains recognizable as a product for a medical setting. The satin finish of the turquoise panel and the color counterbalance of the white panels makes for a controlled color implementation, that does not create the resemblance of a toy.
3.3. Implementation

Figure 3.20. A turquoise color was chosen for the new Kobra.

To take advantage of the semi-translucent property of the colored acrylic panel, some of the material was left exposed on the back side, to allow ambient light to permeate through to the front, creating a glowing effect, as visible in Figure 3.21. A thin edge around the border that frames the stereoscopic monitor was also left bare, so as to create the same effect. The idea was further implemented around the panel that covers the infrared devices, by letting the transparent bronze-colored polycarbonate panel on the front extend past the black panel behind it.

Figure 3.21. The semi-translucent acrylic allows the edges to glow under ambient lighting.

To brand the simulator the logotype of Forsslund Systems was prominently placed on several locations on the product, but applied in a subtle manner, so as to not give rise to a cluttered appearance. The largest and most notable logotype was laser etched onto the front side of the white acrylic panel that frames the main monitor, as seen in Figure 3.22,
where a beholder would expect to find it. A more subtle logotype can be seen laser edged onto the bottom border of the acrylic frame of the side monitor. A careful observer, viewing the simulator from behind, can find a representation of the logotype on backside of the simulator, where it is faintly visible through the colored acrylic panel.

Figure 3.22. A large logotype was laser etched into the white acrylic above the mirror.

Allowing the intricate linkage of haptic devices to be highly visible is an attempt at sparking interest towards the technology incorporated in the simulator in the user.

The polygon mesh producing the surface of the manikin head, in combination with the light color of the soft silicone that it is made of, is used to combat the intimidating appearance, that is a common characteristic of traditional manikins, resulting from a pursuit of anatomical fidelity. Although the manikin head of the new simulator still possesses a significant resemblance to a real patient, which is important in pronouncing the function of the machine, making it initially intuitive and for the creation of an immersible simulation.

Note that the prototype at the time of the images being taken were missing the two haptic devices (a Phantom Desktop was used in some of the images), the manikin head and the acrylic frame of the side monitor.
Chapter 4

Production Methods and Adaptation

4.1 Standard Components

The legs or central column of the simulator could possibly be adapted from height adjustable table legs instead of reinventing the wheel, the aim should in that case be to find a model that fits with the rest of the form language of the device or make sure they are hidden away from the user in line with the overall design. The easiest option would be to use two thinner legs, which are more commonly used in office tables. Although arguable the more elegant option would be to go with a single central pedestal. The Danish manufacturer ConSet [15] has a wide variety of electric adjustable single pedestals in reasonable price ranges, see Figure 4.1 on page 54. After a visit to a ConSet retailer in Stockholm it was decided to order the pedestal at the top right in the figure since it has a wide base that will keep the simulator steady at all times, a sleek design that goes in line with the established mood-board, appropriate height adjustment range, and a tilted footrest in the center that can be utilized for the foot pedals. The only downside that could be found was the height adjustment switches. They where built around two regular black toggle switches which had to be pressed at the same time as a sort of fail safe mechanism which wont be needed in this intended application. However these can easily be replaced and repositioned with other switches, more suitable for the simulator.
Figure 4.1. Four different central pedestal legs from ConSet.

The arm holding the secondary monitor was bought from Item seen in Figure 4.2 on page 55, since it has a design that is coherent with the rest of the simulator and features easy mounting to the frame, a gas spring that allows for smooth adjustment of the monitor, a hidden cable holder and a standard VESA mount for fitting a wide variety of screens.
4.2 Framework

To keep production costs low, the T-slotted 80/20 extruded aluminum building system can be considered a suitable option to custom welded frames, see Figure 4.3 on page 56. The 80/20 system consists of a wide variety of aluminum profiles with different finishes and designs as well as component accessories like fasteners and brackets. The key feature to the system is the modularity which eliminates the need for welding.
Worth to consider is the well known shape of the 80/20 profiles. They are easily recognizable and should therefore be used with caution when included in the design. It should be of high priority to hide the profiles and cover them with panels or other design elements in order to not infringe on the overall design and form language. It could prove challenging to reflect the desirable form language if standard components like these are made too prominent.

4.3 Manipulandum

During the user studies in RSU it became apparent that a heavier and more realistic manipulandum would improve the user experience. In real applications the surgeon would use a stainless steel hand piece. Instead of reinventing the wheel it was decided to modify a real hand piece to work as a manipulandum in order to improve the grip and feel for the user. A hand piece similar to the one used in the Moog Simodont was chosen, as seen in Figure 4.4 on page 57.
4.4 Panels

In order to cover up big sections and reduce unwanted negative space, the usability of acrylic sheets, also known as Plexiglas was investigated. When browsing through the Plexiglas assortment a promising material type was found. A semi-transparent, colored sheet with a bead blasted finish, giving it a frosted surface. The colors that matched the project best where decided to be *Laguna* and *Pacific*, one teal and one blue which can be seen in the mood-board in Appendix C. Material samples were ordered to try out different processing methods such as heat bending as seen in Figure 4.5 on page 58. With a large bending radius of around 20–30 mm and medium heat from a heat gun the acrylic sheet bent easily and was cooled down with cold water. The surface kept its frosted finish and a smooth bend was accomplished without any bigger issues, however when the heat was concentrated in one spot it resulted in a white burn mark on the surface. The inside lip of the bend expanded a bit but was easily taken down to a flush edge with some wet sanding.
Chapter 4. Production Methods and Adaptation

Figure 4.5. Acrylic sheet post heat bending.

During the build phase of the final prototype it was however discovered that larger sheets of acrylic proved to be more difficult to bend. This stemmed from difficulties to evenly distribute the heat from the heat gun. Some of the larger panels took several hours to manipulate into the right shape. Some retailers for acrylic sheets offer the service of cutting and heat bending the acrylics to specs, although this might bump up the production price it should be considered a necessity in order to produce a high quality machine.

It was decided to test different surface finishes through wet sanding. The original edges of the samples had a uneven and light scattering pattern on the surface, as can be seen in Figure 4.6.a on page 59. In the following images (b-e) the surface has been wet sanded with different grains (180P/240P/500P/1200P), the most desirable finish was accomplished with the 240P grain as it resulted in a smooth surface that refracted the light similar to the bead blasted surface on the rest of the sheet. When going through finer grains the surface began to produce sharp reflections where many small scratches from the sanding process could be seen. Later, the surface was masked off and flame polished. Flame polishing is based on one of acrylics material properties to melt and become fluid under an open flame, which results in a glass-like finish. In this case however, the material just burnt and produced off-white blemishes along the edge as seen in Figure 4.6.f. It was speculated that the coloring of the acrylic could be the cause of this phenomenon.
In order to fully utilize the acrylic sheets and not let them limit the design it was crucial to test how it cut with different methods. For free-form cuts, a Computer Numerical Control (CNC) machine of some sort had to be used. Water-jet cutting was tried for both sharp edges and round corners with good results when starting outside the material. This was done since acrylic is a very hard, almost glass-like material with a tendency to crack or delaminate during high pressure conditions. To illustrate this a round 8 mm hole was cut in the middle of the sheet, which indeed resulted in internal cracks in the material as seen in Figure 4.7 on page 60. The surface finish of the cuts was very rough, almost resembling sanded glass. The finish could be wet sanded for a smoother finish but it would be time consuming to do so in all small corners so a different CNC machine was tested, a CO2 laser cutter and engraver.
Figure 4.7. Different cutting methods tried on acrylic sheet.

The 30 W laser could just about pierce the acrylic sheet in one go but it resulted in a smooth surface with sharp corners unlike the water jet which had a 1 mm radius in all corners. On sharp edges a bit of clouding could be spotted in the material, but nothing that would cause any issues. When inspected it was determined that the laser cut edges would not need any other surface treatment. It was also tested how the material responded to laser engraving, a method of scorching the surface of the material with the CO2 laser. It took away a thin layer from the surface, only marginally noticeable when touched, this resulted in a very interesting ghosting effect, where the engraved pattern can be clearly seen from an angle but almost becomes invisible when looked at from a perpendicular angle. This could be used to incorporate the company logo or other patterns.

4.5 Sheet metal

Many components of the simulator is manufactured from sheet metal of either aluminum or steel in thicknesses ranging from 1-5 mm. These components have been water cut to shape and then bended manually when needed. For prototyping purposes or small series production, water cutting can be considered as a suitable way of manufacturing. It could however be of interest to get quotations from manufacturers for punching out the parts in a CNC punch. All components that are visual to the user or those made from steel should
be powder coated in a pure white color in order to protect the surface from corrosion and give a coherent impression with the rest of the simulator. All major components for the simulator can be found rendered and described in detail in Appendix H.

4.6 Manufactured Components

The thesis ended in the manufacturing of a working prototype. Production methods were mimicked to the furthest extent possible with the exception that some of the bigger or thicker acrylic sheets had to be water cut when in reality it would be more convenient to cut with the help of laser. Some images from the build can be seen Figure 4.8.

![Figure 4.8](image)

**Figure 4.8.** Laser cutting and water jet cutting were used to shape the panels of the final prototype. Custom jigs were made to guide the bending of some acrylic panels under heat.

Steel and aluminum components were water cut and coated with enamel spray paint, in real production it would be advised to use powder coating in order to get a more durable and consistent surface finish. The most prominent components that were manufactured for the prototype, excluding standard components and hardware, can be seen in Figure 4.9 on page 62. For more in depth description of all components as well as bought components, see Appendix H.
Figure 4.9. Most prominent manufactured components.
Chapter 5

Discussion and Conclusion

5.1 Discussion

User Studies
The user studies conducted in Riga gave valuable understandings of how the simulator is used by the end user, how they have integrated it into the education and what the teachers and students think of them. It became apparent that the students use the simulators whenever they want to and that they are less integrated in the study plan than originally thought. The instructors are not there to guide students on more occasions than the first introduction, this was due to the fact that the instructors are practicing surgeons that simply does not have the time to act as instructors frequently. Many of the insights gathered concerned the software and would not be directly addressed in the project.

Since the students wont be aided by an instructor it might be necessary to offer more cases with entry level difficulty, suited for first to third year students in order to get more students to use the simulators more frequently. The study also showed that both the students and professors wanted more tool options. Ranging from different drill shapes and sizes to the more complex integration of forceps and suturing tools.

One other solution to improve the learning experience could be to include more information describing the tasks involved in the cases, since the professors could not attend and guide the students all the time. The inability to change the view was a notable constraint, the students often had to guess what they where doing when the drill bit was out of sight, buried in the root canal of a molar. From analyzing the surgeons teaching, it was suggested that they could be loosely divided into two types, in regards to the way they viewed the new technology in their teaching practices. The old school type, who completed their education before the time of simulators and preferred using pig heads for practice, and the new school which saw the entrance of simulators during their education and understood the value of using them.
Due to the limited time assigned to the project, some parts of the user study had to be skipped. An observational study of a real patient surgery was never conducted. Although images and videos of real surgeries were viewed on the Internet during the background study. A follow up study of the final design with the users in Riga would have been valuable for the end result of the project, and might have shown imperfections or design mistakes that have been overlooked in the prototyping phase. Due to the time restriction this step also had to be skipped.

Prototyping
During the early prototypes of the simulator, with measurements copied from the existing model, it became clear that a more experimental approach was needed. When the measurements were transferred from one design to the other, they felt odd and ill fitting. A second model, with the ability to adjust the measurements and angles, was then built, before a final design could be determined. With this mock-up, angles and measurements, derived from a research article could be tested. It was found that neither of these alternatives worked flawlessly with the new design and therefore the dimensions were determined by trial and error.

Many new insights were acquired during the building of the final prototype, regarding the design of the new Kobra simulator and the manufacturing processes intended for its production. Some weaknesses in the construction of the new simulator were only detected during the build of the prototype. For example, difficulties in producing the bent acrylic panels, true to the specified geometry, forced a consideration of new solutions for attaching other components. A particular acrylic panel, being slightly misshaped, caused a visible gap to occur in the interface to an adjacent panel. To reduce the unwanted gap, new mounting points were introduced, connecting the acrylic panel to the top hood with a set of screws to allow the panels to be forced together. This however, had the unwanted effect of deforming the top hood, covering the main display. The thick bead of construction adhesive, connecting the side panels of the top hood to its aluminum corners did not provide adequate rigidity, to maintain its original shape under the newly introduced load. It was concluded that the design did not allow for great enough misalignments to compensate for tolerance errors in the manufacturing and that more attention needs to be directed towards producing better manufacturing jigs, to gain better tolerances or to include overlaps in the design to cover up bigger gaps.

Due to local fractures and chips in the acrylic panel, that where present in the area where water jet enters the material when starting inside the perimeters of the panel, smaller holes (under 20 mm) had to be subsequently bored with a hand-held electric drill.

Some of the acrylic components, that were laser cut, exhibited light burn marks on their edges and required some sanding. Thinner pieces of acrylic were observed to bend from the heat of the laser, causing notable aberrations with repeated passes of the laser. Therefore additional attention had to be paid to how placement and distribution of the components on the acrylic sheets.

Although, the CAD model of the new design translated well through the manufacturing
of the final prototype, some deficiencies in the visual appearance were discovered, upon a preliminary assessment. For example, the laser etched logotype was not as distinguishable as intended, but could be colored in with paint, to provide more contrast, making the logotype more visible.

The building process proved much more time consuming than was originally assumed. With two people combining around 250 working hours. The final prototype therefor features some improvised fasteners and misses some small features, such as a mount for the IR transmitter.

The articulated arm, supporting the side display, serves little function, more than to allow the optimal placement of the display to be found and could be replaced by a simpler rigid arm solution in a future design iteration.

At the time of designing the new Kobra enclosure, the development of the new haptic devices, that are to be fitted into the simulator, was not yet fully completed. Therefore, the enclosure had to be made larger than perhaps necessary. Dimensions form an early design specification of the new haptics, were used to determine the minimum height of the enclosure. Adding to the size of the electronics enclosure, it has been designed to facilitate some additional components, if such are necessary to incorporate in the future.

5.2 Conclusion

After 20 weeks of work, the project was determined to have delivered results that were successful in achieving the intended goals. Inspired by findings from a comprehensive user study, conducted at the teaching hospital in Riga and relevant literature, the new design of the Kobra aims to improve the usability and market attractiveness of the product offering. This while being tailored to utilize the manufacturing technologies available to a small-scale in-house or out-sourced production team.

A key insight from the user studies was that the dynamic interaction between the instructor and the students is likely to be one of the most important features of a simulator. A conclusion that is also supported in the literature. The wide viewing angle of the large co-located stereoscopic display, incorporated in the new simulator, aims to facilitate such interaction.

A full-scale functioning prototype of the concept was built in-house, using the proposed means of manufacture. This to evaluate how the new design translates from a 3D CAD model to a physical product, from a visual appearance and a manufacturability standpoint. The results of the following preliminary assessment of the prototype indicated that the virtual design had been successfully translated through the manufacturing of the prototype, with only small modifications to the original construction, and that the prototype was able to produce the intended visual appearance.
Further, some suggestions for minor design improvements and future development were made, mainly aimed towards better preparing the product for manufacturing and to evaluate the usability of the new design, through a user study. The results of the project was a detailed design proposal, demonstrated to be close to ready for production. Additionally, the user studies yielded important insights about the users needs, that could be beneficial in future development of new software for the simulator.
Chapter 6

Recommendations and Future Work

Due to the limited size of the thesis project, it was impossible to realize every aspect of the simulator. During the user studies in RSU many possible improvements were discovered that would not make it to the final prototype. These findings will be discussed here as well as possible ways to optimize the process of building the simulator.

6.1 The Manipulandum

During the user studies it became apparent that the existing manipulandum would benefit from a redesign. The students and teachers both expressed the need for different interchangeable manipulandums for different simulation scenarios. Today the user has the ability to choose from a drill and an elevator, however in real practice it is also common to use forceps, a tool that is not represented in the simulation. When using forceps it is necessary to use a different manipulandum, which features finger loops at the grasping end that can register when pressure is applied to the handle. If something like this is to be manufactured, it is then important that the different manipulandums can easily be interchanged and that the software recognizes the tool swap. This can be accomplished with the use of a manipulandum stub connected to the haptic device and some sort of snap fit with different electrical connections being shorted depending on what tool is used. One solution could be to combine the locking and electrical connections with the use of neodymium magnets that also acts as galvanic contacts.


6.2 Head Tracking

The need to be able to change views in the simulation proved to be a much needed feature. Either through physically rotating the prosthetic head or through head tracking of the user. Since the patient lies still in clinical surgeries and the surgeon moves around the patient it was deemed suitable to choose head tracking. A head tracking product system was acquired for the project and the IR receiver was integrated in the simulator design in preparation for this feature. What was not fully investigated was the mount for the IR transmitters to the user. These should be mounted to the stereo monitor glasses but how they should be integrated needs to be worked on. It is then important to consider the overall design of the simulator and how this could be coherent to the 3D glasses which now features a design from NVIDIA. Although the basic components needed to support the head tracking feature were included in the final concept, more development and testing need to be conducted, to ensure that it is functioning correctly. Alternatively, if the head tracking solution is proven to not sufficiently support the users needs, an effort should to be made to develop a solution for mechanically rotating the manikin head and connecting a corresponding movement in the virtual environment. Head tracking may be a better feature for marketing purposes, but the choice should in the end be reduced to which solution best supports the function.

6.3 Software Development

Several of the interviewed instructors and students raised issues about the software. There are some areas in this department that would benefit from a revision. When using the elevator, the feeling does not conform to what a real elevator feels like. It sometimes acts unpredictable and moves straight through the model.

The request for more tools was made from several students and instructors. A virtual tool cabinet with different shapes and sizes for the drill bits is a good place to start.

A new category of simulation scenarios consisting of more simple exercises suitable for students without other experience from clinic practice since many of the existing users are first or second year students that want to learn basic surgery instead of the existing advanced cases.

More information and data was requested. Since the simulator now features a bigger side monitor it would be possible to add this in the form of more X-ray images and written step-by-step guides for the cases.
6.4 Design for Immersion

The ideas derived from the user studies included new features to support better immersion. The manipulandum of the haptic device is suggested to include a small speed controlled vibration motor, that could be used to emulate the vibrations of the drill at varying rotational speeds as it encounters varying resistance in the virtual tissue. Similarly, the enclosure could be equipped with a speaker that could replicate the drill sounds.

It was also suggested that the manipulandum should be heavier and to have a geometry that more closely resembles the original tool handle to get a better grip and feel, much like the one featured in the Moog Simodont simulator.

6.5 Other Suggestions for Future Development

To mediate the flaw in the new design of the electronics enclosure and the enclosure of the stereoscopic display, namely that errors in the producing the correct shape of the panels and misalignments in the assembly creates highly visible gaps, alternative construction options could be investigated. For example, it could be considered making the enclosures as one component out of a glass fiber reinforced composite, that would require no panels gaps and that could be more easily prepared to achieve a fine painted finish. Alternatively, it could be reviewed if vacuum forming a sheet of thermo plastic could be a better option.

The active shutter glasses for viewing the stereoscopic display are today stored in a separate drawer in the simulator room. It becomes awkward to store and charge the glasses and it would therefor be recommended to integrate the storage and charging of the glasses with the simulator body.

Another problem that could be addressed in the future, lies in developing a solution for protecting the mirror, so that it does not quickly accumulate dust, that lessens the image quality. Alternatively, a solution could be developed for allowing the mirror to be cleaned without easily scratching its surface.

6.6 Follow-up Studies

A successful user study incorporates a follow-up phase, where the users are confronted with the result of the design study. From that follow-up it is possible to get useful feedback on the new design and highlight issues and design flaws that might have been overseen during the concept phase. Due to time restrictions it was not possible to do this within the time-frame of the thesis project and it is therefor recommended to the company to do this before the production begins.
6.7 Marketing Strategies

The current generation of the Kobra is being labeled as solely an oral surgery simulator. In order to reach a wider range of customers, new marketing strategies needs to be deployed. As part of a suggested product management measure, the new simulator is made to serve as the main hub in a product system that could facilitate a number of different simulation tasks, with only a software update and minor alterations or add-ons to the hardware. With this in mind, the new enclosure was designed to be easily modified to accommodate different types of simulated procedures. The manikin module allows for substituting the manikin head to, for example, a manikin knee or a silicone representation of any other body feature. The universality feature of the system can be further enhanced by developing a support for different manipulandums, representing the grasping end of different medical tools, to be used with the haptic devices.

Further, to promote the open source nature of the platform, a developers kit, aimed at researchers, could be offered in the product lineup. This kit may include, in addition to the new simulator hardware, all the necessary tools needed to develop new software for the platform and to conduct research around it. This product variant could be an effort to encourage research and development collaborations with outside institutions, that could establish and expand the platform.

6.8 Preparing for Manufacturing

Since the thesis project did not include the work of fully adapting the design for manufacturing, this is something that needs to be done. This includes evaluation of the chosen manufacturing methods and producing detailed drawings with critical tolerances marked out. This should be done in consultation with the manufacturers. Thoughtfully planned assembly documents also needs to be produced in order to make the assembly quality repeatable.

Further, to produce future units of the new Kobra, contractors, that are willing to manufacture all the custom components, at sufficient quality and cost, need to be found. The final assembly could be made in house. Moreover, a plan for how to coordinate a build, when a future order is placed, needs to be established as well as the cost of doing so, in order to be able to state a price and delivery time of the product.

6.9 The Future of the Prototype

The final prototype produced in this project will be used to market the new product and serve as a development platform, before it is potentially sold to a customer. To prepare the prototype for public display, some improvements need to be made. Among the most
important work that still needs to be done is to incorporate the new haptic devices that, at the time of this project, are being developed, affix the manikin head and make sure that the head tracking works properly. Further, some of the visual defects, that occurred during the manufacturing, needs to be addressed. To conceal the visible gaps between the panels and corners of the two enclosures, the side panels could be dressed in sheet acrylic, of the same type used elsewhere. To create a floating impression, the new acrylic panels could be offset, at a suitable distance, from the painted aluminum panels behind. Their edges would on some places protrude over a panel interface and cover the existing gap and on others exaggerate the gap, where a good fit would be difficult to achieve. Dressing the sides with white acrylic would also solve some problems with color and texture matching.
References


Appendix A

Gantt Schedule
Appendix B

Risk Assessment

Risk Assessment

The risk assessments are comprised of the possible risks, which are graded based on likelihood of happening and consequence if it does happen. The scale is 1, 3, 9 where 1 is most unlikely and trivial and 9 is most likely or serious consequence. If a risk is graded as a 9 on consequence, an action plan is put together. The risk assessment can be seen in table B.1 on page 78.
Table B.1. Risk assessments with action plans.

<table>
<thead>
<tr>
<th>Possible Risk</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Action Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>No useful design input from pre-study</td>
<td>3</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Visit to RSU gets canceled</td>
<td>1</td>
<td>9</td>
<td>New date for visit or local focus group put together in Stockholm</td>
</tr>
<tr>
<td>Visits to other universities not possible</td>
<td>3</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Information from user studies shows to be irrelevant</td>
<td>1</td>
<td>9</td>
<td>Design will be evaluated by focus group instead</td>
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Appendix C

Moodboard
Minimalistic
Anodized
Natural
Laguna
5H74 DC
Pacific
5H09 DC
Satin
Surfaces
Light but
Strong
Appendix D

Interview Guide

We come from the Royal Institute of Technology in Stockholm and are doing a Master’s Thesis on surgery simulators. We are interested in how you use and experience the oral surgery simulators. We would like to understand the process and work-flow when you are using the machines as well as how you feel that they contribute to your learning process. The interview will take around 10 minutes to complete, your personal information is only used as reference and will not be published. The information we gather from it will be published as a part of a master’s thesis.

Do we have permission to publish this interview?

Observations

We are students at the Royal Institute of Technology in Stockholm, doing our master’s thesis work for Forsslund Systems, the guys who designed the Kobra surgical simulator. We have come here to perform some user studies, that will aid in the development of the simulator. So we will be performing observations of a class using the Kobra today. We are here to conduct some observations and everything will be recorded and transcribed. The transcript will later be published as a part of a master’s thesis.

Do we have permission to publish these observations?

Kobra STUDENT

Personal information

What is your name?

What are you currently studying?

How long have you been studying?

General questions
Appendix D. Interview Guide

Have you had any experience with real patients yet?
Was this your first time with the simulator?
How much time have you spent with the Kobra?
What course is this exercise a part of?
How did you prepare for the exercise?

User experience
(!) What was it like to use the simulator?
(!) What was difficult/hard during the simulation exercise? Was any part stressful?
Describe what you did in the simulation exercise step-by-step!
(!) What did you like about the experience?
(!) What did you not like?
Can you remember any moment where using the simulator gave you an insight?

Kobra practical use questions
Do you remember your initial thoughts of the simulator/simulation? /What was it like to use the simulator at the beginning of the exercise?
What did the instructor help you with?
(!) Were there any part of the simulation that were unclear?
What made it hard to concentrate on the task? /What was distracting? What was confusing?
(!) What made the simulation feel real?

Kobra educational questions
What would you say is the purpose of the simulator training?
(!) Can you describe what you have learnt using it?
In what way has the simulator exercise prepared you for a real surgery?

Conclusion
Go over the questions and answers if there is time
(!) Is there anything you would like to add?

Kobra INSTRUCTOR
Personal information
What is your name?
What is your profession?
How long have you worked as ... ?
How experienced are you teaching with the Kobra?

**General questions**
On how many occasions does the student train with the simulator?
How long are the sessions?
What do you try to teach to the students?

**Simulators in education**
(!) How do you feel working with the simulator?
(!) How do the students feel working with the simulator?
(!) Do the students find the simulator intuitive?
What do the students find hard?
(!) What elements from real-life surgery are missing in the simulator? How do you compensate for the missing elements in the simulation?
(!) Describe how you interact with the students using the Kobra!
When do you think simulator training is most valuable for the student?
What do you look for when evaluating the student’s performance using the simulator?
(!) What cannot be learned in a simulator?
What are the simulator’s limitations?
Describe the student’s reaction when they use the simulator for the first time!
Why are simulators used in the education? /What are your thoughts on using this type of simulator in the education?
Do you see a difference in learning and skill between students who have used the simulators and those who hasn’t?
What role do you hope simulators will have in education in 10 years?
What could motivate you to use the simulator more in the education?
What would be needed to make it more useful earlier in the education?

**Simulator design**
How do you find the screen size?
Appendix D. Interview Guide

Would you like to see any changes in the user interface?

How could the ergonomics be improved?

Have you encountered any issues or difficulties using the simulator? Is there something from your perspective that could be functioning better? Have you experienced any failures with the hardware or software?

If you were to change, add or remove something to the simulator what would it be?

What kind of instructions or guidelines have you gotten for using the simulator?

Conclusion

Go over the questions and answers if there is time

(!) Is there anything you would like to add?

Moog STUDENT

Do you use the sound?

Are you bothered by it?

Comparisons

For us to determine how they differ

Questions that did not make it

Did you feel comfortable asking the instructor for help?

Do you use any props?

Did you feel any part was unnecessary?

What would be needed to make it more useful earlier in the education?

Is it missing any features that the other simulators have?

how much they remembered What do you remember from the simulator exercise?

what they felt was important What elements of the simulator training are important for you?

what they thought was useful What elements do you think are useful?
Appendix E

Kobra Lab Transcript

Transcript of Kobra-lab in Riga

Starting up the Kobras, first start the computer and then start the touchpad, there are some difficulties/issues when starting the touchpads.

Ieva:
They should just have been calibrated so I hope everything will work OK.

Surgeon B:
In Real Life (IRL) we separate only with other (drill) bits but in this simulation, we only have access to a round drill. IRL we would use it to remove some bone but not for separation. When we separate 60% we can now use the elevator and extract one side and then we can place the elevator in this place... In real life, I do separation of molars without levers, only without levers. I separate with conical drill and I do extractions with forceps.

Student:
Can you help us; this elevator feels so strange.

Surgeon B:
Usually it works like this (shows something) but now, it doesn’t. this simulation is not correct. And also, we have only a round drill, it is not correct for this operation. Usually in this place we can take the bone with a round drill but after we need to separate with a conical drill, not this.

Student:
Can you move the head? We would like to be able to move the head. To get better views. (Tries to rotate in the software) Oh, but this is not how the patient looks IRL. IRL we can turn the head or turn around the patient to get a better view. Look at this, we can’t see here, so IRL we would turn around the patient. So, if you could turn the head or have head tracking, that would be good. (Student goes on to show that they want
to rotate in all directions but mainly around the vertical axis and also tilting the head forward).

**Surgeon B:**

We don’t want to traumatize the patient, IRL if we drill too much here we will damage the nerve which can’t be seen here. If I drill here the patient will get trauma for the rest of his life. IRL I can’t do like this (shows something). The idea of this program is very good, but this program is not so good, it’s like Pac man. So now I don’t see, we must drill some more and put the patient at risk. IRL I would extract now because it’s fully separated but now, with this elevator I can’t. (Students are holding the manipulandum with “awkward grips”, like with the entire hand.)

**Student:**

The elevator does not behave as in real life. It’s strange because you think you are in the correct location but then there is no resistance.

**Surgeon B:**

Usually we extract this distal in this place. I shave this root then I take forceps and extract, not only with round drill and straight elevator like in this program. We need more options of instruments. In this place, we usually have nerves and blood vessels but now in this program we don’t have that. (Surgeon B has some issues with an extraction. Wrong part is extracted.) Normally I separate this in four pieces because this bone is like paper. If I take this bone like this simulation in real life all these frontal teeth will be shaped and will also need to be extracted. Maybe after 10 years this program will be much better. (The students want to hold the jaw for support but are hesitant since the rubber head shifts in position and does not feel secure)

**Surgeon B explains different scenarios:**

If the patient is young then maybe we can be a bit more experimental and grow this bone after. But if the patient is maybe 50 years old with general health problems then we only make an extraction, because with this inflammation it doesn’t heal usually. The bone IRL is very different. In some places, it is soft so you can use the elevator and in some places, it is like stone. Usually this bone also has necrosis and doesn’t heal very well. The students tend to hold the manipulandum in strange grips compared to the surgeon teacher. (can be seen around 45 min into the video) could be because of the difference in weight and shape compared to a real drill handpiece.

**Surgeon B:**

usually I like to take photos of surgery and show to students. For instance, with oncological cases where the patient needs me to remove a cyst. On X-rays, everything can look beautiful but in real life you can have scarring and inflammation.

**Student:**

Great idea but difficult. Would like some more instructions, like now when we have a supervisor. For each case to have a walkthrough or a 30-second instruction on what to do.
**Surgeon B:**
More realism is needed.

**Student:**
the ability to move the patient’s head in different directions. A library with more tools (like in the Moog) In real life we need maybe 20-50-100 different devices/tools, here we have only two tools.

**Surgeon B:**
This bone is very different from real life. This program doesn’t imitate the real anatomy of a human with blood vessels and nerves. There is no bleeding and the flaps design is not realistic. In abdominal surgery simulations, it is very realistic and the surgeons can gain from training.

**Student:**
Maybe the haptic device would be better if it had more resistance or make the manipulandum heavier. Now it is very light, it’s like holding a pen.

**Student:**
It would be nice to be able to move the head around and maybe have a sensor so that it also moves on the screen.

**Surgeon B:**
The soft and hard tissue does not feel the same as a real human. If I use 100 x-rays I can teach more than the simulation as it is now. Maybe if it gets more realistic, then it will be useful.

**Student:**
The 3D-glasses are flickering and it makes it hard to focus.

**Surgeon B:**
It would be nice if the manipulandum could imitate a real drill handpiece. The resistance of the different tissues needs to be calibrated. It does not represent the real feeling when drilling in bone and enamel.

**Student:**
The elevator felt very strange. You just have to touch the tooth and it plops out.

**Surgeon B:**
Yes, in real life I can damage the bone with the elevator, in this simulation the bone feels like metal so it is not realistic.

**Student:**
The Moog feels more precise. It gives you vibrations and sound.

**Surgeon B:**
We need more standard cases, like standard extractions before the students move on to more complicated cases. Here we only have difficult cases, students need to study on easy cases like one root extraction with forceps not with elevator.
Student:
It would be nice to have some forceps. Forceps is the most useful tool to practice for students.

Surgeon B:
We need more tools, like different shapes and sizes on the drill bits. For almost every case we use different tools.

Student:
it would be nice to have some cases where we can practice suturing because we aren’t allowed to do that yet on patients. Anesthesia could be nice, where you can see the nerves as well.

Surgeon B:
IRL all flaps are different so that would be nice to incorporate in the simulations. It also needs more nerves, here we have only one but IRL there is more than one and you need to know where they are.

Student:
A scalpel tool would be nice so that we can practice on the flaps.

Surgeon B:
Yes, how to correct the flaps and how we need to do the incisions. And to show where the nerves are. Implant cases are also important, all students need to know how to put in implants.

Student:
The most useful tool for beginner students is the forceps, and they are missing here. One more arm for a mirror would be useful because often we can’t see what we are doing so we must guess.

Student:
The most constraining aspect of the design is that you can’t see because you can’t move the head around, it is the biggest problem (and the elevator).

Surgeon B:
The x-rays presented in these cases are not so informative. We have only one, that is not very good resolution. Usually I take photos or recordings of real surgeries and show to the students. Then it is very easy to show. It could be better to show that in the simulator.

Student:
Head tracking would be really nice and bring an edge against the competitors because they don’t have that. Maybe you could incorporate the Microsoft holo-lenses in some way.

Conclusions:
• The ability to move the head/view or use head tracking on the user to change the view is a needed feature.
• Ability to change the tools in the simulation.
• The addition of forceps.
• The manipulandum needs to be more realistic with more weight.
• The possibility to add a forceps manipulandum tool would be appreciated.
• Better side monitor with higher resolution.
• 30-second instructions and or video of real scenario and more and better x-rays.
• Improved realism with better anatomy.
• The elevator needs to be calibrated.
• Vibrations and sound could improve the realism.
Appendix F

Interview Transcript

Transcripts of interview with Surgeon: A on 9.3.2017

Surgeon A
Surgeon, interviewed in Riga, much experience with Kobra

Some “Yeah?” and “you know?” removed from the transcripts.

[Missing part of the interview]

[...] [Surgeon A] understand a little bit about how to work with straight elevators, maybe.

Martin:
There were some comments about the elevator not feeling the same?

Surgeon A:
Yeah, they don’t feel this pressure, in which way they should hold the elevator. Maybe with the drilling the students don’t have any problems at all.

Martin:
How do you feel the conical drill not being...?

Surgeon A:
Yeah, actually the conical... the [inaudible, fissure?] drill. Yeah? Because mainly in clinics, with round drill, it would take [inaudible] only around with the crown. You know? But for separation tools, we are using fissure or the conical drill. Also, this is mainly the one part students sometimes don’t understand why in clinic we are using only conical drill. Because for separation we’re using conical drill. At first we could make with a round bore a small hole in the crown. But then we separate with the conical drill. If it is possible to make, in the Kobra, with the conical drill, it would be very good.

Martin:
Appendix F. Interview Transcript

So what other elements from real life surgery are missing in these cases? You say it is very basic stuff here?

**Surgeon A:**
From real life... No, I think the basic... Not the basic stuff, but basic principles. Principles of operations. All the cases I think are very good. Maybe we need some more cases in separation... extraction upper jaw molars [?, 1:47] and upper jaw wisdom tooth as well. Maybe in not so easy position. Maybe not vertical, but mainly more mesioangular or horizontal. Because this operation is very hard IRL and the patient. For the students it will be very good to see that. Separation upper jaw molars, one [inaudible, “seiz”?], 2:21 or two [“seiz”?] here, because sometimes we can’t extract only with forceps here, we need to separate each root here. This one. Maybe also root extractions.

Sometimes we separate also each tooth have only one root and it’s fractured maybe on the bone level. We can’t extract with forceps, we separate the root. If the root is one, also we could separate this one root as well.

**Martin:**
Is that a hard exercise?

**Surgeon A:**
Yeah, it’s hard extraction. Root extraction. And implants, if it is possible.

**Martin:**
How do you interact with the students using the Kobra? We have seen now Dr Stepanovs instructing. Do you... Can you describe how you go about?

**Surgeon A:**
So I describe... everything. I start with the Kobra simulator. I start also with position of the patient during operation. Always I try to teach students to hold the the jaws when we operate. Because always... sometimes students also take the drill and doing... No, we should hold the jaw as well. Of course before operative care, how to clean hands, how to use masks, heads, coats also, because mainly the separation we’re doing in operation room and students should prepare for this operations.

**Martin:**
Do you prepare the same way also for the Kobra?

**Surgeon A:**
Yeah, yeah. Not all the time. We show them, they could try, but it’s only the one time. Because actually no we don’t have a lot of time for it. Of course we students teach and show them how to do it, but maybe one or two times I think is all.

**Martin:**
What part is the most valuable for the student?

**Surgeon A:**
I think the wisdom tooth extraction, they mainly want to see it. In Latvia, and I think
in Sweden as well, wisdom tooth are a great… not so great…

**Martin:**
Are they common?

**Surgeon A:**
Common problem and extractions are a tot.

**Martin:**
What do you look for when evaluating the student’s performance?

**Surgeon A:**
No, we don’t have any exams or testing with the Kobra. We only teach them, they practice and that’s all. Of course we see that in Kobra we could see what the student is drilling. For example extracting lower jaw molar, it is very important not to drill the nearby tooth and in Kobra we see it. There is numbers. We try to teach the students not to drill the neighboring tooth, not to drill the bone around a lot, but we don’t have these marks, any marks, any testing in the Kobra. The Kobra is mainly just for practice, for more experience.

**Martin:**
So what can not be learned in the simulator?

**Surgeon A:**
It is a hard question. I think, according to Kobra, it couldn’t be learned, for example, flap design. I think. Because only, according to each situations, the flaps are very different. And I don’t know if it is possible in Kobra to make some simulations with the flap designs, how to do it. With a scalpel, I don’t know. Flap designs, it’s the one part. Then, because I think this feelings of drilling bone, drilling crown is very very similar IRL. Pressure, also. Of course it is not so strong as IRL, but there is a difference. And the students also see, for example, this elevator stuck in bone, they feel it… Maybe the flap design.

**Martin:**
So, a bit of the practical questions. Have you encountered any issues or difficulties with the simulators?

**Surgeon A:**
No. Actually, during from the technical part, it seems there’s no any problems. I don’t hear about it. Every time, when I came to a Kobra, everything was working. The glasses, all the computers, Kobra, no problems. Maybe, I don’t know, maybe Solvita (Solvita Graudina, administrator) knows something about technical part problems. But every time I was working in Kobra room, everything was fine, without any problems.

**Martin:**
We saw here, there was some plates you stand on…

**Surgeon A:**
Ah yeah, these plates. There are plates for the students, for females, because the window
is too high. For me it’s okay. For the students, who are not so high, they can’t see it.

**Martin:**
We saw a lot on the toe and trying to operate the pedal there…

**Surgeon A:**
We put some boxes and then the students can stand on this box.

**Alex:**
How is it compared to real life, when you operate IRL, do you stand or do you sit down?

**Surgeon A:**
When we are... okay, I think IRL we always stand. We always stand. And also IRL, if the surgeon is tall, but if the assistant is not so tall they are using these boxes. IRL as well.

**Martin:**
The user interface, would you like to see any changes in that?

**Surgeon A:**
Interface I think is okay.

**Martin:**
Any features... anything you would like to add over all to the design, or change or anything that you have bugged yourself on?

**Surgeon A:**
No I think design of the Kobra, in my point of view is not so important. It’s important, as technical part, the cases. If there will be more cases, as I mentioned, root extractions, separations of the tooth in the upper jaw, wisdom tooth extractions upper jaw, it would be very good. Or maybe also mesiodens extractions. They are very often from the part of side we have canine extraction, but there is a difference between mesiodens extractions and the canine extraction. This one also.

**Martin:**
How do you benefit from the real-life cases? I know you have sent data to Forsslund.

**Surgeon A:**
Actually if we have in clinics interesting case, we’re speaking with our head of maxillofacial department, with Professor Akota, and then we discuss maybe this case will be good to make it in Kobra simulation as well. And I think the last hand of a choice of this clinical case is in for Ieva, Ieva Bāgante. They choose these cases. We could only suggest something.

**Martin:**
Have you gotten any instructions or guidelines before using this?
Surgeon A:
I think I had only instructions. I didn’t see any papers and instructions. I think I was trying by my own, everything at first time. But it was very easy, because everything is written. Everything you could see, the pedal is... left part drilling, right part elevator or the [inaudible, 11:57]. We only need to know username, password, then everything is written on the tablet. So it is easy.

Martin:
Yeah, so that is about it. Anything you would like to add?

Surgeon A:
Maybe the head of a cobra [jokingly].

Alex:
How do you feel about the prosthetic head. Does this work? We saw some issues in there, where the students wanted to rotate the head.

Surgeon A:
Ah yes. Also sometimes students want to rotate the head. Maybe for them it will be more good. Because also when we’re operating, as the position of the patient not all the time is in one position. Sometimes we need maybe more on the left side, on the right side, to the chest. It would be a good opportunity to rotate the head.

Martin:
How do you feel, do you get proper rest with your hand on the mannequin?

Surgeon A:
For me the height of the patient is very good and height of the mannequin and then the position of the head. Because always when we’re drilling with the one hand or if we are working with elevator, another hand we’re using to hold the jaw. Because it is very important. And I try teach the students as well to hold the jaw all the time.

Martin:
I saw Dr Stepanovs using both his hands when using the tool, the haptic unit. Do you know why that is?

Surgeon A:
I don’t know. I need see this, what he was doing. Actually only... if you are working with the forceps as well, with one hand we hold, with the other we make extraction. With straight elevator as well, we are holding lower jaw. Upper jaw, every time, one hand hold the jaw. Because if we will not hold the jaws we will fracture the jaws. And for the patients also it is very hard to keep his head in one position as well. Sometimes also we have very maybe hard extractions, sometimes assistant is also is holding the head. We hold and assistant.

Martin:
So it’s all Ieva who does the contact with the cases and everything? So you go to her
every time if there is anything you would like to add or something, surgical case or something, it’s through her?

**Surgeon A:**
Yeah, because she is responsible for our educational part.

**Martin:**
Have you used the Moog Simodont as well?

**Surgeon A:**
I, no. I see the Moog one time only, which was very good. I don’t know now why I choose oral and maxillofacial surgery. Because students could practice in Moog, drill... I try it one time.

**Martin:**
Was it a good experience?

**Surgeon A:**
Yeah, it was good.

**Surgeon A:**
We hope to see it later, if there is any students around...

**Surgeon A:**
I think the students [fourth year students standing by, no experience with Kobra] had experience in this Moog.

**Martin:**
Really? Have you used the Moog?

**Student 1:**
Yes.

**Martin:**
How do you like that simulator?

**Student 1:**
Well it’s different from the real life, very different.

**Student 2:**
It’s a good way to practice to be precise.

**Martin**
So how much time have you sat behind the Moogs?

**Student 1:**
A few hours.

**Student 2:**
We had to practice a lot and then we also had a test. So we had to practice before
so, that we pass the test. It was part of the exam for the prosthetics, in second year I think.

**Martin:**
Okay, so you had a score you had to reach?

**Student 2:**
Exactly! And a few girls failed. And they had to redo it, so it wasn’t that easy.

**Alex:**
Is there anything that you feel isn’t working very well with the Moog, something that you dislike?

**Student 1:**
They sometimes vibrate or something like that.

**Martin:**
When is that?

**Student 1:**
I really don’t know...

**Student 2:**
I think if you do something wrong, then it fails somehow and you can’t continue and you have to restart it. So it does some technical difficulties sometimes. But it wasn’t that often.

**Alex:**
How did you feel about the monitor and other hardware?

**Student 2:**
It was okay, yeah.

**Martin:**
So you have done real surgeries already? So what do you think this [Kobra exercise] will be like? Will you do this one time?

**Students:**
We can’t wait to try!

**Martin:**
Would you try, if there is access to... Do they have access to these?

**Surgeon A:**
Of course, in any time.

**Student 1:**
We actually didn’t know that there is something like that. So it is something new for us.
Appendix G

Display Solutions
## Decision Matrix – Display Solutions

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<th>Stereoscopy</th>
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<td>HTC Vive (1080x1200) 10 000 SEK</td>
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<td>Nvidia 3D Vision 2 2 000 SEK</td>
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<td>?</td>
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<td>Nvidia card</td>
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<td>+ Co-location</td>
<td>- Sub-optimal stereo plane</td>
<td>+ Modern</td>
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<td>+ Easy to implement</td>
<td>- Large (beam path)</td>
<td>- Visual fatigue for the user</td>
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</tr>
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<td>- Expensive</td>
<td>- silver screen? polarizing filters?</td>
<td>- Heavy to wear</td>
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<tr>
<td></td>
<td>- Outdated technology</td>
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<td>- Low resolution?</td>
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</tr>
<tr>
<td></td>
<td>- Noisy?</td>
<td></td>
<td>- Focus</td>
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</tr>
<tr>
<td></td>
<td>- Large effort to evaluate feasibility</td>
<td></td>
<td>- Different product</td>
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<tr>
<td></td>
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<td></td>
<td>- Lose contact with surroundings</td>
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Appendix H

Components
The frame is built from 40 x 120 mm extruded aluminum profiles from Aluflex. They are adapted for M8 fastening elements and come from the manufacturer cut to specification. Electrical wiring can be routed through the center voids of the frame for a sleek design without loose wiring. The bottom of the frame is fixed to the bottom plate with four heavy duty angle brackets cut down to allow clearance for the table top. The two segments of the frame are joined at a 60 degree angle with cut 5 mm steel brackets powder coated pure white.
Top Bracket

1.5 mm steel with pure white powder coat.

60 and 30 degree bends to clear monitor.

Oblong mounting holes for easier assembly.

The top bracket fixes the monitor cover to the top part of the simulator frame. It is cut from 1.5 mm thick steel to produce a stiff bracket. The steel plate is bent to allow clearance for the stereo monitor and then powder coated in pure white. The mounting holes have been made oblong in order to aid adjustments after assembly is done.
Top Frame Cover

5 mm pure white acrylic sheets.

Mounts with two M8 screws to top frame.

Heat bended to correct shape.

Made from three parts and cemented together.

The top frame cover encapsulates the top part of the simulator frame to give it a more uniform design. It is made from white 5 mm thick acrylic sheets that are cut to shape, heat bended and cemented together. It is then mounted with two ball head stainless steel M8 screws directly to the top frame.
Main Monitor Cover

5 mm acrylic sheet top.

Ventilation holes to reduce heat build up

1.5 mm aluminum sheet sides, powder coated white.

Extruded aluminum corners cut at a 20 degree angle.

The main monitor cover houses the stereo monitor and retarder filter. In the rear there is two entries for the IR electronics cables. The corners of the cover is manufactured from extruded aluminum with a natural anodized finish. The cover is angled inwards to create a slimmer design.
The retarder consists of a polarizing filter, not unlike ones common in photography. When the light from the stereo monitor reflects in the mirror, the light gets polarized and darkens the seen image. To reverse this effect the retarder polarizes the light directly in front of the monitor so that the light waves can be returned to their original orientation through the mirror.
The retarder frame consists of two cut acrylic sheets bonded together. The white frame holds the retarder filter in place in front of the stereo monitor. The bottom part of the frame has been heat bended and then bonded with the IR transmitting acrylic sheet. The IR transmitting sheet covers the infra red sender and receiver units mounted on each side of the frame.
The IR housing is vacuum formed from 1.5 mm thermoplastic sheets. It houses the infra red transmitter for the 3D glasses and the receiver for the head tracking system.
Embedded in a pure white acrylic frame is a first surface mirror that is mounted on silicone bushings to reduce the transfer of bending forces on the mirror. The frame is consisting of two pieces cut from 10 mm acrylic sheets and bonded together.
The Mirror support is cut from 1.5 mm sheet metal and powder coated pure white. The support arms have 70 degree bends which spread out the load more evenly. The support is mounted to the simulator frame with four M8 ball headed screws.
The front panel covers the extruded aluminum frame between the mirror and the table top to generate a more refined design. It screws directly to the frame and the screwhead is hidden from view underneath the tabletop.
The front cover is made from colored 5 mm acrylic sheets with a frosted surface finish (Pacific 5H09 DC). It is cut to shape and heat bent to 60 degrees with a radius of 156 mm. The front cover hides parts of the frame and gives the simulator a touch of colour. A notch is taken out on the right side of the cover, to make way for adjusting the side monitor arm.
The side monitor arm is bought from Item (0.0.678.76), it has a gray powder coat finish with four hinges for positioning adjustments. The main arm is fitted with a variable gas damper to allow smooth height adjustment regardless of the monitor weight. It screws directly to the simulator frame and cables to the monitor are easily hidden in the black cable holder. The use of a VESA mount allows for many different monitor options.
The prosthetic head acts as added realism and support for the user. During simulations of molar extractions it is common to hold the lower jaw. To increase the rigidity in these cases, the silicone is molded over a thermoplastic core. The model is based on the virtual model in the simulations to add to the coherence of the simulator.
The table top is manufactured from 10 mm thick acrylic sheet with a white color infill (GS WH01). The sheet is cut to shape and a lip on the front is heat bended with a 20 degree incline and 50 mm radius to create an inviting design, signalling to the user that this is where you are supposed to work. The large table top area allows for the use of dual haptic devices if desired.
The table top frame is cut from 3 mm thick aluminum sheet and powder coated pure white. It mounts directly to the computer casing with four M8 screws and the table top can then cover the casing. The table top is fastened with two sliding locks to ensure easy and fast access to the electronics while reducing the need for visible screw heads.
The computer and electronics casing is the heart of the simulator. The corners are made from extruded aluminum in a natural anodized finish. The corners are cut at a 10 degree angle, tilting outwards to create a less boxy design. The panel on the right houses the up and down buttons for the height adjustment and the panel on the rear houses a cable entry point and USB port.
Bottom Plate

Cable entry points for electrical wiring.

Lifting hooks intended for two persons to lift simulator off pedestal.

Mounting holes for pedestal.

Mounting holes for frame and support.

Powder coated pure white

The mounting platform for entire simulator. Cut from 5 mm steel and powder coated white. Lifting hooks allow for two persons to carry the simulator when separated from pedestal foot. The backbone frame for the simulator is mounted in the rear and supported by 90 degree angle brackets.
Table Pedestal

Adjustable height through electric linear actuator.

Adjustible height from 66 to 118 cm.

100 kg lifting capability.

Rubber foot plate for mounting foot pedal

Pedestal is bought complete from ConSet. Serial number: 501-19 7S120 in silver finish. Modifications made to the pedestal is the removal of the table top support structure (not shown in this figure) and the exchange of height adjustment switches to ones more coherent to the general design.