Simulating Dialysis
Concept Evaluation of a PC Training Simulator for Nurses

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Abstract

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Nurses at a haemodialysis clinic are required to handle complex technological equipment in a stressful environment, with the patients’ lives at risk. A training needs analysis (TNA) that was made at Karolinska University Hospital Huddinge in 2010 identifies the nurses’ need to practice alarm situations in the safe environment of a computer-based training simulator. This project builds on the conclusions of the TNA and the aim is to evaluate the concept of a training simulator by developing and evaluating a prototype program.

The simulation model used is the prototype is based on a problem solving approach with virtual patient scenarios. During the entire development process continuous input has been gathered from nurses who work with dialysis. The project was completed by structured user test focusing on evaluating the usability and realism of the prototype.

The conclusion of the project is that nurses working with dialysis need to practice alarm situations and that a training simulator could meet this need.

The report is written in English.
Populärvetenskaplig sammanfattning [Swedish]


Simuleringsmodellen som har framtagits för prototypen bygger på scenarion med virtuella patienter. Användaren väljer hur många patienter som ska simuleras och varje patient har en specifik komplikation. När simuleringen startas larmar dialysmaskinen och det är användarens uppgift att ta reda på vad larmet beror på och försöka åtgärda komplikationen. Simulatorn har utvecklats med teorier om upplevd realism och användbarhet i åtanke. Utvecklingen har skett i nära samarbete med dialyssjukköterskor på Karolinska Universitetssjukhuset Huddinge och utbildningssjukköterskor från både Karoliska Universitetssjukhuset och Fresenius Medical Care Sweden AB. Projektet avslutades med användartester där dialyssjukköterskorna fick utvärdera prototypen.


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1 Introduction

1.1 Background
Haemodialysis is a type of dialysis treatment that can be used when a person is suffering from kidney failure. The treatment cleans waste products from the blood and removes excess fluid which would otherwise accumulate in the body. When receiving a haemodialysis treatment the patient is connected to a dialysis machine, which draws blood from the patient, pumps it through a filter and then returns it to the patient. The treatment generally takes about four hours and needs to be repeated three times a week. Haemodialysis can be performed at home with the patient’s own dialysis machine as well as in a dialysis clinic.

The outline of clinics varies but usually several nurses work together attending several patients simultaneously. A patient requires full attention when the treatment is started and finished but during the treatment the patient only requires regular supervision. The dialysis machine will sound an alarm if any values are outside the predefined limits, and requires a nurse to confirm that the cause of the alarm is seen to. Some alarms cause the blood pump to stop and the treatment to be paused; this both prolongs the time the patient has to be at the clinic and increases the risk of the blood coagulating in the machine. The nurses therefore need to be able to quickly assess the cause of the alarm and then solve it; this in an environment with several other patients, alarms and colleagues that demand their attention.

In order to manage the alarms the nurses need to know how to interpret the interface of the dialysis machine. Modern machines have complex sensors and software algorithms that monitor the treatment and are able to display over 2000 different alarms and warnings. If a complication is treated incorrectly it can harm or be fatal to the patient. The software is therefore designed to be self-instructive and the nurses also receive instructions when the clinic starts to use a new model or gets a software update. This training focuses on standard procedures, familiarising the nurses with the user interface and where to find different functions. It is, however, difficult to cover all alarm situations, especially those that occur rarely.

A training needs analysis (TNA) that was made at Karolinska University Hospital Huddinge in 2010 shows that rarely occurring complications can cause the nurses stress as they feel uncomfortable in handling them. The TNA concluded that the use of a training simulator in the form of a desktop computer program to practice dialysis could be helpful.

1.2 Problem description
Nurses at a haemodialysis clinic are required to handle complex technological equipment in a stressful environment, with the patients’ lives at risk. In order to help the nurses the dialysis machines are designed to minimize complications and guide the nurses to make the correct decisions. However, with a system that has over 2000 different alarms a rarely occurring complication could make even an experienced nurse feel uncertain. If the nurses are educated further they will become more confident and the risk for improper dialysis treatment is reduced. The TNA that was made at Karolinska University Hospital Huddinge in 2010 identifies the nurses’ training needs explicitly as well as outlining a computer-based simulation program. This project builds on the
conclusions of the TNA to further examine the training effect of a simulator by designing and evaluating a prototype.

1.3 Aim
The aim of this project is to evaluate the concept of a training simulation program for nurses at a haemodialysis clinic by developing a prototype program. The program will have a Swedish interface as it is the language used at the clinic where the user tests will be conducted. During the development process three sub-objectives are to be treated.

1.3.1 Update the Identified Needs According to the New Technology
Since the TNA was made the dialysis machines have been upgraded with more complex technology. Can any changes in the need for a training simulator be identified?

1.3.2 Gather Experience for Future Projects
The process of creating and evaluating the prototype gives valuable insights that can be used when designing a complete simulator. During the development process some of the challenges of developing a simulator will be identified and possible solutions or alternatives could be found.

1.3.3 Examine the Potential Training Effect of a Simulator of this Type
By creating a prototype it is possible to display an idea of what a more complete simulator could look like. Through studying how the prototype is received in a user test the potential usefulness and the possibilities of using a simulator as learning tool can be evaluated.

1.4 Limitations
Several limitations of the project have had to be made due to time and resource restrictions.

Using results from a previous project has great benefits but also introduces some limitations. As the training needs analysis was performed with nurses at a haemodialysis clinic, this project focuses on the development of a training simulator for users in their situation. By this limitation, nurses that work at the intensive medical care unit as well as patients that perform their own dialysis at home are excluded. Users who work with other forms of dialysis treatments are excluded in the same way.

In order to show the idea behind the simulator and enable an evaluation it was decided to implement only one alarm scenario completely instead of doing several scenarios partially. In this way all the functions and views for that scenario will be present, enabling the user to understand how the program is intended to work. Implementing several scenarios partially increases the complexity of the program, making it difficult to give the program a realistic feeling under the current time constraints. The process of choosing which alarm to include is described in section 6.2.

The advanced technology in the dialysis machines adds an important limitation. The dialysis machines have a complex interface with a touch screen that is specific for every model. As the dialysis clinic at Karolinska University Hospital Huddinge uses the Fresenius Medical Care 5008 treatment system it was decided to give the simulator program a machine interface that imitates that model. Should the hospital decide to use another model the simulator would most likely feel less realistic as the interface would look different to the new model. Developing a more generic appearance would however also make the simulator less realistic as the different steps in the treatment could in that case not be associated with buttons and images on the screen.
1.5 Outline of the Report
This report addresses any readers with an interest in medical training. It aims to be informative to readers both with and without previous knowledge of dialysis and simulators.

In the introduction the background of the project is described together with the problem description, aim and limitations. Section 2 outlines the foundation of the project; including other works that exist and what useful conclusions they present. The theory and methods section (section 3) presents the theories that exist about designing a simulator for training purposes.

In section 4 the equipment and procedures are described as well as possible complications. This section should enable readers with no previous medical knowledge to understand the reasoning in the modelling section.

The execution of the project and the results are intertwined and are both described in sections 5 to 8. Section 5 describes the choice of methods used in different parts of the project. Section 6 focuses on the specific choices made about the simulation model and why the different scenarios were chosen. In addition, excluded scenarios are described, providing possible inputs for future projects. Section 7 covers the scenarios and how the simulator works in detail. It also explains some design choices. At the end of the section the structure of the code is outlined. In section 8 the results from the user evaluation are presented. The reason for presenting the execution and the results together is that they are hard to distinguish from one another. The aim of the project is not solely to produce a prototype, but rather to analyse the process of making it. This blurs the line between execution and result.

The discussion of the project is divided into two parts: section 9.1 and section 9.2. The first part is a discussion of the results and how they correspond to the aim of the project. The second part is an evaluation of the project and the experience gained. The conclusions are then presented in section 10. Section 11 describes the project’s contributions in large and section 12 then gives suggestions about what could be done in a future project.
2 Previous Work

Existing research about nursing education does indicate that computer-based simulators could be beneficial to the education. In a study from 2012 evaluations of Computer-Based Nursing Learning (CBNL) in undergraduate nursing education are examined (Carrillo de Gea, Fernández Alemán, & Sánchez García). The study concludes that further evaluation of CBNL is needed to confirm that it is a better alternative than traditional methods in all aspects. However, most evaluations examined in the study do conclude that nursing education could benefit from using information technology.

The need for a simulator is emphasised by the Master’s thesis that is the foundation of this project. The Master’s thesis IT-baserat utbildningssystem för dialycontorpersonal – en användarcentrerad förstudie [English title: IT based educational system for dialysis staff: a user-centered exploratory study] was made by Filippa Jonsson in 2010 at Uppsala University. The aim of the thesis was to examine the possibility of using an IT-based learning system for education at the dialysis clinic and how such a system could be designed. Three questions were studied:

- Which procedures are most important to practice?
- How are these procedures best practiced with the support of an IT system?
- Which requirements are there on the functions and design of the IT system?

The result of the thesis was a training needs analysis (TNA) identifying the needs of the nurses at the dialysis clinic at Karolinska University Hospital Huddinge. The project also generated concrete sketches and suggested functions of a computer-based training simulator.

As the need for practicing real-life medical situations without risking the health of the patient is recognised, projects developing computer-based simulators are emerging. One example is the doctoral dissertation Virtual Patients for Education, Assessment and Research: A web-based approach (Zary) from 2007, which describes a project where a virtual patient system for health-science students was developed and evaluated. The study concludes that the program was well received by the health-science students and that it was applicable in different medical disciplines and settings.

Fresenius Medical Care is the company that develops the dialysis machines presently used at the clinic in Huddinge. The company also provides a basic simulator through their Online Learning Center. This simulator focuses on the software and where to find different functions during standard treatment. The patient is not part of the simulation and alarm situations are not simulated. To complement this and meet the needs identified in the TNA that was made at the clinic in Huddinge, a simulator that includes the patient and rare alarms is required.

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1 A virtual patient is an interactive computer simulation used for medical training.
2 For more information about the company visit their website: [http://www.fmc-ag.com/](http://www.fmc-ag.com/).
3 Theory and Methods
This section describes theories and methods concerning how simulation can be used as a tool for learning. The long term aim of developing a training simulator is to make dialysis treatment safer for the patients and improve the work environment for the nurses by making them feel more secure and experienced. The question is how the training simulator should be developed in order to best achieve this.

3.1 Simulation
In the article The future vision of simulation in health care Professor David M Gaba (2004) defines simulation as follows:

"Simulation is a technique, not a technology, to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner."

Simulation is not limited to computer-based simulators. It has been around as a method of learning since 3000 BCE in the form of war games similar to chess (Gestrelius, 1993, p. 6). In many parts of health care education simulation is present in the form of written scenarios, dummies and role playing. There are also highly advanced simulators that look like patients and can display different symptoms and even talk. However, an advanced simulator in itself does not guaranteed efficient learning. Also, a simulator does not have to be advanced to be a sufficient learning tool. When designing a simulation Yngve Hansson (2004, p. 43) suggests answering the following questions:

- What is the purpose of the simulation?
- What is the content to be taught?
- Who is going to use the simulation?
- How much time is available?
- How large is the group that are participating in the simulation?
- How much money is available?

The answers will limit the simulation and can be used to make a specification of its requirements.

3.1.1 Realism
In the case of most medical simulation the aim is to provide a real-life situation without endangering the patients. The difficult part is to decide how to make real-life real enough without losing the learning effect. Kurt Gestrelius (1993, p. 47) claims that even though the effectiveness of a simulation as a tool for learning is dependent on the realism of the simulation, a simulator with high realism is not necessarily needed. He states that the instruction technique used during some simulations for example is said to decrease the realism but increase the learning. He also writes that perceived realism is usually considered more important than actual realism.

Arne Rettedal (2009, pp. 202-214) compares the realism of simulations to a magician’s illusion. The audience will perceive a high level of overall realism if the gaps between unrealistic components are small enough. With enough realistic elements in a simulation, the mind will
“bridge the gaps” (p. 206) and ignore the unrealistic ones. From this reasoning follows that in order to design a realistic training simulation the important components of the simulation need to be identified.

The simulation has to be accurate concerning the content that is being taught. If the simulation teaches an incorrect behaviour the design has failed. Even if it does not teach incorrect behaviour, but does not enable practice of the desired content the design has failed. Arne Rettedal gives the example that “if the goal is to instil a specific anaesthetic procedure using teamwork, then a sophisticated simulator may be needed” (2009, p. 205). Procedures like inserting a needle in the middle of a vein require real-life objects to see and touch, and can only be limitedly practised with a computer-based simulator. However, when humans process the world, and any training situation, we will have a mental image of what is going on. Rettedal calls this “internal simulation” (2009, p. 205). Many components of health care consist of knowing in what order to perform actions, and where to examine the patient. If the simulation is realistic enough for the student to feel like it is a real-life situation these routines can be practiced despite lapses in realism in specific components.

3.1.2 Validity
Validity describes the extent to which simulation represents what the users will face in reality. In order for the users to experience a training effect, the simulator has to provide the elements that they need to practice. In order to evaluate the validity of a simulator the following two criteria need to be fulfilled:

1. The simulated scenario has to be carefully chosen to be representative as well as clearly defined.
2. The users’ previous experience, as well as their ability to perceive the simulation has to be identified and assessed.
3. A comparison between the first two criteria should be the basis of evaluation of the validity of the simulation.

(Gestrelius, 1993, p. 44) In order for the simulation to have a high validity the simulation has to represent the elements of the real world that are to be practiced in such a way that the users can assimilate it.

3.1.3 Virtual Patients
Virtual patients can be used as a way of modelling a simulation. A virtual patient can be defined as:

An interactive computer simulation of real-life clinical scenarios for the purpose of medical training, education, or assessment. Users may be learners, teachers, or examiners. (Ellaway, Candler, Greene, & Smothers, 2006)

During the simulation the user will be presented with “a set of data that describes an individual as a patient” (Ellaway, 2007). Depending on the aim of the simulation the user could then be supposed to diagnose the patient and suggest a treatment.

There are two main categories when designing a virtual patient: A narrative approach or a problem-solving approach. In a narrative approach the user receives more guided instructions. For example a set of symptoms could be described and the user is given four alternatives of what type of medical examinations to do. A problem-solving approach is more open, the student has to gather necessary
information by navigating through the simulator, without being given an outspoken set of options. Studies indicate that a narrative approach may create a stronger sense of connection with the patient, making the simulation feel more real. A problem solving approach is instead suggested to be more suitable for training clinical reasoning skills, as the users have to explore the simulation on their own. (Bearman, Cesnik, & Liddell, 2001)

3.2 User Centred Design

3.2.1 Usability
Many projects developing IT-based support systems today fail because the users are not sufficiently considered (Bengt Sandblad, 2002, p. 9). When developing a computer program such as a simulator it is therefore very important to recognise the requirements of the users. ISO\(^3\) defines usability as

The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. (ISO 9241-11 1988)

That is to say how useful the users find the product when trying to accomplish the intended task. In order to make an interactive product with high usability the designer therefore has to gather information about how the product is going to be used, and by whom. The needs of the users have to be in focus:

- What benefits do the users expect from using the product?
- In what situations will the product be used?
- What requirements do the users’ previous knowledge and interests present?

(Berndtsson & Domingues, n.d.).

3.2.2 Involving the Users
The wiki-book Användbarhet i praktiken [English: Usability in Practice] (Berndtsson & Domingues, n.d.) describes a method of working when developing an interactive product in order to ensure its usability. The method has three phases: the concept phase, the building phase and the improvement phase. During the concept phase the concept of the product is specified and the benefits of the product are estimated. The description of the concept is then supposed to be used for the building phase. During the building phase the concept is realised and the actual product is made. During the improvement, or maintenance, phase flaws in the product are identified and fixed. In all three phases the needs of the users are central. The development process is iterative, and the users are involved in all stages.

Jan Gulliksen and Bengt Göransson (2002, pp. 107-108) also emphasise an iterative process to involve the users. To achieve a usable system the following principles should be followed:

- An early –and continuous – focus on the users. This includes identifying possible users, their situation and needs, as well as including them in the design process.
- Empirical measuring. The users reactions of proposed scenarios, sketches and prototypes should be measured early in the process. When the development process has produced

\(^3\) International Organization for Standardization. For more information visit their website: [http://www.iso.org](http://www.iso.org).
more usable prototypes, the users’ reactions while using them to perform the intended task should be observed and analysed.

- Iterative design. Problems in the design should be identified and addressed during the development process. This means that the process has to be iterative, the design has to be evaluated and redesigned continuously according to the users input.
- Integrated design – in which all aspects that involves the usability are developed together.

From this reasoning it can be concluded that in order to make a product with high usability the needs of the users have to be identified and the intended use of the product has to be made clear. The users also have to be involved during the entire development process, as the designer cannot predict all of their reactions.

3.3 Measuring Training Effect

It is difficult to find a single definition of training effect. In this project it means the extent to which the nurses will gain more knowledge and feel more confident compared to if they do not use the simulator. This type of training effect could be measured through a comparative study. Either two groups of nurses could be observed, one that receives complementary training with the simulator and one that does not. Or a comparison of the knowledge before and after the use of a training simulator could be made.

The problem is that a prototype with limited functionality cannot be fully examined in this way. The intention of the prototype is not to be a tool for learning; it is to evaluate the potential training effect of a complete simulator. The potential training effect has to be estimated by observing users testing the prototype. There are however other aspects that can be evaluated as well. The SUMMIT Evaluation Framework (Youngblood & Dev, 2005) lists seven components for evaluating new learning technologies in medicine:

1. Beta-Testing
2. Review by Content Experts
3. Usability Testing; Validity Testing
4. Assessing Learning Outcomes
5. Integration into Curriculum
6. Transfer of learning to Clinical Practice.

Components one to three are most appropriate for prototype applications.

3.3.1 Evaluating Learning

In order to evaluate learning and training Donald K. Kirkpatrick (Chapman, n.d.) proposes a four level training evaluation model:

1. Reaction: How the delegates felt about the training or learning experience.
2. Learning: Evaluating the increased knowledge before and after.
4. Result: The effect on the business or environment by the trainee.
When evaluating a prototype it is apparent that only the first level is directly applicable. However, one way to assess the potential training effect could be to try to estimate the results of the other three levels.

### 3.3.2 Evaluating Usability

Even though high usability does not guarantee a training effect, a simulator with low usability is likely to have a low training effect. If the simulator is difficult to use, the users are less likely to enjoy using it. They will also need to spend more time trying to figure out how to use it and less time learning.

There are two main types of evaluation of usability: examination by a usability expert, and user-testing. When experts evaluate a system or a product they look at the theoretical aspects of usability and use their knowledge of best practice in order to determine whether or not the system fulfils usability goals. During user-testing, potential users are asked to perform the intended task by using the product that is being tested. It is preferable to perform the test in the environment where the product is intended to be used. Through observation and or evaluation forms the users’ reactions are recorded. (Berndtsson & Domingues, n.d.)

Berndtsson & Domingues describe several ways of conducting user tests, three common ones are structured usability tests, pair tests, and walk-up-and-use:

- In a structured usability test each user is presented with realistic assignments that are to be solved with the product that is being tested. The users are supposed to explain their reasoning by thinking out loud. The test leader is supposed ask questions to clarify the user’s idea of the situation and make the user feel comfortable. An observer is supposed to note the user’s reactions. At least five separate user tests are needed to find the major usability flaws.
- In a pair test the users work in pairs, discussing how to solve the problem. The test leader takes notes of the discussion and can also nudge it in right direction if needed. This type of test is most suitable for identifying the needs of a user group.
- In a walk-up-and-test random users with no prior experience of the product are asked to test it. The test leader is supposed to encourage the users to think out loud and explain their reasoning. If all users try different aspects of the product it may be difficult to draw general conclusions.

(Berndtsson & Domingues, n.d.)

In all types of user-testing it is important to observe the user, and not just ask them what they think. For example, in the 1950s a study of the weight of a telephone handset was conducted. Upon being asked prior to the study if they would like a lighter handset, most users said no. However, when the test was conducted the users preferred the handset with half the weight. (Nielsen, 1993, p. 11)
4 Medical Background: The Techniques of Haemodialysis

This section contains the medical background needed to understand the simulation model and discussion about design choices. The information in this section is obtained from several different texts about dialysis as well as interviews and study visits to Karolinska University Hospital Huddinge and interviews with an educational nurse at Fresenius Medical Care Sweden AB. The written works used are: National Kidney and Urologic Diseases Information Clearinghouse, n.d.; Donne, 2012; Henriksson, 2012; Misra, 2005; Daugirdas, Balke, & Ing, 2007; and Ronca and La Greca, 2002. If the reader is interested in more information about haemodialysis these works provide excellent further reading.

In short a haemodialysis machine works as an external kidney. It filters the blood from waste products and removes excess fluid. A schematic sketch can be seen in Figure 4-1. The blood is drawn from the patient through the artery blood line by a blood pump. The blood pump then pushes the blood through hundreds of thin fibre membranes in the dialyser. Dialysate fluid is pushed around the membranes in the other direction. The waste products diffuse through the membrane into the dialysate and excess fluid is removed. The blood is now cleaned and returned to the patient through the venous blood line. The artery and venous blood lines are not to be confused with the veins and arteries in the body. The blood is both drawn from, and returned to, a vein in the patient’s arm, see Figure 4-2.

4.1 Equipment and Procedure

The dialysis equipment is very complex and consists of many parts. In this section those parts with most relevance for this project are described. A schematic sketch is displayed in Figure 4-1. In Figure 4-3 an operating dialysis machine can be viewed.

Figure 4-1. Schematic sketch of a haemodialysis system. The letters represent different parts of the system and are explained in section 4.1.
Figure 4-2. A sketch of an arm with an arteriovenous (AV) fistula. The blue vein has grown because of the extra blood flow from the artery.

Figure 4-3. A picture of a haemodialysis machine. Different models have the same basic functions but different designs.
A) The access: There are three main ways of accessing the patient’s blood stream: through an arteriovenous (AV) fistula, an arteriovenous graft or a venous catheter. A graft and a fistula are placed in the patient’s arm whereas a venous catheter is placed in a main vein, usually in the chest or neck. In Figure 4-2 a sketch of a fistula is displayed. A fistula is created by surgically connecting an artery to a vein. Because of the increased blood flow the vein will grow larger and stronger, providing easy access to the blood stream. A graft works in the same way, but the connection between the vein and the artery is made with a synthetic tube instead of the existing blood vessels. A graft can generally be used sooner after the operation than a fistula but is more vulnerable. With both fistulas and grafts the blood stream is accessed through the insertion of new needles for every treatment. In Figure 4-2 a two-needle insertion is shown. Two needles are used, one for drawing the blood and one for returning blood. It is also possible to do single needle treatments, but with a different kind of needle. A graft can often be used two or three weeks after the operation and a fistula takes several months to develop. If the patient is in need of dialysis before that, a venous catheter is used. The catheter is inserted into a main vein and remains there between the treatments. No needle insertions are required; the blood lines from the dialysis machine are connected directly to the catheter. The use of venous catheters is less common as a long term solution as the risks of infection and other complications are higher.

B) The arterial pressure monitor: The arterial pressure monitor monitors the pressure in the arterial blood line before the blood pump and the dialyser. The blood pump draws blood from the patient by creating suction in the arterial blood line. The arterial pressure is therefore defined as negative, values being around -150 mmHg during a normal treatment.

C) Anti-coagulants: To prevent the blood from clotting when it passes through the dialysis system anti-coagulants are used. Traditionally a heparin pump, which constantly injects the anti-coagulant heparin was used. Today drugs like Innohep are more common, as they can be injected once at the start of the treatment.

D) The venous pressure monitor: The venous pressure monitor monitors the pressure in the venous blood line after the dialyser but before the venous drip chamber (E). The venous pressure is usually around 150 mmHg during a normal treatment.

E) The venous drip chamber: In Figure 4-3 a blood filled venous drip chamber is circled. Air bubbles in the blood rises to the top and get trapped. At the bottom of the chamber a mesh catches any large blood clots and prevents them from clogging the venous needle or entering the patient’s blood stream.

F) The air detector: The air detector detects air bubbles in the venous blood line after the venous drip chamber but before the blood is returned to the patient. Air bubbles that enter the patient’s blood stream can be fatal and this detection is therefore very important. In a closed system no air is supposed to be able to enter, but as there are many connections between the different parts of the system there is always a risk of leakage or residual air.

The software and alarms: Today dialysis machines have very complex software that monitors the treatment to ensure the safety of the patient as well as guiding the nurses through an advanced touch screen user interface. If any values are outside the predefined intervals different alarms or
warnings will go off, alerting the nurses to the situation. If continued treatment could risk the safety of the patient the blood pump stops automatically when the alarm goes off. The nurse then has to confirm that the cause of the alarm is seen to before the pump can be restarted.

4.2 Complications and Alarms
There are many possible complications and alarms that can occur during a dialysis treatment and it is not possible to include all of them in this report. This section describes the major complications and alarms that are examined as potential scenarios to include in the simulator prototype.

**Low blood pressure:** One of the most common complications is that the patient’s blood pressure decreases too much. During a dialysis treatment of 4 hours the patient can lose several litres of water, by having fluid removed from the blood. If the body does not refill the blood with water from the body the blood volume will decrease, resulting in a low blood pressure. To monitor this the patient’s blood pressure is measured at least every hour, and newer machines can even do it automatically with a desired interval. An alarm will then sound if the values are outside a specified interval.

**Low arterial pressure alarm:** If the arterial pressure is below a specified interval the low arterial pressure alarm will go off and the blood pump will stop. There are several complications that will cause this behaviour: the patient’s blood pressure can fall and change the suction resistance; there can be a blood clot in the arterial blood line, blocking the suction; there can be a kink on the arterial blood line, or an external obstruction like the patient sitting on it, also blocking the suction; the needle can also be too close to the wall of the blood vessel, starting suction of the wall.

**High arterial pressure alarm:** If the arterial blood pressure is above a specified interval the high arterial pressure alarm will go off and the blood pump will stop. High arterial pressure has two main causes: the patient having increased blood pressure; or the arterial needle or blood line getting disconnected or broken.

**Low venous pressure alarm:** If the venous pressure is below a specified interval the low venous pressure alarm will go off and the blood pump will stop. The primary cause of low venous pressure is a disruption of the blood circuit between the access and the blood pump, for example if the venous needle is removed or the blood line gets detached from the needle. If the blood pump did not stop in this situation the patient would quickly lose a lot of blood as the normal blood flow rate through the dialysis machine is 300 ml/min.

**High venous pressure alarm:** If the venous pressure is above a specified interval the high venous pressure alarm will go off and the blood pump will stop. High venous pressure can be cause by an obstruction on the venous blood line, clotting in the venous drip chamber or complications in the access area. An obstruction on the venous blood line can be a kink, a closed clamp or that the patient is leaning or sitting on the blood line. Access complications include hematoma, stenosis and displacement of the needle. Hematoma is when the tissue around the access is filled with blood. This is caused by damage to the access, for example the needle penetrating both sides of the vein. Stenosis is a narrowing of a blood vessel and can develop over time and cause clotting of the blood and recirculation; that is when the returned blood goes directly back into the arterial needle and only
a fraction of the blood is cleaned. Displacement of the needle can be caused by the needle not being inserted into the middle of the vein or by the patient moving the arm.

**Air detection alarm:** If air bubbles are detected in the blood after the venous drip chamber the air detection alarm goes off and the blood pump stops. Air bubbles that enter the blood stream can cause air embolism which is very dangerous. Air bubbles in the blood line are caused by an opening in the circuit, enabling air to be sucked in, or by residual air remaining in the blood lines. As air embolism is such a dangerous complication strong measures are taken to prevent it. Therefore the alarm is very rare. To provide safety however, the detector is very sensitive and may react to micro bubbles that do not pose a threat.

**Blood leakage alarm:** The blood leakage monitor ensures that the blood and the dialysate fluid are not mixed. A leakage in the dialyser can cause dialysate to enter the patient’s blood stream. If blood is detected in the dialysate the alarm will go off and the blood pump will stop. A leakage is caused by a malfunction in the dialyser, for example if it was damaged during transportation.

**General note on alarms:** Modern dialysis machine software has more complex algorithms for detecting deviations from normal values than fixed interval limits. For example, a very fast falling venous pressure can cause an alarm even before the value is outside the interval, in order to quickly detect a disrupted blood line.
5  Choice of Methods

This section describes how the project was carried out and the methods that were used. The project has its starting point in the training needs analysis that was done at Karolinska University Hospital Huddinge in 2010. In the documentation generated in that study the needs of the users as well as sketches of proposed functionality for a simulator are described. The challenge was to choose an appropriate part of that to implement in the prototype. Together with the nurses at Huddinge, and assistance from Fresenius Medical Care, this project has aimed to design an appropriate prototype according to the theories proposed in section 3.

5.1 Collecting Information

The collection of information can be divided into five parts: (1) collecting general information about dialysis and its complications; (2) collecting specific information about how the nurses at the clinic work; (3) collecting specific information about the dialysis machine they are using; (4) collecting information about designing a simulator; (5) collecting information about implementation and coding.

General information about dialysis and its complications was obtained through educational material and research papers about dialysis, as well as study visits to the dialysis clinic at Karolinska University Hospital Huddinge. The study visits were complemented by interviews with the nurses as well as with an educational nurse from the clinic in order to provide information about how the nurses work. Interviews with an educational nurse at Fresenius Medical Care Sweden AB were conducted to gain even more information about the specific dialysis machine model that the nurses are using.

The theories previously outlined about simulation, user centred design, and evaluation are based on research papers and educational material about these topics. Information about implementation and coding was gained through educational material as well as support from my colleagues at Sjöland & Thyselius.

5.2 The Development Process

The project has used an iterative design with continuous contact with the clinic at Karolinska University Hospital Huddinge during the development process. At the start of the project the findings of the previous TNA were examined during a meeting with an educational nurse at the clinic. It was concluded that even though some of the requirements had changed because of new technology and provision of educational material on the basic procedures from Fresenius Medical Care, the need for simulator training of rare alarms persisted. Through the study of information about dialysis and observation of the nurses’ work at the clinic, an alarm scenario was chosen in consultation with an educational nurse at the clinic. The reasoning behind the choice is described in the sections 6.1 and 6.2.

Through more reading, study visits to the clinic, and interviews with nurses at both the clinic and at Fresenius Medical care, a model for the scenarios was devised. The foundation of the model is both the routines of the clinic, and the clinical knowledge of the nurses at the clinic and at Fresenius Medical Care. The model was confirmed by an educational nurse.

The interface of the simulator was designed with a starting point in the sketches and ideas from the previous TNA. Not all ideas were applicable and some changes were made to make it more suitable
for the implementation. The design choices were made based on feedback from the nurses as well as on the theories about simulation and usability that are described in section 3.

5.3 The Simulation Model
The most realistic model of a patient would be an actual patient. Trying to simulate all parts of a human body and how it would react to different medications and treatment would be extremely complex. For example, creating a mathematical or physiological model of the blood stream connected to a dialysis machine to accurately simulate the changing pressure is not within the scope of this project. As the discussion about realism in section 3.1.1 shows, however, this is not necessary. The model of the simulator prototype is instead based on scenarios. Every scenario is represented by a virtual patient.

A problem solving-approach is used in the prototype. Every patient has a complication that will cause an alarm. During the simulation the user navigates through the simulator to gather information and determine the complication. When the users have determined which complication they think has caused the alarm, they are supposed to navigate freely through the simulator and correct the cause. When the alarm is turned off and the dialysis treatment is resumed the patient simulation is complete.

For every complication there is one or more sub-scenarios describing the correct order of actions, modelling the response of the system. These are not visible to the user; instead if an action is performed in the wrong order a popup box prompts the user to try again. The user is, however, able to navigate freely around the simulator without any guidance. A separate sheet with instructions on how to determine and treat the complications will be available. The original idea was that all actions would be available at all times, in order to avoid helping the user too much. Unfortunately it proved too difficult to predict how the real system would have reacted to incorrect behaviour, and actions performed in the wrong order were therefore excluded from the model.

A problem-solving approach was chosen over a narrative one because the goal is to practice the clinical reasoning that is required in a stressful situation. The nurses need to know how to navigate the user interface of the dialysis machine and be familiar with where to look for different complications.

5.4 User Evaluation
5.4.1 General Design
The evaluation has been designed to discover the nurses’ general impression of the simulator and to identify issues. The applicable parts of Kirkpatrick’s evaluation theories were used in an attempt to estimate the potential effect. The evaluation also addresses the experienced realism as well as including a large section on usability. There has not been enough time and resources to perform the examination by a usability expert described in section 3.3.2.

The test is designed to be a structured user test that finishes with a structured interview. The idea is to divide the test in two parts, an introduction and an evaluation. The introduction is supposed to start with a presentation about the aim of the prototype and the user evaluation. The presentation is followed by a demonstration of how the program works. The users are then to be allowed to try out
the prototype themselves and ask questions. Detailed instructions are to be provided. The introduction is estimated to take about 30 minutes.

The evaluation part is designed to either be conducted straight after the introduction, or within a couple of days. Before the interview the users are supposed to try out the simulator a second time. General guidelines are provided to ensure that they try all the scenarios. The users will also get a walkthrough describing the scenarios. When they have completed the tasks in the guidelines a structured interview will be conducted. The users will also be observed while trying the simulator in order to catch any usability issues.

The purpose of having a separate presentation with a demonstration and then the evaluation is to minimize the impact of a beginner’s threshold. The training simulator is not designed to be used without proper instructions. The nurses are supposed to learn how it works and then use it to practice alarm situations. Though it is important that the usability is not too low, it will always take some time to understand how a new program works. If no introduction is given, users will take longer to understand how to use the program. If this introduction time is included in their perception of how to use the program it will affect their answers in the interview. They may have difficulties differentiating assessing realism and the training effect with trying to find where the right buttons are located.

If there are serious usability issues the introduction will not be enough to overcome them, and the issues will be visible in the evaluation. In addition, by observing the users and their questions during the introduction some usability issues may also be identified.

The user evaluation is to be conducted in Swedish as it is the language used at the clinic. All the instructions are therefore also going to be in Swedish.

5.4.2 The Structured Interview
The complete interview form can be seen in appendix 15.2. The interview is to be conducted as a dialogue with the user, with the interview form as a support.

The interview starts with general questions to discern traits including how long the user has been working with dialysis and how long they have been working with Fresenius’ 5008 model.

The next section is about the user’s general impression of the simulator. This section is intended to pick up general positive and negative feelings towards the simulator. If the users do not like a program in general they will be less likely to use it and so learn less. The questions concern how easy, fun and realistic it felt to use the simulator, and whether the users felt they learned something new. The users grade their experience on a five-option scale.

After that there is a section about the clarity and usability of the simulator. The questions include: how easy the setup is to understand; whether the assessment part of the simulation is easier or more difficult than in a real-life situation; how the buttons and popup messages affect the perceived realism; and how the users feel about the direct feedback given if the wrong action is performed during the simulation. In this section the aim is to find specific areas that may have a negative effect on the usability and or the perceived realism.
In the next section the users are asked to estimate the potential training effect they could receive. Firstly, they are to consider whether they believe they would have benefited from using a training simulator during their dialysis education. Secondly, they are to estimate the same thing when using a simulator once they have started working. They are also to rate how much they think they would use a simulator if they were given as much time as they like. This section is included to give an estimate to whether the nurses feel a simulator may be more effective during education or regular work. It is interesting to see if this depends on the level of experience of the nurse.

The interview is finished by a section that gives room for general comments.
6 Specification of the Simulation Model

This section provides a specification of the simulation model as well as a description of how the model was obtained and why some scenarios were chosen to be included while others were excluded.

6.1 Choosing an Alarm

In the TNA from 2010 (Jonsson) different procedures were evaluated according to their level of difficulty, level of importance and level of occurrence. Handling rare, difficult alarms that are potentially dangerous have the highest priority. Standard procedures are also very important and will pose a risk if done incorrectly. Two examples are assessing how much fluid that needs to be drawn from the patient and which arterial and venous pressures that are optimal. They are however easier to practice with the supervision of an experienced nurse as it needs to be done at every dialysis treatment. In addition some software to practice standard interaction with the dialysis machine already exists. It was therefore decided to choose one rare alarm with the highest priority to implement in the prototype. It was decided to choose one alarm with the possibility of several sub-scenarios, rather than several alarms with one scenario each. This decision was made in order to better display the idea of the users getting to assess the cause of the alarm. If there is only one scenario for each alarm the user would not experience the investigating part of the simulator.

Together with a training nurse at the dialysis clinic at Karolinska University Hospital Huddinge the results of the TNA were reviewed. It was decided that the high venous pressure alarm was a good initial choice for several reasons:

- Several complications resulting in a high venous pressure alarm have priority one or priority two. The different complications are listed in section 6.2.
- It is easy to expand and decrease the model during the modelling process as challenges arise, as there are several sub scenarios that can be included or excluded.
- The different complications resulting in high venous pressure provide a mixture of rare and common scenarios. This enables the simulator to show the usefulness of being able to simulate rare complications yet being familiar and relatable.
- When designing the simulation model the mixture of complications also enables the observation of the nurses working with the patient. Observing the nurses handling common alarms gives a much more accurate idea of their environment then only interviewing them about rare ones. It is also possible for the nurses to provoke the alarm without endangering the patient while explaining how they would have managed a similar rare complication.

There are some other alarms and complications that also have priority one but that has not been chosen for different reasons.

One example is the low venous pressure alarm. The alarm can be the result of a blood leakage and the nurses at the clinic therefore always check the blood lines for disruptions when there is any pressure alarm. There are however not as many other possible causes for the alarm as there are for high venous pressure alarm. As the need for limitations unfortunately made it necessary to only include high venous pressure alarm, the instruction to check the blood lines was instead included in the external guide to the program.
The procedure of disconnecting the patient and pausing the treatment when the patient has to go to
the bathroom was given priority one as well. This procedure has however been made a lot easier
with the new dialysis machine models and is no longer considered to be difficult.

The last other procedure with priority one was air detection. As described in section 4.2 the presence
of large air bubbles in the bloodstream is very rare but potentially very dangerous. Because it is so
dangerous there is however already focus put on it. In addition, the procedures to assess the risk of
air embolism as well as removing micro bubbles require real-life objects to see and touch and are
difficult to train with a computer-based simulator.

6.2 Specification of the Scenarios

6.2.1 Included High Venous Pressure Scenarios
The following three scenarios were included in order to best display the intended use of a training
simulator:

- External obstruction.
- Addressing hematoma with the circulation program.
- Addressing hematoma by returning blood.

The scenarios were chosen to illustrate the assessing elements of the simulator as well as the
possibility to address a complication in different ways. The user first has to assess which of the two
complications has caused the alarm. If the cause is hematoma the user can also choose one of two
paths. Treating patients requires craftsmanship and the two ways represent how every clinic and
every nurse can choose to perform the procedure slightly differently. The implementation of the
scenarios is described in detail in section 7.2.

6.2.1.1 External Obstruction
There are several reasons for implementing a common complication like an external obstruction.
Firstly, there had to be more than one complication in order to demonstrate the assessment idea.
There was not enough time to do another complex one such as hematoma, thus a simpler one had to
be chosen. Secondly, external obstructions are listed as possible causes for the alarm in the interface
of the dialysis machine. The list is visible if a question mark button is pressed when the alarm is
active. Implementing an external obstruction scenario could therefore increase the realism of the
simulator. Finally, having a common scenario could make the simulator feel more familiar to the
user. It is important that the complex scenarios feel related to the everyday work and mixing in
common scenarios could accomplish that. In addition, even though common scenarios may be easier
it is important not to forget them as they also cause the alarm to go off and the blood pump to stop.
Assessing an alarm is all about knowing which complication has caused it, whether it is common or
rare.

An external obstruction can be a kink on the blood line or that the patient accidentally leans on the
blood line. It is not a dangerous complication and is easily fixed when discovered. It is however
important to know where to look for it as patients often have blankets that obscure the blood lines.
In the TNA external obstruction is not listed explicitly. A patient sitting on the venous blood line is
grouped with high and low venous pressure which has priority one.
It may be easier to find an obstruction in the simulation than it is in real life but an important element of training is to know to look for it. Once found, there is no complex manoeuvre to fix the problem. Simulating removing the obstruction with a button does therefore not diminish the realism too much. In addition other common alarms have a more complex interaction with other alarms and values, which makes them difficult to simulate without more extensive clinical knowledge.

6.2.1.2 Hematoma

Hematoma means red swelling and denotes a bleeding inside the arm above the venous access. It was the first complication to be chosen for implementation. It is listed alongside external obstructions as a possible cause of the high venous pressure alarm in the dialysis machine interface. The realism of the simulator could therefore be increased by the implementation of hematoma. In addition, hematoma is an important complication address quickly as the access can be damaged. Perforation of the access vein which causes hematoma has been given priority two in the TNA. Hematoma is also grouped with high and low venous pressure which has priority one. Most important, addressing hematoma requires a more complex scenario that can be done in several ways. Implementing hematoma therefore enables the prototype to display the idea of the simulator.

It is very important to protect the access as the patient needs to receive treatment three days a week and it takes some time to develop a new fistula. As soon as a hematoma is detected above the venous needle it is important to stop treatment, otherwise more blood will be pumped into the hematoma. If the patient is near the end of the treatment the nurse usually terminates the treatment a little earlier in order to avoid stressing the access unnecessarily. However, the assessment is made for each individual patient based on several different parameters, often in consultation with a doctor. This requires too much clinical knowledge to be simulated correctly in this prototype. Therefore the patients in the simulation all have three hours left of their treatment when the alarm goes off, always making the correct choice to continue treatment.

If the hematoma is small enough it is possible to insert a new venous needle above the hematoma and then continue the treatment. If the hematoma is too large for this the nurse has to consult a doctor on how to proceed. Simulating a consulting is difficult and has been excluded from the simulator. When the hematoma is examined in the simulation, text based information is displayed, saying that the hematoma is small and that it is possible to insert a new needle.

Addressing Hematoma with the Circulation Program: Newer models of haemodialysis machines have a circulation program. The arterial and venous blood lines can then be connected to each other and the blood pump circulates the blood in a closed circuit without being connected to the patient. The nurse can then take time insert a new needle above the hematoma with precision without worrying that the blood pump has stopped and the blood is coagulating.

At Karolinska University Hospital Huddinge most nurses do not use the circulation program when the patient has hematoma. The clinic have decided not to use the circulation program when the patient leaves the bed to for example go to the bathroom as there is a risk of hypotension. This may have made the nurses unaware of the possibility of using the circulation program in a rare hematoma situation. The reason to implement the scenario is therefore to show that there are other ways of using the dialysis machine, which can be learned with a simulator.
Addressing Hematoma by Returning Blood: An alternative to using the circulation program is to return the blood to the patient through the arterial needle. If the hematoma is small enough it is possible to connect the venous blood line to the arterial needle and return the blood to the patient. The ability to use the arterial needle is tested by flushing the needle and making sure that the hematoma is not affected. In the simulation the hematoma is never affected. Other ways of addressing the hematoma would require consultation with a doctor and are therefore too complicated to simulate in this project.

After the reversed connection is made the returning of blood procedure is done in the same way as at the end of a normal treatment. When the blood is returned the nurse connects the venous blood line to a plastic bag and pumps the saline solution through the system at a lower flow rate. The nurse can now insert a new needle without worrying that the blood is coagulating. When the new needle is inserted and the patient is reconnected the dialysis treatment can be resumed.

This scenario was implemented because it is the procedure that is used at the clinic. The realism of the simulator could be greatly diminished if the user is not able to handle the complication the way it is done at the clinic. The returning of blood is also a very familiar action as it is done at the end of every treatment and the users will have a clear image of how it is supposed to look. By studying the user’s perceived realism of this familiar element in the user tests, the perceived realism of other scenarios can be estimated.

Some very experienced nurses are able to very quickly assess whether it is possible to insert a new needle, insert the new needle, reconnect the blood lines and then restart the treatment right away without giving the blood time to coagulate. This type of assessment is very difficult to simulate and has therefore not been implemented. In addition, it is impossible to estimate how long a specific user takes to insert the needle into a specific patient.

6.2.2 Excluded High Venous Pressure Scenarios
There are several other possible causes to a high venous pressure alarm. At the start of the project including high venous pressure alarm caused by blood clots in the venous drip chamber was planned, but it had to be abandoned to ensure the completion of the other scenarios. The blood clots scenario was excluded because it was difficult to find a routine for how to assess and fix it. It is different for every patient and the nurses always ask a college before making any decisions. In addition the methods used to determine if there is clotting or not include for example using a flashlight to try to see darker patterns in the venous drip chamber. These types of visual inspection methods require a large data base of medical images or detailed descriptions in order to provide any training.

Stenosis denotes the narrowing of a blood vessel and develops over time. A high venous pressure alarm caused by stenosis was excluded as the scenario requires assessing the patient’s history over a longer period of treatments as well as consultation with a doctor.

It can be difficult to insert needles into some of the patient’s accesses and this can result in the needle not being inserted into the middle of the vein. If the needle is too close to the wall of the vein this can cause the pressure to be too high. It can be regulated by changing the blood flow rate as well as adjusting the patient’s position. Usually the artery pressure is affected by this as well and the scenario was excluded because of its dependence on other alarms. In addition, it is very difficult to predict how changes in the blood flow affect the system.
7 Implementation

In this section the implementation of the prototype is described. First there is a description of the program and the reasoning behind the different design choices. Secondly, there is a description of the different scenarios that are implemented and which actions the user can perform. Finally there is a description of how the code is structured.

7.1 Description of the Program and Explanation of Design Choices

The aim of creating the simulator program prototype is to display what a more complete simulator could look like. It was decided early in the project that the best way to do that was to implement some functionality completely rather than snippets of wider-ranging functionality. Only the necessary functions for the chosen scenario are therefore implemented. Some additional functionality is displayed but not possible to interact with, aiming to show what a more complete simulator could provide.

7.1.1 Logging in and Setting up the Simulation

When the simulator program is started the user is shown a log in page. No log in functionality is implemented, the user only has to press “log in” to proceed. The user then chooses which complication to train. It is however only possible to choose high venous pressure alarm. The user can also choose how many patients they want to simulate. Valid choices are one to five, as suggested in the TNA (Jonsson, 2010).

The ability to choose the duration of the simulation, the level of difficulty, and whether to have instructions or not are also displayed but not enabled. When the user has made the choices they press “start the simulation” and proceed to the next page if the choices are valid. If any choices are invalid the user is asked to enter the choices again until valid values are entered. Screen shots from the log in page and the setup page can be seen in Figure 7-1.

![Figure 7-1. Screen shots from the log in view and the setup view.](image)

7.1.2 Pre-Simulation

Upon entering the simulation page the user is presented with the number of patients they chose. See Figure 7-2. The patients are presented as tab items in a tab and can be accessed by clicking on the tab header. The tab header contains the patient simulation number, the patient’s name, and the patient’s ID-number. The names and data are fake and not based on any real patients. The patient simulation number represents the patient’s bed number and is also used in the program to keep track of the patients. In a future project a data base of patients with complete histories and
potentially images could be created with the help of someone with clinical knowledge of dialysis. The data base would have to be large in order to prevent the users recognizing the different cases.

![Simulation Page](image)

**Figure 7-2. Screen shot of the simulation page before the simulation has started.**

Each patient is represented by an image of a patient connected to a dialysis machine as well as a short description of the patient. The patients have different hair colour and sweatshirts but otherwise look the same. The user is supposed to navigate between each patient to gain information before the simulation scenario is started.

The idea was to display the patient’s medical record and earlier hourly reports from the treatment as well, but there has not been time to include these. In a real life situation the nurses are assigned different patients that they will get to know. The nurses will not be assigned the same patient every time, but as the patients undergo treatment three times a week the nurses will treat them often enough to quickly get to know them. At the start of a treatment they also read the medical record and talk to the patient in order to predict any complications. Enabling the user to read a little about the patient was intended to simulate this.

### 7.1.3 The Simulation

When the user has gained enough information they press “start scenario”. All the patients’ alarms will then go off at once. The idea was that the alarms would go off with a random interval but there has not been enough time to implement this. Therefore the concept of deciding which patient has the highest priority will not be properly displayed in the prototype.

Each patient will still be represented by an image of the entire haemodialysis setting on the left side of the screen; with the patient in a hospital bed, the medical record and the dialysis machine. On the
right side of the screen the medical record is still displayed. They user can click on different parts on
the left side in order to change what is displayed on the right. There are six different areas that are all marked with a purple circle or square:

- **The medical record.** The square is located at the feet of the patient where the nurses usually keep the medical record.

- **The patient’s head.** When the circle on the patient’s head is pressed it is the equivalent of asking how the patient is feeling. The patient’s reply is displayed in a textbox to the right.

- **The fistula on the patient’s arm.** When the circle around the patient’s arm is pressed a magnified sketch of the arm is displayed. The user can then see how the blood lines are connected as well as whether the patient has a hematoma or not. The image is also clarified with text. Four action buttons are available for changing how the blood lines are connected. A screen shot from the program can be seen in Figure 7-3.

- **The blood lines.** The circle around the blood lines is located between the patient and the dialysis machine. If pressed a sketch of the blood lines displays whether there is a kink on the blood line or not. Text also clarifies the image. An action button to remove the kink is enabled if there is a kink. A screen shot from the program can be seen in Figure 7-4.

- **The dialysis machine.** The square is located on the middle of the dialysis machine. If pressed a button to inspect the venous drip chamber is displayed. Some other buttons are displayed but not enabled.

- **The Interface of the Dialysis Machine.** The square is located around the screen of the dialysis machine. If pressed an interactive image of the screen is shown as well as text indicating the state of the blood pump. There are ten action buttons here. See more about the interface in section 7.1.4.

The image with the clickable areas is supposed to represent the dialysis setting; with the patient and the machine as a system. The user sees everything at once but in order to see any specific part more clearly one has to lean closer, which is represented by pressing an encircled area and magnifying it.

The user is supposed to determine the cause of the alarm by navigating through these different pages and then using the action buttons to address the problem. A flowchart illustrating the sequence can be seen in Figure 7-5. The specific scenarios for addressing the complication are described in section 7.2. When the dialysis treatment is restarted the simulation of the complication is considered completed and an information message asks the user to see to the next patient. All action buttons and navigation is then disabled for that patient. When all the patients have been seen to the simulation is automatically cancelled and the user is directed to the feedback page. The user is also able to cancel the simulation at any point, but is then not able to return to the same point.
Figure 7-3. Screen shot of the fistula sub view of the simulation page.

Figure 7-4. Screen shot from the blood lines sub view of the simulation page.
Figure 7-5. Flowchart of the order in which users are supposed to assess the cause of the alarm.

7.1.4 The User Interface of the Dialysis Machine

The user interface of the dialysis machine simulates the real interface in both appearance and behaviour in chosen areas. A screen shot from the program can be seen in Figure 7-6. All functionality is not implemented, only those buttons necessary to complete the described scenarios. The buttons implemented, however, are supposed to work in a realistic way. In order to clarify which buttons work, the clickable ones are marked with a purple border. The buttons are divided into navigational buttons and action buttons. The navigational buttons enable the user to move around the interface and are available in the same way as they are in the real interface. The action buttons changes the state of the simulator and are part of the scenario to address the cause of the alarm. These are also available in the same way as they would be in the real interface. If they are pressed in the wrong order a message tells the user that the wrong action is performed. The navigational buttons and the action buttons are not distinguishable to the user.

Emphasis was put on making the user interface of the dialysis machine look and behave in a realistic way for two reasons. Firstly, during the design meetings with the nurses they expressed a wish to practice using the interface of the dialysis machine. They learn how to navigate during normal procedures and common alarms but do not get the same opportunity to practice rare alarms. Learning what the interface looks like and which buttons to press may relieve stress in a critical situation even if there are instructions on the screen. Secondly, it was estimated that lacking realism in the user interface of the dialysis machine would damage the overall realism. The interface is central to the treatment as it is both a source of information in the form of values and instructions, and the main means of affecting the patient.
The user interface of the dialysis machine is implemented using screenshots of the machine generated through simulations with saline solutions. There are therefore some inconsistencies in the images of the dialysis machine. For example, the arterial pressure is positive in the simulator when normal values are around -150 mmHg. The value of the venous pressure is also incorrect. Other small examples include that the accumulated blood volume when returning blood changes between views, and inconsistencies with some of the parameters like UF speed and UF goal. The nurses, however, do not need to check these parameters in order to complete the implemented scenarios and are likely not to focus on their inaccuracy. It was considered more important that the venous pressure value is red, indicating that it is too high, then that it has a plausible value. During the interviews with the nurses it was found that their first reaction in an alarm situation is not to look at specific values, but rather they immediately check the access to see that there is no leakage of blood upon noticing pressure alarm. At a later stage they may check specific values when assessing the cause of the alarm, but in the implemented scenarios they do not need to do that.

7.1.5 The Feedback Page
When the simulations are completed or cancelled the user is directed to the feedback page. No feedback system is implemented, there is simply a standard text depending on whether the simulation was completed or cancelled. The intention is to show that feedback could be displayed here, for example if something took too long or if an incorrect assessment was made.

The user can choose to log off and is then directed back to the log in page. The user can also choose to start a new simulation and is then directed to the set up page. The program is closed by pressing the close window icon in the upper right corner.
7.2 Description of the Scenarios
This section contains detailed descriptions of the implemented scenarios and all the actions they include. Flowcharts describing the sequences are available in Figure 7-7 and Figure 7-8.

First there is a list of all implemented action buttons according to which page they appear on:

Blood line page:
- Remove obstruction

Access page:
- Blood lines together (the venous and arterial blood lines are connected to each other and not to the patient)
- Blood lines reversed (the venous blood line is connected to the arterial needle)
- Insert new needle
- Connect the blood lines (connect the venous blood line to the venous needle and the arterial blood line to the arterial needle).

Interface of the dialysis machine:
- Confirm alarm
- Enter circulation mode
- Confirm start of circulation
- Stop circulation
- Restart treatment
- Enter returning blood mode
- Confirm returning of blood
- Continue returning (continue to return blood to a plastic bag after the return volume is reached)
- Stop returning (blood)
- Resume session (restart the treatment after having returned the blood to the patient)
Figure 7-7. Flowchart describing the kink on the blood line scenario as well as the start of the hematoma scenarios. The flowchart is a continuation of the flowchart depicted in Figure 7-5.
Figure 7-8. Flowchart of the two hematoma scenarios: the circulation program-scenario and the returning of blood-scenario. The flowchart is a continuation of the flowchart shown in Figure 7-7.
7.2.1 External Obstruction
External obstruction is represented by a kink on the line. In order to examine if there is an obstruction the user has to press the purple circle around the blood lines. The blood lines are then enlarged and clearly show whether there is an obstruction or not. There is also a text stating if the blood lines have a kink or not. If there is a kink the button to remove it is enabled (action button: remove obstruction). The fact that the user has to press the blood lines to investigate them represents remembering to check under the blankets in a real-life situation.

Once the blood lines are free the user should navigate to the dialysis machine interface and press the confirm alarm button (action button: confirm alarm obstruction). The scenario is then completed.

7.2.2 Addressing Hematoma with the Circulation Program
If the simulated patient has a hematoma it will be visible at the access page. The access page is shown if the user presses the patient’s arm. A button saying hematoma is visible and a part of the arm above the venous needle is discoloured. The user is then supposed to navigate to the interface of the dialysis machine to determine that there are three hours left of the treatment. From that information the user should draw the conclusion that the treatment needs to be continued. The user then decides whether to use the circulation program or to return the blood. Returning blood is described in the section 7.2.3.

The first step in the circulation program scenario is to connect the blood lines to each other (action button: blood lines together). When the blood lines are connected to each other the alarm can be confirmed in the interface of the dialysis machine (action button: confirm alarm). The user then has four seconds to enter the circulation program before a warning message is shown. The warning message symbolises that other pressure alarms might go off as the system is trying to perform dialysis when the patient is not connected. In order to enter the circulation mode the user presses the extra option tab in the interface of the dialysis machine, chooses the circulation program and then presses start (action button: enter circulation mode). The blood pump is then stopped. In the next step the user is the supposed to confirm the start of the circulation program (action button: confirm start of circulation).

Now the user can navigate back to the access page and press the insert new needle button (action button: new needle). Inserting a needle requires a skill that can never be obtained by only using a computer simulator. However, it is a very important step in the routine and the button therefore symbolises the entire procedure of sterilising, inserting and flushing the needle.

The user then navigates back to the interface of the dialysis machine and stops the circulation program (action button: stop circulation) and can then reconnect the blood lines to the appropriate needles on the access page (action button: connect blood lines). Next the user can resume the dialysis treatment in the interface of the dialysis machine (action button: restart treatment). When pressing the button there is a message box instructing the user to increase the blood flow, which was automatically decreased during the circulation program. In real-life, the dialysis machine will give a warning if the flow is not increased after a short period of time and the message box represents this. The scenario is now completed.
7.2.3 Addressing Hematoma by Returning Blood

How to determine that the patient has a hematoma and needs more treatment is described in section 7.2.2.

The first step in the returning blood scenario is to attach the venous blood line to the artery needle (*action button: blood lines reversed*). When pressing the button a message box pops up asking the user to flush the arterial needle in order to ensure that the hematoma is not affected. This type of action is very difficult to simulate with only a computer as it requires feeling the resistance of the needle and watching the effects on the arm. Therefore it is not implemented as an action but the message box serves as a reminder as it is part of the routine.

When the venous blood line is connected to the arterial needle the user can enter the returning blood mode in the interface of the dialysis machine (*action button: Enter returning blood mode*). The user can then confirm the start of returning the blood (*action button: Confirm return of blood*) as well as confirm the alarm (*action button: confirm alarm*) in any order. The returning of the blood will start once both actions are performed. The returning of blood takes ten seconds to represent the two to three minutes it takes in a real-life situation without taking an unnecessarily long time from the simulation.

When the blood is returned the user can press continue to return blood (*action button: continue returning*); a message box is then shown telling the user to connect the venous blood line to a plastic bag and lower the blood flow to 30 ml/min. This was put in a message box rather than in buttons as it was difficult to find a logical place to put the buttons without losing realism or making it too easy.

While the blood is slowly being pumped into the plastic bag the user can insert a new needle at the access page (*action button: new needle*) and then stop the returning in the interface of the dialysis machine (*action button: stop returning*). The blood lines can then be reconnected to the patient at the access page (*action button: blood lines connected*) and the treatment session resumed in the interface of the dialysis machine (*action button: resume session*). When the resume session button is pressed there is a message box informing the user to increase the blood flow and turn on UF*. This represents a warning message that will be shown on the dialysis machine in a real-life situation if either the blood flow is not increased or the UF is not turned on after the treatment is resumed. When the user presses OK in the message box the scenario is completed.

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*Ultra Filtration: removal of fluid from the blood.*

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7.3 The structure of the Code
The program is written in Visual Studio using C# and Windows Presentation Foundation (WPF). It runs on Windows XP and later versions of Windows. The patient model is made up of four state variables: Alarm, Complication, Blood lines and Blood pump. The state of each simulated patient is determined by the values of these variables. The user can change the states by using the action button described earlier in this section. A complete list over how each scenario changes the state variable can be seen in appendix 15.1. The possible values of the state variables are as follows:

**Alarm:** Active, Inactive

**Complication:** Obstruction, Free, Hematoma

**Blood lines:** Connected, Reversed, Together, ConnectedToHematoma

**Blood pump:** Stopped, Running, CirculationMode, Circulation, BloodReturnMode, BloodReturnRequested, BloodReturned, KeepReturning

The program tests if the action that the user wants to perform is correct or not by checking the values of the state variables. If the values indicate that the action is incorrect, a message is displayed informing the user to try again. If the state indicates that it is the correct action the state is changed and the interface is updated accordingly. The controlling part of the program starts by checking the value of the complication variable. For each complication only the correct actions for that complication are implemented. If an action is not implemented the controller knows that it is incorrect without having to check the rest of the state variables. If the action is implemented the controller proceeds to checking if the action is correct for the current values of all state variables.
8 Results from the User Evaluation

The user evaluation was conducted in the nurses’ computer room at Karolinska University Hospital Huddinge during four sessions that were spread out over four days. Each session took about one hour and was conducted in the afternoon, just before the nurses finished their working hours. The time was chosen by the clinic as there are usually less patients and a smaller workload in the afternoon. The language used was Swedish and therefore all citations from the nurses are translated. Due to miscommunications four nurses attended at the same time the first day, making it difficult answer all their questions and collect all feedback. During the other three days two nurses attended at the same time during each day, except for the last day when two nurses attended separately. Therefore ten nurses in total tried out the program. However, only three of the nurses during the first day had time to fill out the evaluation. In addition, as the first session became somewhat unorganised it is difficult to be sure that the users understood the questions in the evaluation correctly and less emphasis is put on their answers.

8.1 Descriptions of the Four Sessions

8.1.1 Session One

During the first day the initial presentation was held as planned and described in section 5.4.1. However, no demonstration was held as there was a lack of space around the computers and no projector was available. Instead the nurses were asked to follow the instructions given and explore the program on their own computer. One computer was provided for each participant. Some issues immediately arose as only one of the four participants read the instructions. The other three required help by complete oral instructions. There were several comments about the scenarios as the nurses felt that the way they would handle the simulated complication was not represented. In a group discussion the concept and limitations of the simulator were emphasised again and the evaluation could proceed.

As the nurses had limited time and started to get impatient after the introduction it was decided to proceed to the evaluation questions without letting the nurses explore the program further on their own. Even though one of the nurses had to leave before answering the questions it was still difficult to conduct the planned structured interviews with three remaining nurses. Instead the nurses filled out the evaluation questions on their own and the test leader tried to observe and discuss as much as possible with each participant as well as answer questions.

8.1.2 Session Two

During the second day the initial presentation of the project was held. This was followed by a demonstration where the test leader went through the scenarios described in the instructions with the two participants. The nurses were then asked to try out the different scenarios on their own computer, with the guidance of the walkthrough-leaflet. The nurses did not show much interest in the walkthrough but asked for help when they got stuck instead. They did, however, seem to grasp the concept of the simulator a lot faster than the participants in the first session and could focus on the scenarios.

The evaluation was conducted in the form of a structured interview with the two participants together. Each question was discussed and it was beneficial to interview the two nurses
simultaneously as they gave each other new ideas. All comments were recorded by the test leader but the nurses were also allowed to write down their answers on their own evaluation form sheet.

8.1.3 Session Three
Session three was conducted in the same way as session two, with the same positive results. The participants still preferred oral instructions when they tried the program themselves but showed some interest in reading the walkthrough as well.

8.1.4 Session Four
Session four was divided into two parts with one participant in each. This difference occurred because during the previous day all the nurses had less to do in the clinic at the same time, whereas this day they had some time to spare at different times. The user tests were therefore conducted in the same way as during session two and three, except with one participant at the time. There was slightly less discussion as the test leader could not provide insights about dialysis in the same way as a fellow nurse could. Again, little interest was shown in the written walkthrough. The overall response to the evaluation was however positive.

8.2 User Comments
This section is organised to follow the evaluation questions described in section 5.4.2.

8.2.1 Information about the Participants
The first part of the evaluation interview concerns traits of the participants. It was found that the nurses that participated in the evaluation had worked with dialysis for between 10 months and 22 years. The *Fresenius Medical Care 5008 treatment system* machine has been used at the clinic for the last 2 to 3 years and all the nurses in the study had worked with it since it was introduced, or since they started working at the clinic.

8.2.2 General Impressions
The second part of the interview concerns the participants’ general impression of the simulator. All the participants found the simulator fun, slightly fun, or okay to use. They also all rated it easy or fairly easy to use, despite the fact that several participants had some problems understanding it initially.

The rating of the realism of the simulator varied a lot among the participants depending on how they interpreted the question. Most participants did not think that the realism was diminished by actions like inserting a new needle being represented with a button. Two of the participants did however say that they missed “seeing the patient”. Several nurses also had difficulties relating the scenarios to real-life situations as they would not handle a real-life hematoma situation in the same way as they were required to with the simulator. Four of the participants also stated that they thought that a sounding alarm would make the simulator more real. The added stress from the alarm sound would make the user “more alert”. Another suggestion was to have more consequential alarms, like the one that appears in the hematoma-circulation scenario if the user confirms the alarm and then waits more than four seconds before starting the circulation program (see section 7.2.2 for details). In a real-life situation the machines often have several alarms active at once; making it difficult for the nurses to know what caused it in the first place. If an incorrect action is performed or if the nurses take too long other alarms can appear as well. This can be very stressful and the suggestion was to try to include more scenarios like this in the simulator.
Most participants answered that they had learned something new during the user tests, one mentioning the circulation program.

8.2.3 Clarity and Usability
In the next part of the interview the clarity and usability of the simulator is examined.

The participants were asked to rate the setup of the simulation, where a general picture of the patient and dialysis machine with clickable area to the left and enlarged features with action buttons to the right are visible. All nurses rated the setup as easy to understand, rather easy to understand or okay. None of the nurses rated it as difficult despite the fact that several of them experienced difficulties when navigating. There were, however, several comments saying that they thought navigation became easier when they “had got used to it”.

The main issue with navigation for the users was that they had problems understanding that there were some action buttons on the arm-page and some on the machine interface-page and that they could change between the pages at all times. The users seemed to expect the pages to be in chronological order, and asked “how to go back”. The desire to go back was also present after the user had pressed an action button. In addition, several users wanted the different scenarios to be visible in the simulator. That is to say that they wanted to have one button for initialisation of the circulation program-scenario and then one button for initialisation of the returning of the blood-scenario.

The next question concerned what the users’ experienced when assessing which complication had caused the alarm. The users were asked to rate if it was easier or more difficult to assess the complication in the simulator compared to in a real-life situation. Unfortunately the assessing part of the simulator was not properly conveyed to the users. In order to explain to the users how the simulator works the assessing part had to be partly neglected, as a lot of emphasis had to be put on how to deal with the hematoma. In addition, the nurses stated that it may be as easy to detect a hematoma or a kink on the line in a real-life situation as in the simulator but in a real-life situation there are many more factors to consider. It may also be more difficult to simulate the assessment of other complications as accurately.

Determining which factors affect the realism is difficult and seems to vary between users. As mentioned in the general impressions section (section 8.2.2) most nurses did not experience a diminished realism from the actions buttons for inserting a new needle and handling the blood lines. One of the users who did feel that the lack of hands on experience was a hindrance was one of the newer nurses with less than a year of experience. This user suggested that the simulator program could be run on the dialysis machine to increase the realism and enable connection and disconnection of the blood lines. The main realism issue seems to be the users’ difficulty to form a mental picture of the state of the simulator. Several nurses described that they “missed seeing the patient” or that they did not know what to do as they “could not see the patient”. Despite knowing how to handle the situation in real-life most of the nurses were unsure of the order of actions and also which actions had already been performed.

The last question about clarity and usability concerned how the simulator deals with incorrect user actions. In the present state, when an incorrect action button is pressed a warning message saying “incorrect action, press ok to try again” is displayed. When ok is pressed the simulator returns to the
state that it was in before the incorrect action was performed. The users were asked if they liked this setup or if they would prefer a different one. Two other suggestions were given: Either there could be a message accompanying the warning explaining why the action was incorrect, or there could be no warning message and the machine would enter a state simulating the state a real machine would enter when this incorrect action was performed. The users were evenly divided among the options. Most agreed that some sort of guidance, like a “correct answer-button” could be available if the user got completely stuck. Some argued that it was best that the correct answer should be provided together with the warning message as “one learns by seeing the right answer”. Others felt that it was a good thing that a warning message was displayed to tell user that something was wrong but that other indications should be left out to allow the users to think for themselves and learn by exploring. The last group felt that there should be no warning message at all to make the simulator behave as much as a real machine as possible.

8.2.4 Potential Training Effect
This section of the interview includes questions about the potential training effect of a more complete simulator. The potential training effect is estimated through questions considering whether the nurses feel that a simulator would be helpful in different situations.

The first question concerns how the users experienced their introductory education when they started working with dialysis. The most experienced nurses felt that the equipment that was used during their education could not be compared to the one that is used today. It was therefore difficult to relate the use of a simulator to their learning experience. Other could not remember exactly but felt that a simulator would generally be a good idea. Most of those who did remember said that they would have wanted to practice some alarms more. They also believe that a simulator could have helped. A few were unsure if it would help or not and one participant felt that it would not help.

In the next question the users were asked if they felt that the simulator could make them feel more secure with handling rare alarms. Most of the nurses answered that they personally would probably not use the simulator that much for everyday situations, but that it could be helpful when, for example, new software features were released. They also agreed that it could be useful for refreshing one’s knowledge after a longer break like parental leave.

The users were also asked whether there were any particular situations that they would want to practice. The micro bubble alarm was mentioned as well as the general air detection alarm. There were checkboxes for the high and low venous and arterial pressure alarms, which were checked by several nurses. It was suggested that new nurses may want to practice more everyday alarms whereas more experienced nurses may want the more rare alarms. In the last question the users were asked how often they would want to use a simulator. Most answered “a few times a year”.

8.2.5 General Comments
Some of the general comments were that the simulator is a good idea but that it feels “unfinished” and that it is lacking a sounding and flashing alarm. One user described the simulator as “having a nice design” and “including all important elements”.

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Another user wanted the ability to choose which complication to simulate, instead of which alarm. The user meant that this would enable practicing specific scenarios. If one patient is chosen in the present state of the simulator the complication can be either hematoma or a kink on the blood line. If the user wants to practice handling hematoma it is unfavourable if the patent has a kink on the blood line or vice versa. Other users argued the complete opposite. They wanted the alarms to be completely random to make the simulation more realistic. They also suggested consecutive or simultaneous alarms. Some wanted a complete walk-through, with popup messages describing what was happening and giving alternative choices.
9 Discussion

The discussion of the project is divided into two parts. The first part is a discussion of the results and how they correspond to the aim of the project. The second part is an evaluation of the project and the experience gained.

9.1 Discussion of the Results

The discussion of the results is divided according to the sub objectives defined in the aim in section 1.3.

9.1.1 Update the Identified Needs According to the New Technology

As initially assumed some procedures have become easier with the newer dialysis machine models. The one specific example identified is disconnecting patients when they need to go to the bathroom during treatment. There are also more instructions on the screen of the dialysis machine to help guide the nurses. It is difficult to estimate how this affects the difficulty of specific procedures without a more thorough investigation.

The manufacturers of dialysis machines have addressed the increased complexity of the software with basic simulation programs where standard procedures and functions can be practiced. There is also an education program to teach the nurses about new functionality when software updates occur. Despite this the nurses seem unsure of some of the new functionality. For example they choose to use the method of returning blood instead of using the circulation program when addressing a patient with hematoma.

One reason for the insecurity could be that there are no simulation programs for practicing alarm situations. With the new technology the alarms are more refined and specific, making individual alarms even rarer in the clinic. Knowing that a specific functionality exists may be of less use if it has not been practiced while applied to an actual scenario with a patient.

The conclusion is that there still seems to be a need for a training simulator that enables the user to practice scenarios that include both the dialysis machine interface and the patient, especially in alarm situations.

9.1.2 Gather Experience for a Future Project

Although the prototype program may seem like the more palpable result of this project, the process of developing it can be even more important for a future project. By choosing and implementing an alarm and its sub scenarios the suitability for implementation of different elements in the clinical procedure is evaluated. An obvious example is the observation of the difficulty of realistically implementing any action that involves the patient. More subtle is the comparison between hematoma and clotting in the venous chamber. With limited clinical knowledge they seem to be similarly difficult to implement. Upon closer inspection however, it is found that clotting poses far more challenges because of the way it is assessed. Several challenges like this were identified during the course of the project and are described in sections 6 and 7.

One challenge is how to deal with the parts of the simulation when the user is supposed to interact with the patient. With a PC based simulator it is difficult to practice inserting new needles and similar procedures. In the prototype the solution is to use symbolic buttons for the main actions as well as popup messages as reminders for some others.
Another challenge is how to make the interface structured and usable. In the prototype the design from the TNA with patient tabs was used. It was combined with the idea of seeing the patient and dialysis machine as a system with parts that could be inspected more closely. The user presses different parts to magnify the area, to look closer.

Several scenarios were excluded because of a lack of clinical knowledge. In order for the user to be able to make an informed assessment they need realistic information. One more challenge is to gather enough clinical knowledge and documentation to implement the information needed for the user to assess, for example, if it is likely that the patient has stenosis.

Also very beneficial for future projects are the described scenarios, procedures and alarms that were not chosen for implementation. Many were left out simply because there was not enough time to include them. See section 6 for detailed descriptions. Section 7 then contains many functions and ideas about the simulator that were left out or only partially completed. The excluded functions and scenarios could be used as a starting point for new functionality, while the reasoning around the included scenarios and functions could provide insights regarding what to consider when implementing the new functionality.

9.1.3 Examine the Potential Training Effect of a Simulator of this Type

Much feedback was collected from the user evaluation, both in the form of identified issues and in the form of suggestions from the nurses. It is difficult to distinguish any general trends as the evaluation was qualitative rather than quantitative. Nine nurses participated in the user evaluation and the conditions of the evaluation varied from day to day. No clear conclusions can therefore be drawn about how different user traits affect the users’ experience of the simulator. The only factors that could be vaguely discerned are previous computer experience and attitudes towards computers and learning.

The main issue identified is the difficulty the users had in obtaining a mental picture of the simulation. There are most likely several reasons for this and a much longer evaluation is needed for a proper identification. The difficulties may be caused by a lack of realism in one or several areas of the simulator, but could also be an effect of the short introduction during the user tests. There are several keys present in the simulator to indicate which state it is in and it was stated in the evaluation interview that “all important parts are included”. If the users were given the opportunity to become more familiar with the simulator they might be able to relate the keys to a real-life situation and the issue would be resolved. If an extended use of the simulator does not help, the realism should be more closely evaluated. The mental picture is essential to the learning as discussed in section 3.1.1 and if the users’ cannot form a mental picture of the situation the training effect will be greatly diminished.

One usability issue is also identified. Several users experienced difficulties because the simulator would not let them perform actions in the order they are used to. The real user interface of the dialysis machine is very flexible and allows several paths to handle any situation and every nurse has a slightly different approach. There was not enough time to imitate this behaviour in the prototype program and the users’ reactions do suggest that more emphasis should be put on it in a future project. As discussed in section 3.3.2 usability is one of the key factors that affect the training effect.
of a simulator. High usability does not guarantee a training effect, but low usability will most likely be a hindrance. According to Berndtsson & Domingues (n.d.) five participants are needed to find the usability issues in a user test. Excluding the three evaluations during the first session that were not optimally performed six nurses participated in the user tests. As no new issues arose in the last sessions it is possible to conclude that most major usability issues with the simulator are likely identified.

The importance of watching what the users do and not only what they say is also evident in the user evaluation (theory described in section 3.3.2). Inconsistencies between how the users interact with the program and how they answer questions are clearly seen. For example most users experienced problems when navigating in the simulator and handling the complications. Despite this no one rated the simulator as being difficult to use or the setup to be unclear. One reason for this could be that the questions were not understood as intended. The questions were mostly answered as part of an interview with a lot of emphasis put on making the participants understand the questions. However, this is no guarantee that there were no misunderstandings. Another reason could be that they rated the simulator as they thought it would feel if they had used it for a longer time and that they were better at recognising the learning threshold than anticipated in section 5.4.1.

Another important conclusion that can be drawn from the evaluations is that if there are to be any written instructions they should be displayed on the computer screen within the simulator program. In the evaluation it was mentioned that the nurses are used to learning by doing, and it became evident that they do not prefer long written detailed instructions. Either the program should be introduced by demonstrations and oral instructions or by short instructions within the simulator in the form of popup messages and indications on the screen.

The overall result from the evaluation is that the nurses at the clinic generally have a positive attitude towards a training simulator. They feel it would be most useful for new nurses, after a longer break from work, or when a new dialysis machine model or software is received. There are many contradicting suggestions for improvements of different features and functions as everyone has their own preferred style of learning. It is very difficult to know what will work best for as many people as possible, and one idea is to try to include choices at different states of the simulator. Caution is advised, however, as too many choices make it more complex and, as is evident from evaluation, the nurses prefer a straight-forward approach and not detailed instructions.
9.2 Evaluation of the Project

This project has been very stimulating and educative. Being quite a small project it has felt like there is much more to do than there has been time for. Learning how to limit the project without diminishing the results has been a challenge. However, there are also benefits with a smaller project. Being involved in all parts of the development process has been truly engaging and enabled an understanding of how different parts in a software development project work, interact and depend on each other.

The most amazing part of the project has been the support I have received from the nurses at Huddinge as well as the educational nurses at both Huddinge and Fresenius Medical Care Sweden AB. The nurses were not compensated for the time spent teaching me about dialysis, or giving feedback on or evaluating the prototype. Still they went to great lengths to accommodate both me and the project. In return I have tried to show how much I value their involvement and have made an effort to record all their input so it can be used in a future project.

The greatest challenge has been the modelling of the scenarios. I expected that my lack of medical knowledge would present difficulties and that I would have to spend some time learning about dialysis. Although it has been my lack of medical knowledge that has provided the challenge, it is in ways that I did not anticipate. It was not so much lacking a knowledge of anatomy and medical vocabulary that was a hindrance, as having a completely different viewpoint and lacking clinical experience. Studying engineering physics at university does not provide any insights into how nurses at a dialysis clinic perceive their work. During discussion with the nurses I thought that I understood their routines, only to realise a week later that I had got most of it wrong. The nurses do not analyse the results and methods of their work in the same way as an outsider does. At the clinic more experienced nurses teach new nurses by first letting them watch and then supervising them. A lot is therefore lost when they describe the procedures to an outsider.

It took me some time to realise this, and I was relying too much on interviews at the beginning of the modelling. It was not until I changed my approach and observed them working with the patients that I got the scenarios right. As the alarm situations that I am modelling are so rare I could not watch a complete real-life situation. The nurses were however able to trigger the alarm without endangering the patient and show me what they would have done if it was a real alarm.

Another difficulty that I did not anticipate was the complexity of the scenarios. My original idea was that all action buttons were to be available at all times, in order to prevent giving clues. With fifteen action buttons and scenarios with up to eight steps, enabling all the actions at all steps generates too many paths to implement. Instead I had to start with the correct paths for each scenario and focus on that. Having only a few paths also causes problems as all nurses work slightly differently. I have tried to follow the main routine but in a real-life situation there is room for individual alternations.

Many of the limitations that restricted the prototype became apparent in the user evaluation. The inability to make individual alterations proved for example to be a major usability issue. Most evident are the effects of my different viewpoint and lack of medical experience. Realising that, as the developer, my understanding of the prototype would far exceed that of any first-time user, I prepared an extensive instruction manual. I tried to be very clear and not assume any previous knowledge of the program. Once again I did not anticipate the extent of my different point of view.
The nurses learn by doing and by watching someone more with experience, not by reading lengthy instructions.
10 Conclusions

The aim of this project has been to evaluate the concept of a training simulation program for nurses at a haemodialysis clinic by developing a prototype program. A prototype program has been developed and evaluated and in this way the three sub-objectives defined in section 1.3 have also been addressed.

The first objective was to update the identified needs according to the new technology. The observations gathered during the project confirm that the new technology has affected the level of difficulty of some situations. A more extensive examination is needed to determine all the effects. However, the need for a training simulator is still present. The simulator should enable the nurses to practice rare alarm scenarios that include both the dialysis machine interface and the patient.

The second objective was to gather experience for future projects. Several challenges have been identified during the development process and some have been addressed. They are all described in this report and are thereby available for other projects. The reasoning behind which features and scenarios to include and exclude in the prototype program also provides an excellent platform for further work.

The final objective was to examine the potential training effect of a simulator of this type. It is very difficult to estimate the training effect from a prototype but the user evaluation does indicate that a training simulator could have a positive impact on the nurses’ learning. The nurses showed a positive attitude towards the idea of a simulator and believe that it may be useful. In order to increase the chances that a complete simulator generates a positive training effect it is important to address the issues identified in the user evaluation and to continue to develop the simulator together with the nurses.
11 Contributions

This project is intended to contribute to a better work environment for the nurses as well as increased safety for the patients. The project shows that one way of making the nurses more secure and therefore increasing patient safety could be a computer-based simulator. As clinics often experience tight budgets, cost-effective solutions are very important. Evaluating the concept of a cost-efficient computer-based simulator shows that there is an alternative to a complex simulator with a real-life size patient. User-patient and user-machine interactions can both be practiced with only a computer. In addition, with a developed feedback system the nurses could practice a lot on their own without requiring constant supervision from teachers or simulation managers.

During the project it has, however, become apparent that it is not as simple as only providing a simulator. There is a need for a better understanding of the importance of human-computer interaction in healthcare. Despite the fact that technology is being developed to make life easier for people, products are lacking in usability. One problem is that users and developers often have completely different viewpoints and experiences. A result can be that products may include well developed solutions without the users knowing about them. A simulator that combines interaction with the dialysis machine and the patient can be a tool to give the users information on how to best use the available technology in their clinical routines. Designing and evaluating such simulators may also provide a better understanding on how the nurses interact with the technology.
12 Future Work

There is a lot of work that could be done concerning training simulators in health care education. This project barely scratches the surface and the intention is that the results could be used as a starting point for future works. Section 6 contains descriptions of included and excluded scenarios and section 7 describes included and excluded functionality. The results and comments from the evaluation also contain insights of how the nurses perceive the simulator. This can be seen in section 8. The challenges identified and how they were handled are discussed in section 9.

An important conclusion from the project is that the new technology has affected the training needs. Before proceeding with developing a complete simulator it would be beneficial to perform a new training need analysis as well as a risk analysis to determine which complications pose the greatest threat to the patient safety.

It is also recommended that both sound and stressful disruptions are included in a future project. During the user tests the nurses suggested that the simulator should have a sounding alarm. In a real-life situation the dialysis machine will give off a beeping sound when the alarm goes off to further attract the nurses’ attention. The alarm sound would probably increase the realism of the simulator as it activates one more of the senses. The work environment of a dialysis clinic also contains a lot of distractions, in addition to the sounds of alarms from the nurses’ own patients and other patients at the clinic. Other patients and colleagues are constantly present and may demand the nurse’s attention. An idea in the TNA (Jonsson, 2010) was that these stress factors may be simulated with popup disruptions. For example that a short puzzle has to be completed before the user can proceed with treating the patient. This could further increase the realism as well as add an element of practicing stress handling.

Another aspect could be to analyse the need of other people using dialysis equipment. One potential group is patients performing their own dialysis at home. As they only gain experience from treating themselves they have very limited chances of experiencing rare alarms and it is very important that they know what to do and not panic. Another important group is the nurses at intensive care units. The patients treated at such units are very ill and require a lot of complex medical equipment. The nurses then need to be able to handle a lot of different technical equipment and will not be able to get particularly familiar with each specific model. Both patients that treat themselves and nurses at intensive care units could potentially therefore benefit greatly from a simulator.

When proceeding with a larger project it is important to keep involving the users. The users know their work environment best and have a lot of input to give. A challenge in this project has been the lack of clinical knowledge. It is therefore also important to create a project with both developers and people with expert knowledge in medical procedures and routines. In order to address the pedagogical aspects it would be beneficial to involve someone with an educational background as well. Developing educational technology is an interdisciplinary project and it is very important to remember that everyone does not think alike.
13 Acknowledgements

This project would not have been possible without all the support I have received. First and foremost I want to thank Sjöland & Thyselius Datakonsulter AB (S&T) and Anna Skytt for setting up and enabling this project. Furthermore I want to thank my supervisor at S&T Fredrik Stråhle as well as my reviewer Bengt Sandblad at Uppsala University. I am also very grateful for all the programming advice and support I have gotten from my colleagues at S&T.

I also want to thank the nurses at the dialysis clinic at Karolinska University Hospital Huddinge as well as the people at Fresenius Medical Care Sweden AB, especially Ulla Holm and Torun Karlsson. Their clinical knowledge about dialysis and the Fresenius Medical Care 5008 treatment system has been essential.

In addition I want to thank my family and friends for their support and encouragement.
14 References

14.1 Images


Figure 4-1. Kirk, A. & Tattersall, J. (n.d.) Haemodialysis (HD). Retrieved August 8, 2013 from [http://www.renalmed.co.uk/database/haemodialysis-hd](http://www.renalmed.co.uk/database/haemodialysis-hd)

Figure 7-1, Figure 7-2, Figure 7-3, Figure 7-4, Figure 7-6. Screenshots made of the prototype when executed on a PC.

Figure 7-5, Figure 7-7, Figure 7-8. Flowcharts made during the development process.

14.2 Written Works


### 14.3 Other Sources of Data

Study visit to CAMST (Centrum för avancerad medicinsk simulering och träning), a centre for simulation at Karolinska University Hospital Huddinge. (May 2013)

Study visits to the dialysis clinic at Karoliska Univeristy Hospital Huddinge. (April-June 2013)

Interviews with nurses at the dialysis clinic at Karoliska Univeristy Hospital Huddinge. (April-June 2013)

Interview with medical technician at the dialysis clinic at Karoliska Univeristy Hospital Huddinge. (April 2013)

Interviews with educational nurse at the dialysis clinic at Karoliska Univeristy Hospital Huddinge. (April-July 2013)

Interviews with educational nurse at Fresenius Medical Care Sweden AB. (April-May 2013)
15 Appendix

15.1 How the State Variables Change according to the Action Buttons

**Alarm goes off:**

User should check

1. Access/fistula  
2. Blood lines  
3. Ask patient how they feel  
4. Maybe check medical record (not much info implemented)

**Hematoma:**

User finds hematoma at access page. Sign saying hematoma.

- Check if the patient needs more dialysis (always 3 hours left).

Click hematoma button to get more information answering:

- Is it possible to insert a new needle? (size of hematoma) (always possible)

**Starting state of the patient:**

- **Alarm:** Active  
- **Complication:** Hematoma  
- **Blood lines:** Connected to hematoma  
- **Blood pump:** Stopped

**Alternative 1:**

1. Connect venous blood line to artery needle. (Messagebox to flush artery needle)

   - **Alarm:** Active  
   - **Complication:** Hematoma  
   - **Blood lines:** Reversed  
   - **Blood pump:** Stopped

2. Enter Return mode. (press I/O-button on return blood page). Blood flow rate is automatically lowered to 100 ml/min.

   - **Alarm:** Active  
   - **Complication:** Hematoma  
   - **Blood lines:** Reversed  
   - **Blood pump:** BloodReturnMode
3. The two following steps can be done in either order. The blood pump will not start until the alarm is confirmed as well as start returning blood is confirmed. Returning the blood will take 10 seconds.

First: Confirm return of blood

Alarm: Active
Complication: Hematoma
Blood lines: Reversed
Blood pump: BloodReturnRequested

Second: Confirm Alarm

Alarm: Inactive
Complication: Hematoma
Blood lines: Reversed
Blood pump: BloodReturned

OR

First: Confirm Alarm

Alarm: Inactive
Complication: Hematoma
Blood lines: Reversed
Blood pump: BloodReturnMode

Second: Confirm return of blood

Alarm: Inactive
Complication: Hematoma
Blood lines: Reversed
Blood pump: BloodReturned

4. Keep returning blood (message box to lower the blood flow rate to 30ml/min).

Alarm: Inactive
Complication: Hematoma
Blood lines: Reversed
Blood pump: ContinueReturning

5. Insert a new needle.

Alarm: Inactive
Complication: Free
Blood lines: Reversed
Blood pump: ContinueReturning

   **Alarm:** Inactive  
   **Complication:** Free  
   **Blood lines:** Reversed  
   **Blood pump:** Stopped

7. Connect the blood lines to the patient.

   **Alarm:** Inactive  
   **Complication:** Free  
   **Blood lines:** Connected  
   **Blood pump:** Stopped

8. Restart the session. (Messagebox reminds the user to increase the blood flow rate and start UF)

   **Alarm:** Inactive  
   **Complication:** Free  
   **Blood lines:** Connected  
   **Blood pump:** Running

   **Simulation completed.**

**Alternative 2:**

1. Connect venous and artery blood lines to each other.

   **Alarm:** Active  
   **Complication:** Hematoma  
   **Blood lines:** Together  
   **Blood pump:** Stopped

2. Confirm the alarm. (If circulation program is not started within 4 seconds, a message box appears to warn the user)

   **Alarm:** Inactive  
   **Complication:** Hematoma  
   **Blood lines:** Together  
   **Blood pump:** Running

3. Start the circulation program. (The blood flow rate is lowered to 100 ml/min automatically)

   **Alarm:** Inactive  
   **Complication:** Hematoma  
   **Blood lines:** Together  
   **Blood pump:** CirculationMode
   
   *Alarm*: Inactive
   *Complication*: Hematoma
   *Blood lines*: Together
   *Blood pump*: Circulation

5. Insert a new needle
   
   *Alarm*: Inactive
   *Complication*: Free
   *Blood lines*: Together
   *Blood pump*: Circulation

6. Cancel circulation program
   
   *Alarm*: Inactive
   *Complication*: Free
   *Blood lines*: Together
   *Blood pump*: Stopped

7. Connect blood lines to patient
   
   *Alarm*: Inactive
   *Complication*: Free
   *Blood lines*: Connected
   *Blood pump*: Stopped

8. Restart treatment (Messagebox reminds the user to increase the blood flow rate)
   
   *Alarm*: Inactive
   *Complication*: Free
   *Blood lines*: Connected
   *Blood pump*: Running

   Simulation completed.
Obstruction:

User finds information that there is an obstruction on blood lines page (patient sitting on blood lines or the blood line is bent).

Starting state of the patient:

Alarm state: Active  
Complication: Obstruction  
Blood lines: Connected  
Blood pump: Stopped

1. Remove obstruction (button only available when there is an external obstruction)

   Alarm state: Active  
   Complication: Free  
   Blood lines: Connected  
   Blood pump: Stopped

2. Confirm alarm

   Alarm state: Inactive  
   Complication: Free  
   Blood lines: Connected  
   Blood pump: Running

Simulation completed.
15.2 User Evaluation Questionnaire [Swedish]

**Utvärdering av dialyssimulator**

Hur länge har du arbetat med dialys? __________________

Hur länge har du arbetat med 5008 maskinen?______________

Har du arbetat på någon annan dialysklinik eller varit borta från arbetet en längre period under de senaste två åren? ___________________________

**Helhetsupplevelse:**

1) Roligt | Ganska roligt | Sådär | Ganska tråkigt | Tråkigt
---------|--------------|-------|---------------|---------
Var det roligt att använda simulatorn? | | | | |

2) Lätt | Ganska lätt | Sådär | Ganska svårt | Svårt
--------|------------|-------|--------------|-------
Var det lätt att använda simulatorn? | | | | |

3) Verklig | Ganska verklig | Varken eller | Ganska overklig | Overklig
----------|----------------|--------------|-----------------|---------
Hur realistisk kändes simulatorn? | | | | |

4) Ja | Nej
-----|-----
Lärde du dig något nytt? | | |

Kommentar:________________________________________________________________________
__________________________________________________________________________________

**Tydlighet:**
När man gör en simulator måste vissa saker förenklas jämfört med verkligheten. Om man förenklar för mycket kan simulatorn bli mindre verklighetstrogen och göra så att användaren inte lär sig lika mycket. Jag har därför några frågor om vad du tyckte om de olika momenten i simulatern.

5) När simuleringen börjar ser man patienten och dialysmaskinen och man kan trycka på olika delar för att visa dem till höger.

<table>
<thead>
<tr>
<th>Vad tycker du om det upplägget?</th>
<th>Lätt att förstå</th>
<th>Ganska lätt att förstå</th>
<th>Sådär</th>
<th>Ganska svårt att förstå</th>
<th>Svårt att förstå</th>
</tr>
</thead>
</table>

Kommentar:________________________________________________________________________
__________________________________________________________________________________

6) I simuleringen ska du avgöra om larmet orsakas av att patienten har hematom eller av att det är en knick på slangen.

<table>
<thead>
<tr>
<th>Upplevde du att det var lättare eller svårare att avgöra orsaken till larmet jämfört med att avgöra det i verkligheten?</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
</table>
5 = lättare, 4= lite lättare, 3 = samma, 2= lite svårare, 1= svårare.

7) Det är svårt att simulera de saker man gör med patienten, till exempel sätta en ny nål. I simulatorn är de istället knappar.

<table>
<thead>
<tr>
<th>Gör knapparna att simulatorn känns overklig?</th>
<th>Overklig</th>
<th>Lite overklig</th>
<th>Påverkar inte</th>
</tr>
</thead>
</table>

8) Andra åtgärder nämns enbart i pop-up rutor när man trycker på en annan knapp. Till exempel att ändra blodflödet.

<table>
<thead>
<tr>
<th>Är det förvirrande att vissa saker är knappar och andra är pop-up:er?</th>
<th>Förvirrande</th>
<th>Lite förvirrande</th>
<th>Påverkar inte</th>
</tr>
</thead>
</table>

9) När man gör fel i simulatorn kommer en pop-up ruta där det står ”felaktig åtgärd”. Nu kommer frågor om vad du tycker om andra alternativ.

Ett alternativ skulle vara att det även står vad man har gjort för fel, till exempel ”felaktig åtgärd, du försökte återställa larmet när det är en knick på slangen”.
Ett annat alternativ är att det inte står någonting alls. Till exempel om larmet återställs när det är en knick på slangen så försöker simulatorn återställa larmet men det går igång igen eftersom det är stopp.

Gradera vad du tycker om följande alternativ (1-5):

5=starkt positiv, 4 = positiv, 3 = neutral, 2 = negativ, 1 = starkt negativ

<table>
<thead>
<tr>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ha var det som det är nu, att det bara står felaktig åtgärd.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Att det står felaktig åtgärd och varför det är fel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Att det inte står någonting alls.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Att man själv kan välja bland de tre alternativen innan simuleringen.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Träningseffekt:**

Tanken bakom den här simulatorn är att den ska göra det möjligt att träna på situationer som inte uppstår så ofta i det dagliga arbetet. Nu kommer därför frågor där du ska bedöma hur det känns att träna med en simulator.

**Att använda simulatorn för att träna under dialys-utbildningen**

<table>
<thead>
<tr>
<th>10)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Var det några larm eller situationer som du skulle ha velat träna mer på under introduktionsutbildningen?</td>
<td>Ja</td>
<td>Nej</td>
<td>Kommer inte ihåg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tror du att du hade lärt dig mer om du hade tränat mer på dem med en simulator?</td>
<td>Ja</td>
<td>Nej</td>
<td>Vet inte</td>
</tr>
</tbody>
</table>

**Att använda simulatorn när man har börjat jobba själv:**

<table>
<thead>
<tr>
<th>12)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tror du att du skulle känna dig säkrare på ovanliga larm om du fick träna på dem med en simulator?</td>
<td>Ja</td>
<td>Nej</td>
<td>Vet inte</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vilka situationer/larm skulle du vilja träna på?</td>
<td>Högt ventryck</td>
<td>Högt artärtryck</td>
<td>Luftvachtslarm</td>
</tr>
<tr>
<td></td>
<td>Lågt ventryck</td>
<td>Lågt artärtryck</td>
<td>Annat</td>
</tr>
</tbody>
</table>
14) | Flera gånger i veckan | En gång i veckan | Några gånger i månaden | Några gånger per år | Aldrig |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Om du fick möjlighet att använda en simulator på arbetstid, hur mycket skulle du då vilja använda den?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Allmänna kommentarer**

Var det något du saknade med simulantern? ____________________________________________________________

__________________________________________________________________________________

Var det något som var extra bra? _________________________________________________________________

__________________________________________________________________________________

Var det något som var dåligt? _________________________________________________________________

__________________________________________________________________________________

Övriga kommentarer _________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________

__________________________________________________________________________________