

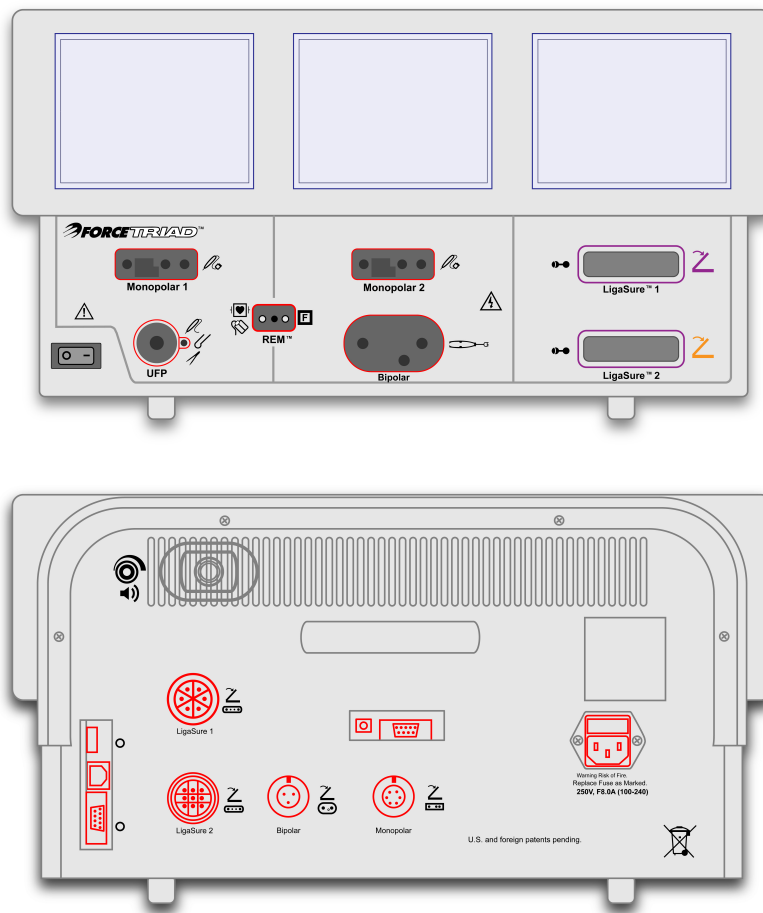
Improving skills related to medical equipment

An interactive computer training simulation

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Abstract

Background: Incidents with medical equipment have been observed by several studies [23, 5], and the lack of proper training has been identified as one of the main reasons for the occurrence of these errors [5]. Providing proper training is costly and logistically problematic for hospitals. Simulations can successfully resolve some of these problems, as has been proven in aviation and surgeons' laparoscopic skills training [6]. The aim of this study is to develop a simulation meant to train tasks related to operating medical equipment and to establish content-, face-, and concurrent validity for this simulation.

Methods: An interactive simulation of an electrosurgical device was developed to enable users to practice procedural and cognitive tasks on a computer. This gives the users the ability to independently *learn by doing*. Content validity was established by asking 2 experts' opinion concerning the content of the simulation. A total of 18 certified operating room nurses participated in this research. The participants were divided into two groups: (1) Simulation Trained (ST) and (2) Real life Trained (RT). The ST group received 2 training sessions with the simulation, whilst the RT group received a traditional hands on training. Before the ST group started using the simulation the goals, content, and features of the simulation were explained. To determine face validity they were asked to answer 16 structured questions concerning their first impression, training capacities, and statements regarding the simulation (face validity). These questions could be ranked on a mark ranging from 1 = very bad/useless to 5 = excellent/very useful and the statements had to be answered with "agree", "disagree", or "no opinion". To determine concurrent validity all participants were individually tested on their skills, related to an electrosurgical device, prior to, and after, having received their corresponding additional training. Errors were tallied and categorized into 3 types: (1) connection, (2) identification, and (3) procedural errors, using an assessment form. The results of the pre- and post test of ST group were compared with that of the RT group.

Results: Experts agreed that the content of the simulation complied with the reality. The results of the questionnaire show that the nurses rated the training capacities of the simulation and their first impression between a mean value of 4.0 for user friendliness and 4.4 for appearance and design of the software. In response to statements, 8 out of 9 participants (88%) considered this simulation useful for training procedural tasks related to the medical device, and all participants agreed that the simulation was useful to train identification tasks. During the experiment a reduction of 7 errors was observed for the ST group after having received the simulation training ($p = 0.038$). The RT group made 4 errors less after having received their additional training ($p = 0.257$).

Conclusions: Content-, face-, and concurrent-validity of the developed simulation has been established. OR nurses considered the simulation useful for training tasks related to the electro-surgical device. Participants of the ST group significantly improved their performance, while this was not the case for the RT group.

Contents

Abstract	1
List of figures	5
List of tables	7
Acknowledgments	8
1 Introduction	9
1.1 Background	9
1.2 Problem statement	9
1.3 Scope and objectives	10
1.4 Document overview	10
2 Literature review	11
2.1 Errors	11
2.1.1 Concept of errors	11
2.1.2 Occurrence of errors in surgery	12
2.1.3 Factors influencing surgical error	13
2.1.4 Error prevention	14
2.2 Learning	15
2.2.1 Dreyfus' five stage model	15
2.2.2 Anderson's model of adaptive control of thought	16
2.3 Learning Theory	17
2.3.1 Apprenticeship model	17
2.3.2 Adult learning theory	17
2.3.3 Constructivism	18
2.4 Simulations	19
2.4.1 Potential benefits simulation training	20
2.4.2 Features of simulations	22
2.4.3 Quality criteria for Computer Simulations	24
2.5 Process of simulation development	26
2.6 Summary	28

3	Simulation design process	29
3.1	The need	29
3.2	Content specification an task analysis	29
3.2.1	Medical Device	29
3.2.2	Task inventory	31
3.3	Instructional framework	32
3.4	Assessment strategy	32
3.5	Media selection	33
3.6	Simulation production	33
3.6.1	Theory	33
3.6.2	Freestyle	34
3.6.3	Training	34
3.7	Summary	38
4	Evaluation method	39
4.1	Target group	39
4.2	Content validity	40
4.3	Face validity	40
4.3.1	Questionnaire	40
4.4	Concurrent validity	41
4.4.1	Experiment	41
5	Results	43
5.1	Content validity	43
5.2	Face Validity	43
5.2.1	Questionnaire results part 1	43
5.2.2	Questionnaire results part 2	44
5.3	Concurrent validity	44
5.3.1	Real life Trained group	46
5.3.2	Simulation Trained group	47
5.3.3	Simulation training versus real life training	48
5.3.4	Errors per power modi	49

6	Discussion	50
7	Conclusion and Recommendations	54
8	References and Bibliography	55
A	APPENDIX: Theory slides simulation	58
B	APPENDIX: Individual performance results	61

List of Figures

2.1	<i>Rasmussens Skill, Rule & Knowledge model and Reasons Generic Error-Modeling System [29]</i>	12
2.2	<i>Swis cheese model</i>	12
2.3	<i>Model of factors influencing surgical errors</i>	13
2.4	<i>Dreyfus' five-stage model</i>	15
2.5	<i>Anderson's model of Adaptive Control of thought</i>	16
2.6	<i>Kolb's learning styles</i>	18
2.7	<i>The E-learning continuum</i>	19
2.8	<i>Reality-Virtuality (RV) Continuum</i>	20
2.9	<i>Types of Virtual Reality systems [52]</i>	23
2.10	<i>"Scaffolding": Decreasing feedback while increasing difficulty</i>	25
2.11	<i>Epics description of the e-learning development cycle.</i>	26
3.1	<i>The ForceTriad</i>	30
3.2	<i>Start up screen simulation</i>	33
3.3	<i>Simulation theory presentations</i>	34
3.4	<i>Pictures of monopolar adapter with different backgrounds</i>	34
3.5	<i>Pictures of monopolar laparoscopic cable with different backgrounds</i>	35
3.6	<i>Screenshot Simulation during Freestyle</i>	35
3.7	<i>Screenshot Simulation during Training at Beginner level</i>	36
3.8	<i>Screenshot feedback during Simulation</i>	36
3.9	<i>Screenshot Simulation during Training at Proficient level</i>	37
3.10	<i>Screenshot of feedback pop-up during proficient training</i>	38
4.1	<i>Simulation training set-up</i>	42
5.1	<i>Errors observed during pre- and post tests</i>	45
5.2	<i>Pre-Errors made by each individual</i>	45
5.3	<i>Post-Errors made by each individual</i>	45
5.4	<i>Pre- and Post errors RT group</i>	46
5.5	<i>Pre-Errors made by each individual, RT group</i>	46
5.6	<i>Post-Errors made by each individual, RT group</i>	46
5.7	<i>Pre- and Post errors ST group</i>	47

5.8	<i>Pre-Errors made by each individual, ST group</i>	47
5.9	<i>Post-Errors made by each individual, ST group</i>	47
5.10	<i>Pre- and Post errors of the RT and ST group</i>	48
5.11	<i>Number of errors per power mode</i>	49
6.1	<i>ST Group results including and excluding adapter error</i>	52
6.2	<i>RT Group results including and excluding adapter error</i>	53
A.1	Theoryslide 1	58
A.2	Theoryslide 2	58
A.3	Theoryslide 3	59
A.4	Theoryslide 4	59
A.5	Theoryslide 5	60
B.6	Errors nurse 1	61
B.7	Errors nurse 2	61
B.8	Errors nurse 3	62
B.9	Errors nurse 4	62
B.10	Errors nurse 5	63
B.11	Errors nurse 6	63
B.12	Errors nurse 7	64
B.13	Errors nurse 8	64
B.14	Errors nurse 9	65
B.15	Error nurse 10	65
B.16	Errors nurse 11	66
B.17	Errors nurse 12	66
B.18	Errors nurse 13	67
B.19	Errors nurse 14	67
B.20	Errors nurse 15	68
B.21	Errors nurse 16	68
B.22	Errors nurse 17	69
B.23	Errors nurse 18	69

List of Tables

3.1	<i>Task inventory</i>	32
3.2	<i>Specification overview Simulation</i>	38
4.1	<i>Target group characteristics</i>	39
4.2	<i>Questionnaire Face validity part 1</i>	41
4.3	<i>Questionnaire Face validity part 2</i>	41
5.1	<i>Results Part 1 Face validity Questionnaire</i>	43
5.2	<i>Results Part 2 Face validity Questionnaire</i>	44
5.3	<i>ST and RT group error scores for Pre- and Post test</i>	48

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1 Introduction

1.1 Background

Making errors is a part of normal human behavior [1]. However, when errors have significant consequences or occur in high risk industries they become of paramount importance. Health care is such a high risk industry where making errors can lead to human suffering and even death. The report “To Err is Human, Building a Safer Health System” emphasized the occurrence of errors in medicine [2]. It is estimated that each year at least 44,000 people die as a result of medical errors in the United States, but this number may be as high as 98,000 [2]. Thus, even when the lower estimate is used, more people die in one year as a result of a medical error than from motor vehicle accidents. Another study [3] quantified that 10% of hospitalized patients are effected by medical error. One of the most common sites where these errors occur is the operating room (OR). As many as 50% of the errors that occur in healthcare are believed to be surgery related [3]. Different factors, which can cause human error in the OR, have been identified and categories often mentioned as conditions for human errors include: Task requirements (e.g. prolonged attention required), bad ergonomics (e.g. lack of standardization of control parts), and workplace lay-out (e.g. bad equipment attainability) [5]. However, the lack of proper training is the most commonly mentioned condition for the occurrence of errors [5]. Current training for OR personnel is still largely mired in the 100-year-old apprenticeship model best exemplified by the phrase “see one, do one, teach one”. Personnel is trained during actual procedures and could compromise patient safety. Evidence is mounting that this, long-established, approach to training is no longer acceptable in the current ethical and professional climate.

1.2 Problem statement

This creates opportunities for alternative approaches of the traditional “learning by doing” training method in clinical context. A good example of this development is the variety of virtual reality (VR) simulators available for the training of surgeons’ psychomotor skills for laparoscopic surgery. These simulators have proven to be successful [6] and are becoming increasingly implemented in surgeons’ training curricula. Other examples, of alternative approaches to training in health care, include the use of mannequins for intubation and communication training and role-play for different procedures like baby delivery¹. Both of these training methods are aimed at increasing training frequency in a safe manner by applying the traditional way of *learning by doing* outside the OR. However, no additional training is available for skills related to handling medical equipment. Errors related to medical equipment have been observed by James Cooper [5] which examined 1089 critical incidents in the field of anesthetics. Another study by Verdaasdonk [23] quantified errors related to medical laparoscopic equipment and found that in 87% of the observed procedures 1 or more errors occur with medical devices. This situation is still of present interest as a national study conducted by the Dutch Health Inspectorate [7] in 2002 concluded that 50% of the 100 visited hospitals lack quality guidelines for introducing new equipment. Illustrative of the situation is that none of the hospitals considered attendance at the introduction of a new device compulsory. A follow-up study in 2005 reasserted most of the findings of the previous study. Not all incidents in healthcare, like those with medical equipment, lead to adverse events which directly endanger the patient’s health. For this reason, most incidents seem to have no consequence at all, but if multiple errors occur at the same time or in sequence, the result can be an adverse event. In a study conducted by James Reason [30], the system approach was used to study major adverse events and accidents. He concluded that seemingly unimportant incidents occur prior to major accidents or adverse events [30]. As mentioned, the lack of proper training has been identified as one of the main conditions for the occurrence of medical errors. Therefore it is important to identify the components of the current teaching and training methods applied in health care:

¹www.MedSim.nl

Current education and training in health care

Most health care personnel follow a vocational study, which is a combination of work and teaching. In the first period of the study only theory courses and no practical assignments are given. Gradually this ratio changes to more and more practical assignments and less theory. The theory is tested by way of exams and written assignments and during the practical part of the study a mentor judges the student on his or her work. The assigned mentor verbally and physically explains everything the learner needs to know about the subject at hand. This way of acquiring skills and knowledge is also known as the apprenticeship model. In most hospitals this is the only time learners get instructed and tested on their skills and knowledge. Training can be time consuming and the acquired skills could diminish over time if the learner does not often apply their skills, e.g. when they go on a vacation. To solve this problem the *Leids University Medical Center (LUMC)*, in the Netherlands, incorporated a yearly “refresh course” which covers the whole operating room (OR) and its attributes, but the effectiveness of this type of instruction is not yet validated. These findings indicate that there is a need for an additional training tool related to medical equipment which reduces the number of errors with these devices.

1.3 Scope and objectives

The aim of this study was to develop a simulation meant to train basic tasks related to operating medical equipment and to establish content-, face-, and concurrent validity for this simulation. In this study the design, development, and validation of an “interactive training simulation” is presented. Such a simulation can be used for training personnel outside the OR, thereby decreasing risks for patients and increasing training frequency without the addition of extra personnel, comparable with a simulation used in aviation. By face- and concurrent-validity the opinion and the effectiveness of the simulation, compared to that of the “refresh course”, will be determined. It is hypothesized that members’ performance, trained with the developed training simulation, will improve greater than members who receive the traditional way of training, because of the active participation in the simulation, which is not the case during the “refresh course”.

1.4 Document overview

In the following chapter (chapter 2) of this thesis a literature review is presented which discusses human errors, learning, learning theories, and training simulations’ features and potential benefits. Also in chapter 2 the process of designing and developing a training simulation will briefly be discussed and in chapter 3 this process is applied in designing and developing an interactive simulation of an electro-surgical medical device. In chapter 4 the methodology used for the evaluation of the developed simulation is stated. The validation methods applied for the developed simulation include content-, concurrent-, and face validity. Next in chapter 5 the results of the validation methods are presented and discussed in chapter 6. Finally in chapter 7 conclusions and recommendations for future work will be stated.

2 Literature review

This chapter is aimed at providing the necessary knowledge and information, needed, for designing and developing a training simulation. Key issues concerning error and the actual learning process of humans should be clear. In addition to what generally is meant by the actual learning process, it is also important to know how computer simulations can contribute its features, in such a way, that it provides an effective and efficient learning environment. This chapter discusses these issues. In the first part of this chapter human error and factors which can cause them are discussed. Next, the question *What is Learning?* together with different views on how the human learning cycle works, are discussed. Thirdly simulation technologies are analyzed. This analysis states the different features of simulations, the potential benefits, and quality criteria of good educational software according to literature. Finally, the process is explained of designing and actually developing a training simulation according to theoretical models.

2.1 Errors

2.1.1 Concept of errors

To understand why errors occur generically the psychologist Rasmussen developed the Skill, Rule & Knowledge model (Fig. 2.1) [29]. He defined three levels of human behavior where errors could occur:

- ▷ *Skill-based*: At the skill level, actions are automatic, and are enacted by way of “stored patterns of pre-programmed instructions”. These actions are frequently performed and are often said to “come naturally” to the operator. However, these skills can be acquired with practice. An example of an everyday skill is walking. Many tasks from the health care personnel can be considered as a sequence of skilled acts. For example, when an experienced operating room (OR) nurse hands over an instrument to the surgeon smoothly, without conscious control over his or her movements.
- ▷ *Rule-based*: On a rule level, tasks are completed using stored sets of rules. These rules consist of familiar, rehearsed patterns of actions. Tasks which use rule-based cognitive mechanisms require a greater degree of thought than skill-based tasks, as the rules which need to be applied to complete the situation must be selected. An example of rule-based behavior in a hospital is the choice by an OR nurse which instrument to hand off to the surgeon, requires rule-based behavior.
- ▷ *Knowledge-based*: On a knowledge level, unfamiliar tasks are performed with a high degree of conscious thought as the operator attempts to devise a novel solution to a situation which has not previously been encountered.

Reason [30] used Rasmussen’s classification as a framework for his categorization of errors, attaching a specific type of error to the three levels of cognitive performance: errors in execution of skill-based tasks were termed lapses, and errors in execution of rule and knowledge based behaviors were termed mistakes in his Generic Error-Modeling System. Lapses characteristically relate to an error in the actual execution of the task, whilst mistakes are more abstract errors, relating to errors in planning (where a strategy not suitable for the situation is carried out), or in problem-solving. In the case of lapses, the plan is correct but the actions are carried out incorrectly, leading to an error; whereas in the case of mistakes, the actions are carried out correctly, but it is instead the plan which is incorrect.

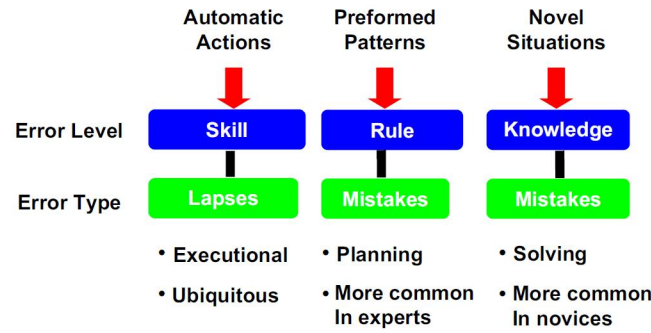


Figure 2.1: *Rasmussen's Skill, Rule & Knowledge model and Reasons Generic Error-Modeling System* [29]

2.1.2 Occurrence of errors in surgery

During surgery the mentioned error types also have the potential of occurring. Correctly performing surgery involves a combination of good decision making (pre-operatively, operatively and post-operatively), team performance and communication (surgical, anaesthetic, nursing and other essential staff members), and technical skill. It is believed that the combination of these skills and a high patient volume operating rate achieve a reduced patient mortality and morbidity [32, 31]. It is unlikely that no errors will occur during this process, not even in the most simple situations. However, these surgical errors are seldom solely responsible for an adverse event. Examples of adverse events are infections, secondary surgical burns, and sometimes even death. James Reason believes that an adverse event is a result of multiple errors sequentially occurring [4]. He stated that seemingly unimportant incidents occur prior to major accidents or adverse events. Prevention of future accidents starts with investigating the occurrence of these minor incidents in order to design adequate defenses. The “cheese model” (Fig. 2.2), after the theory postulated by Reason [4], clarifies how these defenses in a system can influence the occurrence of adverse events. In complex environments, such as the OR, several defense mechanisms (cheese slices) secure the safety of the patient. Examples include the design of equipment, experience of the personnel, and the use of certain protocols. Weaknesses in these defenses clear the way for incidents (represented in the model as holes in the defenses). According to the model, because effective defenses exist on different levels, not all incidents in the OR lead to adverse events that endanger the patients health. For this reason, most incidents seem to have no consequence at all, but if all occur at the same time or in sequence, the result can be an adverse event. In a complex environment (such as the OR) a chain of events may cause an accident trajectory (large arrow) and lead to adverse events.

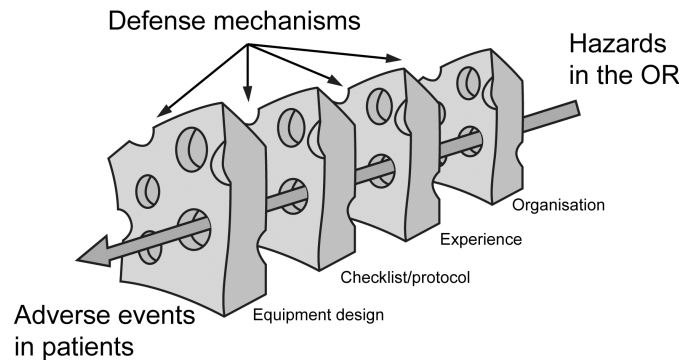


Figure 2.2: *Swiss cheese model* [30]

2.1.3 Factors influencing surgical error

Surgical processes are bound by many factors which can influence the final satisfactory or unsatisfactory patient outcome. Performing highly skilled surgical tasks involves a cognitive cascade of complex processes for the surgeon and his team [33]. Sudip [34] developed a theoretical model of how errors may occur in surgery (Fig. 2.3).

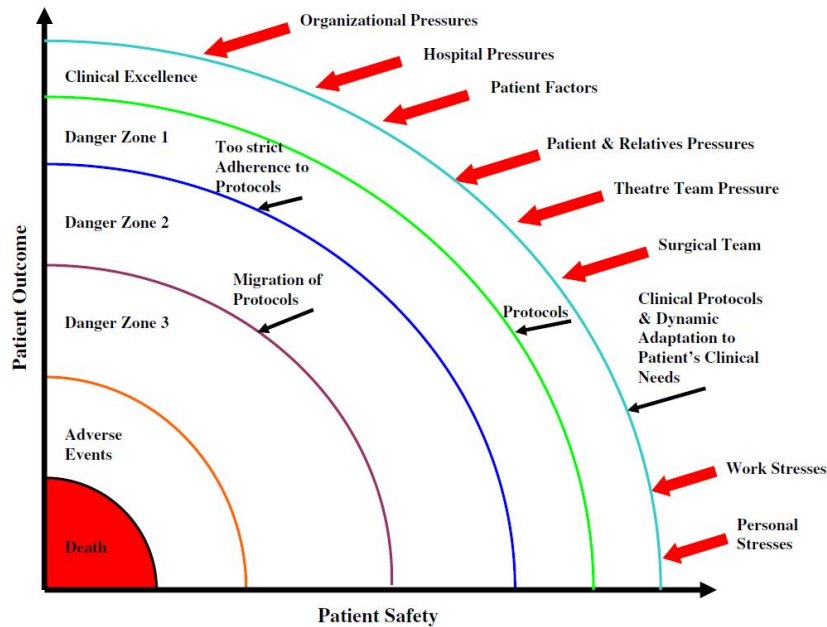


Figure 2.3: *Model of factors influencing surgical errors*

Sudip believes this model is applicable to the whole patient pathway and the concept was developed after studying migration of protocols in industry environments [34]. This section explains individual factors, which are believed, to influence surgical error:

- ▷ *Organizational environment:* Factors in the organizational environment may play an important role in patients' safety. Research has shown that poor patient referral rates can lead to reduced patient volumes and increases the mortality and morbidity rates [32, 31]. Medical personnel who do not perform operation-specific tasks in sufficiently large numbers may suffer from a procedure specific technical error rate. Moreover, the surgical unit or firm may not be familiar of the care of the particular specialized surgical patient. It has also been shown that in anaesthesia the combination of faulty equipment, lack of trained staff, etc. can lead to errors occurring during an operation [35].
- ▷ *Hospital environment:* The hospital environments are the various areas where surgical decisions are made and care is provided outside the theater environment. These can be in the outpatient department, endoscopy suite, casualty, recovery, high dependency or intensive care units, the ward and multi-disciplinary meetings. These surgical interfaces are where errors can occur and may involve many health care professionals.
- ▷ *Surgical team:* The surgical team may be under pressure to complete the operation list on time, there may be factors influencing the operation e.g. inexperienced assistant, or time pressures influencing the course of the operation e.g. life threatening emergency in casualty.
- ▷ *The theater team:* The theater team is important as decisions made for example by the key players e.g. surgeon, anaesthetist and scrub nurse if not in unity or in collaboration can influence the operation being performed, errors occurring and possibly the eventual patient outcome.

- ▷ *Patient and relatives pressures*: The surgeon may be under pressure from relatives or the patient to have a successful outcome. This may be due to unrealistic expectations or previous complications or errors occurring to the patient.
- ▷ *Patient factors*: All patients are not the same, and so all the operations surgeons perform are also heterogeneous. Factors like ASA grade, surgical pathology, etc. all can influence the technical skill and performance of the surgeon as well as the post-operative recovery and eventual patient outcome [36].
- ▷ *Surgeons work and personal stresses*: Surgeons can be subjected to various stressful factors which can influence their performance in decision making, team interaction and technical skill. Work related stresses include fatigue due to sleep deprivation, high workload and long commutes; hierarchical bullying, time constraints, and poor supervision for trainee surgeons, communication and teamwork.

Although this thesis solely focuses on error reduction while using medical equipment, all the mentioned factors have the potential to effect the errors related to medical equipment. Therefore it is important to be aware of all these possible “interferences”.

2.1.4 Error prevention

A number of approaches can be used to prevent incidents, related to medical equipment, from happening: (1) redesigning of equipment, (2) the use of protocols and checklists, and (3) additional training. These 3 possibilities will now briefly be discussed:

1. *Redesigning equipment*: The redesign of equipment and systems is expensive and a slow process. Nevertheless, there are already systems available in operating rooms which might solve some of the problems related to medical equipment. However, not many hospitals have the financial resources for OR’s of the future. Furthermore, increasing high-tech applications often create unforeseen problems.
2. *Protocols & checklists*: Another way to deal with reducing medical errors is to use checklists or protocols. Verdaasdonk [38] showed that the number of errors reduced with the use of a checklist focused on medical equipment. However, the use of this checklist does not take into account the competence of the users of the device, which is the focus of this study.
3. *Additional training*: As stated in the introduction part of this thesis, the lack of proper training has been identified as one of the main reasons for the occurrence of errors related to medical equipment. Training provides learners with the opportunity to create a standardized safety culture among OR personnel. The current way of training can be time consuming and knowledge and skills can fade over time. Recurrent training is therefore needed. The addition of a computer simulation could resolve these problems related to the traditional way of training.

This brief discussion states that an additional effective training tool can have a very high added value in the process of reducing medical error related to medical equipment. This additional training method should be focused on improving humans’ skills and knowledge related to medical equipment. The skill and information acquisition (learning) of humans and in what way this can most effectively be done is the point of discussion in the following sections of this chapter.

2.2 Learning

Generally, learning is defined by psychologists as “any relatively permanent change in the behavior, thoughts, and feelings of an organism, human, or other animal that results from experience” [8]. This change in behavior, thoughts, and feelings is thought to be a process. Fitts and Posner [9] suggested that the learning process is sequential and that we move through specific phases while learning. He defined three stages to learning a new skill:

- ▷ Cognitive phase: identification and development of the component parts of the skill - involves formation of a mental picture of the skill
- ▷ Associative phase: linking the component parts into a smooth action - involves practicing the skill and using feedback to perfect the skill
- ▷ Autonomous phase: developing the learned skill so that it becomes automatic - involves little or no conscious thought or attention whilst performing the skill

2.2.1 Dreyfus’ five stage model

This idea of humans moving through different phases is supported by Dreyfus [10]. He described skill acquisition in a five stage model (Fig 2.4) with increasing difficulty. According to Dreyfus learners start off at a novice level and ideally end up at the “mastery” level.

When a person is new to performing a certain task he or she is a novice. The task environment

Skill level Mental Function	Novice	Competent	Proficient	Expert	Master
Recollection	Non-situational	Situational	Situational	Situational	Situational
Recognition	Decomposed	Decomposed	Holistic	Holistic	Holistic
Decision	Analytical	Analytical	Analytical	Intuitive	Intuitive
Awareness	Monitoring	Monitoring	Monitoring	Monitoring	Absorbed

Figure 2.4: *Dreyfus’ five stage model of the mental activities involved in directed skill acquisition*

is decomposed into context-free features that can be recognized without the benefit of experience (non-situational recollection). The novice is then given rules for determining an action on the basis of these features. To improve, the novice needs monitoring, either by self-observation or instructional feedback, so as to bring his behavior more and more completely into the conformity with the rule. With increased experience in real situations the novice proceeds to the stage of competence. The student now sees the features of the task environment in their context, and recurrent meaningful patterns come to light. These patterns are now recognized by singling out perspicuous examples, recollection is now situational. The third stage is proficiency. After enough practice the student now recognizes whole situations and their relevance to the achievement of a long-term goal. Aspects can now appear more or less relevant to the achievement of this goal. Recognition is now holistic instead of decomposed. The fourth stage is expertise. In previous stages the student always needed some sort of analytical principle (rule, guideline) to connect the knowledge about the general situation to that of the specific situation. Now the student has experienced so many situations that each specific situation immediately dictates an intuitively appropriate action. In the fifth stage mastery occurs. Experts only sometimes and temporarily move up to this fifth stage. The expert is intensely absorbed in his work and ceases to pay conscious attention to his performance, which results in even higher level performance. When designing training aids, it is important to keep at least the first four developmental stages of the student in mind, to facilitate the student’s advancement to the next stage. When this is not done, the student could never improve to higher levels or even fall back to a lower level.

2.2.2 Anderson's model of adaptive control of thought

Dreyfus' idea is that when moving from one phase to the other or advancing from one level to a higher one, people acquire skills effectively. Anderson's [11] model of Adaptive Control of Thought (ACT) (Fig 2.5) can shed some more light on how this skill acquisition works. The model describes not only skill acquisition but also the acquisition of knowledge. It describes the way the human brain organizes information. Anderson distinguishes between:

- ▷ Declarative knowledge: "knowing that", basically facts
- ▷ Procedural knowledge: "knowing how", knowing how to use knowledge

Where declarative knowledge is relatively easy to acquire - you just listen to what a teacher says or read a book - procedural knowledge takes some more effort. Anderson describes the learning process as compilation of knowledge, consisting of two components, composition and proceduralisation. Composition means that a series of several productions are reduced to fewer ones so that steps in the thinking process can be skipped. Proceduralisation means that declarative knowledge is incorporated in productions and procedures. When teaching people skills, it is important that you make sure they acquire the right procedural knowledge. This means that students not only have to remember their facts (declarative knowledge) right, but should also make the right procedural connections between those facts. These procedural connections are formed when the person performs a task more and more over time.

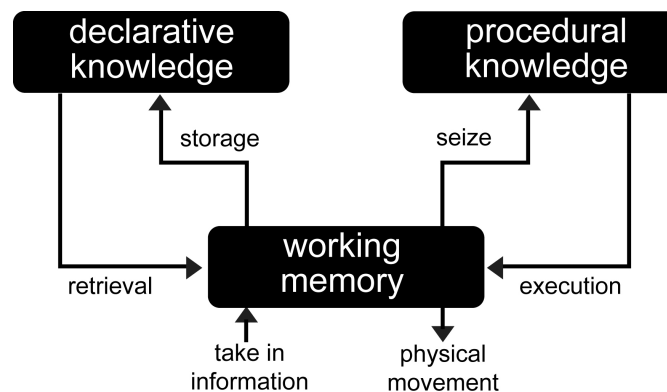


Figure 2.5: *Anderson's model of Adaptive Control of Thought*

Both Dreyfus and Anderson state that proceeding to a higher level of task execution can only be reached by practice. To be able to make the right procedural connections to move up to higher levels of task execution, a person has to practice a task. While practicing, the student moves through different stages of task execution. Just practice does not make perfect. The way the student practices, the amount of instructional feedback, and the level of the student has to change. These changes have to be considered when designing training methods. In the following section different theories on how humans acquire knowledge and skills effectively are discussed.

2.3 Learning Theory

Unlike Dreyfus' and Anderson's model, which discuss human behavior, a theory refers to an event clarification made-up of integrated principle statements that attempt to make a predication about something. Thus, reasoned definitions of learning theory are presented as a forecast explanation about learning based on a set of integrated principles and categorized by the variance in the main belief sets to predict learning. In simple terms: learning theories describe the way of the knowledge arrangement. In pedagogy four studying theories are essentially discussed: Adult learning, Behaviorism, Cognitivism, and Constructivism. As stated in the introduction of this thesis the current method of training medical personnel is the apprenticeship model. In terms of learning theory this training model is closely related to adult learning theory and constructivism. For this reason the current teaching/training method of health care, the apprenticeship model, and these two learning theories will briefly be discussed.

2.3.1 Apprenticeship model

The current training of health care personnel is largely mired by the apprenticeship model which is best exemplified by the phrase “*see one, do one, teach one*”. Most of their training is done on the job. While working, an experienced worker guides the apprentices and teaches them the trade. The necessary theoretical knowledge is given in the form of lectures prior to the “on the job training”. This methodology of acquiring skills is a proven and effective method, but when taking issues like patient safety and costs into account it might not be the optimal method for training.

2.3.2 Adult learning theory

All the learners in hospitals are adults (18+) and proponents of the adult learning theory state that adults do not learn like children. Adult learning theorists contend that adults are self-motivated, self-directed individuals who prefer learning that involves active participation, practical experience, variety, feedback, and real world problem solving. One of the theorists of the adult learning theory is David Kolb [12]. Kolb believes that all people learn in a four-step pattern which is illustrated in fig 2.6. Kolb first showed that learning stages could be seen as a continuum:

- ▷ Concrete Experience (CE): being involved in a new experience
- ▷ Reflective Observation (RO): watching others or developing observations about own experience
- ▷ Abstract Conceptualization (AC): creating theories to explain observations
- ▷ Active Experimentation (AE): using theories to solve problems, make decisions.

Although Kolb thought of these learning stages as a continuum which learners moves through over time, usually each learner prefers one stage above the other. So during the design of any kind of learning environment we need to take these styles into account. Kolb's learning theory identifies four distinct learning styles (preferences), each representing the combination of two preferred stages. These four styles of thinking are illustrated in fig 2.6 by a two-by-two matrix. Kolb named these four styles: diverging (CE/RO), assimilating (AC/RO), converging (AC/AE), and accommodating (CE/AE) [28]. Ideally the learning process represents a cycle where the learner “touches all the bases”, i.e. a cycle of experiencing, reflecting, thinking, and acting [12]. But this is not always possible. When comparing these different styles to the current learning style, related to medical equipment in hospitals, we see that this is closely related to the *accommodating* learning style (*Learning by doing*) defined by Kolb. Whereas the teaching method applied for theoretical knowledge closely corresponds with the *assimilating* learning style.

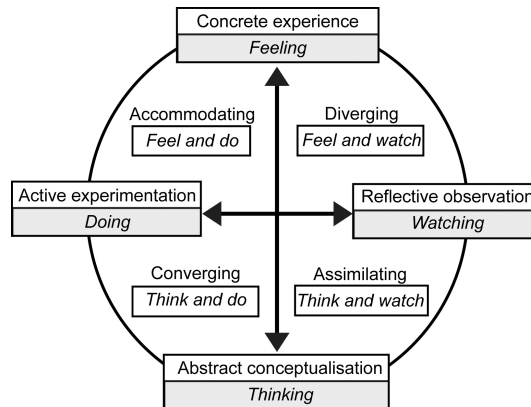


Figure 2.6: Kolb's learning styles

2.3.3 Constructivism

Constructivists believe that learning occurs through practical application which builds upon prior knowledge [13]. New knowledge must be “realized”, “learned”, “experienced”, and integrated into the already available knowledge structure [14]. This is also the case in the current way of educating and training medical personnel. These learners first acquire theoretical knowledge, in the form of lectures, and apply this knowledge in their actual working environment.

The idea of constructivism and adult learning is globally accepted and therefore largely applied in the current educational method of schools and universities in the form of lectures and internships. The problem of applying these theories in the healthcare sector is the fact that it is not always ethical to train during actual procedures, because this could comprise patient safety. Another problem is the low frequency of training. The training possibilities are also limited to the amount of procedures and the availability of tutors and/or equipment. Alternative training environments could solve these problems.

2.4 Simulations

Simulations applied for educational/training usage (also known as virtual learning environments) are generally defined as artificial environments that are carefully created to manage individuals' experiences of reality. Jones [20] defines a simulation as an exercise involving "reality of function in a simulated environment". Cannon-Bowers [17] notes that an essential feature of simulations and other synthetic learning environments (e.g., virtual reality) is, "the ability to augment, replace, create, and/or manage a learners' actual experience with the world by providing realistic content and embedded instructional features".

There are a number of constructs that conceptually overlap with simulations. For instance, games represent a specific type of simulation that features competitive engagement, adherence to a set of rules, and a scoring system [17]. Thavikulwat [18] notes that games and simulations are terms that are used relatively interchangeably (e.g., simulation-based games). Also, virtual worlds represent very elaborate simulations that allow for interactions among multiple players as well as between players and objects in the world [17]. For the remainder of this thesis-report the term simulation-based training is used to refer broadly to all types of computer-based simulations that are used to create synthetic learning environments.

Simulation-based computer training programs are also often said to be part of the Electronic-Learning domain. A graphical presentation of all available computer educational media available in this domain is shown in figure 2.7. In this representation the different educational media are put alongside the, so-called, learning pyramid.

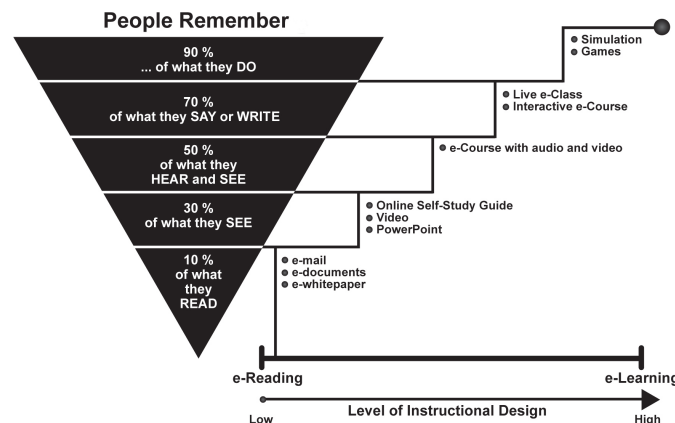


Figure 2.7: *E-learning continuum*, adapted from: Charles Merrill, 1960 Education Media

At the lowest level of the continuum the static options of learning media are shown. According to this graph these options have the lowest effect on what humans remember. These options of media are often called Learning Management Systems (LMS), which facilitate the management and offering of digital content, e.g. Blackboard and It's Learning. However important, these LMS merely organize digital information. These types of educational media are more "interpassive" than interactive [15], and typically, these programs rarely support more than multiple choice questions, mappings, and quizzes. To move from the "interpassivity" of today's virtual learning environments to real interactivity (and thereby moving up on the e-learning continuum), the emphasis should be on the development of interactive, pedagogically well-designed, and domain-specific educational software, also known as simulations.

These simulations apply computer technology which is often called Virtual Reality (VR). A more recent development in technology which is also being developed and used for educational purposes is mixed reality (MR). Both of these technologies will now briefly be discussed:

Virtual Reality:

Many different definitions exist for VR. For example Gaddis [39] defined VR as: "a computer generated simulation of the real or imagined environment or world". According to Fitzgerald

and Riva [40] the basis for the Virtual Reality idea is that a computer can synthesize a three-dimensional (3D) graphical environment from numerical data and by using visual and auditory output devices, the human operator can experience the environment as if it were part of the world. This computer generated world may be either a model of a real-world object, such as a house; or an abstract world that does not exist in real sense but is understood by humans, such as a chemical molecule or a representation of a set data; or it might be in a completely imaginary science fiction world. Although these definitions give some explanation of what VR is they do not cover all of the possibilities one can explore by use of VR. VR can be used for much more than “just” representation of objects or environments. Not only can VR, as part of computer science, allow computer-based models of the real world to be generated, but VR can also provide humans with a means to interact with these models through new human-computer interfaces and, thus, to nearly realistically experience these models. This actively interacting with the created environment is a key feature of VR and is allowed by the use of external input devices (mouse, joystick or typical VR peripherals such as Dataglove [41]) responding to the user’s reactions and motions. VR is at the same time a technology, a communication interface and an experience.

Mixed reality:

Another more recent development virtual computer technology is mixed reality. Mixed reality (MR) refers to the incorporation of virtual computer graphics objects into a real three dimensional scene, or alternatively the inclusion of real world elements into a virtual environment. The former case is generally referred to as augmented reality (AR), and the latter as augmented virtuality (AV). The difference between AR and AV can be explained by the so-called Reality-Virtuality (RV) Continuum. This concept was first introduced by Milgram [42], who generally defines a Mixed Reality environment as being “... anywhere between the extrema of the RV Continuum”, where the Reality-Virtuality extends from the completely real to the completely virtual environment with AR and AV in between (figure 2.8).

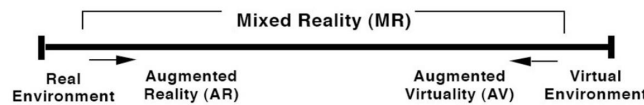


Figure 2.8: *Reality-Virtuality (RV) Continuum* [42]

Azuma [43] has defined three characteristics that are integral to an augmented reality interface. Firstly, it combines the real and the virtual. Secondly, it is interactive in real time. Third, it is registered in three dimensions. Mixed reality comprises concepts and technologies to design innovative user interfaces where physical and digital artifacts co-exist in the same computer-based environment. Mixed Reality is focused on merging real and virtual worlds, combining a variety of techniques to mix and/or link real with virtual objects [42]. 3D modeling, tracking, haptic feedback, simulation, rendering and display techniques are core elements of Mixed Reality applications. Early developments were mostly based on blending computer generated virtual worlds or simulations with real-life video. Later on, interfaces were developed, which sense and generate real-life data being exchanged between virtual objects and their physical counterparts. The use of MR as training application is still in the experimental stage and can also be very time consuming and costly [61].

2.4.1 Potential benefits simulation training

Whether VR or MR technology is used to develop simulations in both cases the developed simulations may have many benefits compared to “conventional” teaching. Some of these potential benefits are:

- ▷ *Experiential and active learning:* Simulations provide experience with new technologies through actual use: learning in simulations requires interaction, thus encouraging active

participation rather than passivity. Students and trainees assimilate knowledge more effectively when they have the freedom to move and engage in self-directed activities within their learning context. Finding and structuring content autonomously, they invest mental effort for the construction of conceptual models that are both consistent with what they already understand and with the new content presented. According to McGuire [45] this active process allows students to reach understanding of the world through an “ongoing process of making sense out of new information-by creating their own version of reality instead of simply receiving the author’s view”. The effective adaptation of old knowledge to new one leads to understanding and, when the students are in charge of this process of “accommodation”, success is also intrinsically motivating. Simulation of the real world provided by VR offer students the opportunity to learn while they are situated in the context where what they learn is to be applied; this results in more meaningful and effective learning, as compared with learning out of context [46, 47]. Nicaise and Crane [48] point out how, within constructivist perspective, physical engagement with material is central in the learning process. Students reach an understanding of the material under study through object manipulation and building of physical artifacts. To the extent that “immersion in a virtual world allows the same kind of natural interaction with objects that participants engage in the real world” [49], action in VEs can support this process of knowledge construction.

- ▷ *Visualization and reification*: Virtual learning environments can be an alternate method for presentation of material, new forms and methods of visualization. Its use can be very important in domains where information visualization is needed, such as manipulating and rearranging information using graphic symbols; it is useful also when it is needed to make perceptible the imperceptible (e.g., as a means to teach abstract physics and biological concepts which are part of health-care professionals curricula). For example, researchers at George Mason University and the University of Houston [50] developed “NewtonWorld” and “MaxwellWorld”. These systems provide immersive learning environments in which students may explore the kinematics and dynamics of motion, electrostatic forces, and other physical concepts.
- ▷ *Learning in contexts impossible or difficult to experience in real life*: Virtual reality allows observation and examination of areas and events unavailable or impossible (e.g., “traveling” inside human body, moving among molecules) by other means. Furthermore, it allows extreme close-up examination of an object, as well as observation from a great distance. VEs can also be a good solution when teaching or training using the real thing is dangerous (e.g., there is risk of injury to the patient), or for logistic reasons (e.g., the possibility of training without moving from the laboratory or the clinic). VR can furthermore provide effective training in situations requiring the use of equipment prohibitively expensive or impossible to obtain otherwise.
- ▷ *Motivation enhancement*: Interacting with a VR model can be as motivating, or even more motivating than interacting with the real thing, for example, using a game format. It can be a good solution to make learning more interesting and fun, for example, when working with boring material.
- ▷ *Collaboration fostering*: Shared VR can encourage collaboration and foster the learning of skills that can be better developed through shared experiences of a group in a common environment. It is most useful when the experience of creating a simulated environment, or model is important to the learning objective.
- ▷ *Adaptability*: VR learning offers the possibility to be tailored to learner’s characteristics and needs (different students are characterized by different learning rates and styles). Learners are allowed to proceed through an experience at their own pace, and during a broad time period not fixed by a regular class schedule. Furthermore, well designed VEs can flexibly present trainees a broader, deeper set of experiences than those that can be found in the “standard” educational environment.
- ▷ *Evaluation and assessment*: VR itself offer a great potential as a tool for evaluation, since every session in the virtual environment can be easily monitored and recorded by trainers and teachers, thus facilitating assessment tasks [51].

These are all potential benefits and not self-evident. Computer simulations have different features which can be used to achieve these benefits which will be discussed next.

2.4.2 Features of simulations

As mentioned in the previous section, VR has different features which can be included in the design of a simulation depending on its purpose of development. These features include: Interactivity & Navigation, Haptic/kinesthetic feedback, and Immersion & presence. These features will now briefly be discussed:

- ▷ *Interactivity and navigation:* Basically, VR is about using computers to create images of 2D or 3D scenes with which one can navigate and interact. By the term navigate, we imply the ability to move around and explore the features of a scene such as a building; while interact implies the ability to select and move objects in a scene, such as a chair. Interactivity not only changes the role of the user from that of observer to participant, but also promotes learners' active learning. During the studying experience, interaction can offer the learner various controls, such as interacting with the virtual environment and manipulating characters or objects in the virtual environment. A VR system can be designed with or without interaction, and with this in mind two different visions of designing VR can be identified [44]: (1) Virtual Reality as only a presentation of virtual objects to all of the human senses in way identical to their natural counterpart, (2) A human-computer interaction paradigm in which users are active participants within a computer-generated three-dimensional world. To enable a user to interact with the environment different tracking devices and interactive devices can be used. Examples are force balls (cricket ball-sized objects fixed to a platform and incorporating strain gauge sensors) and conventional mice (Similar to the standard desktop pointing devices, but incorporating a 6 degree of freedom sensor). Depending on the application the choice is made to implement interactivity or not and if so, which device to use.
- ▷ *Haptic/kinesthetic feedback:* Another feature of VR is Haptic/kinesthetic feedback. Haptic technology refers to technology that interfaces to the user via the sense of touch by applying forces, vibrations, and/or motions to the user. This mechanical stimulation may be used to assist in the creation of virtual objects (objects existing only in a computer simulation), for control of such virtual objects, and to enhance the remote control of machines and devices (teleoperators). Kinesthetic feedback is the knowledge people have about the position and movement of their bodies based on nerves in their joints and muscles (also known as proprioception). Such feedback may play a role in hand-eye coordination, the use of input devices, and reaction to output devices that cause the body to move. Haptics are gaining widespread acceptance as a key part of virtual reality systems, adding the sense of touch to previously visual-only solutions. Most of these solutions use stylus-based haptic rendering, where the user interfaces to the virtual world via a tool or stylus, giving a form of interaction that is computationally realistic on today's hardware. One can say that haptic feedback contributes to the "realness" of the virtual world and that reduction in sensory feedback requires some readjustments in performing routine tasks. Without that feedback many actions can become difficult or even impossible.
- ▷ *Immersion and presence:* Immersion and presence represent distinct concepts. Mel Slater [52] defines the terms this way: Immersion refers to the objective level of sensory fidelity a VR system provides, while presence refers to a user's subjective psychological response to a VR system. Immersion is objective and measurable-one system can have a higher level of immersion than another. Presence, on the other hand, is an individual and context-dependent user response, related to the experience of "being there". Different users can experience different levels of presence with the same VR system, and a single user can experience different levels of presence with the same system at different times, depending on state of mind, recent history, and other factors. Three main categories by the sense of immersion can be identified. These categories include non-immersive systems, semi-immersive projection

systems and fully-immersive systems. While many researchers are studying the psychological phenomenon that is called presence, it might be more practical of studying immersion's effects since its control level can be measured and because this approach could have a large real-world impact.

Although it is difficult to categorize all VR systems, most configurations fall into three main categories, and each category can be ranked by the sense of immersion [52]. These categories include: (1)non-immersive (Desktop) systems, (2)semi-immersive projection systems, and (3)fully immersive systems as shown in figure 2.9.

VR system	Non-Immersive VR	Semi-immersive VR	Fully-immersive VR
Input devices	Mice, keyboards, joysticks and trackballs.	Joystick, space balls and data gloves.	Gloves and voice commands.
Output devices	Standard high-resolution monitor,	Large screen monitor, large screenprojector system, and multipletelevision projection systems	Head mounted display (HMD), CAVE
Resolution	High	High	Low-medium
Sense of immerions	Non-low	Medium-high	High
Interaction	Low	Medium	High
Price	Lowest cost VR system	Expensive	Very expensive

Figure 2.9: *Types of Virtual Reality systems [52]*

1. *Non-immersive systems*: Non-immersive systems, as the name suggests, are the least immersive implementation of VR techniques and therefore a user has a low or no sense of immersion when using this kind of system. Using the desktop system, the virtual environment is viewed through a portal or window by utilizing a standard high resolution monitor. Interaction with the virtual environment can occur by conventional means such as keyboards, mice and trackballs.
2. *Semi-immersive systems*: Unlike non-immersive systems a semi-immersive system can deliver a medium to high sense of immersion. Instead of mice or keyboards as input devices a semi-immersive system uses joysticks or data gloves as input devices for the user to navigate/interact with the environment. A semi-immersive system will comprise of a relatively high performance graphics computing system which can be coupled with a large screen monitor, a large screen projector system or multiple television projection systems. Using a wide field of view, these systems increase the feeling of immersion or presence experienced by the user. However, the quality of the projected image is an important consideration. It is important to calibrate the geometry of the projected image to the shape of the screen to prevent distortions and the resolution will determine the quality of textures, colors, the ability of define shapes and the ability of the user to read text on-screen.
3. *Fully-immersive systems*: The most direct experience of virtual environments is provided by fully immersive VR systems. These systems are probably the most widely known VR implementation where the user wears some form of head-coupled display, such as head mounted display. All fully immersive systems will give a sense of presence that cannot be equaled by the other approaches discussed earlier, but the sense of immersion depends of several parameters including the field of view, the resolution, the update rate, and contrast and illumination of the display. Although fully-immersive systems deliver a higher sense of immersion than none and semi immersive systems, empirical studies [53] show that various components of immersion provide other benefits and that full immersion is not always necessary.

Because of the wide range of possibilities, which technology has to offer, it is important to distinguish between good and bad quality criteria for designing effective educational software. This is the subject of discussion in the following section.

2.4.3 Quality criteria for Computer Simulations

A study by Reichert [15] suggests that the emphasis of educational software is in danger of neglecting the desired pedagogical added value. And for this reasons Reichert proposed five high-level quality criteria which good education software must satisfy:

- ▷ *Content based on fundamental ideas*: The production of educational software is expensive. Therefore, long-lived content should be at the center of interactive learning environments. Fundamental ideas guarantee the selection of content which is cognitively demanding, relevant, and long-lived. Schwill [16] summarized the concept of fundamental ideas as follows: A fundamental idea, with respect to some domain, is a schema for thinking, acting, describing, or explaining which is applicable in different areas, may be demonstrated and taught on every intellectual level, can be clearly observed in the historical development and will be relevant in the longer term, and is related to every day thinking. In this thesis-report a simulation is proposed for training skills related to medical equipment. Because medical equipment is very expensive hospitals are inclined to use these devices as long as possible. Therefore a simulation for such a device complies with this criteria.
- ▷ *Incorporating different cognitive levels*: Ideally, educational software offers a broad range of tasks on different cognitive levels. This criterion complies with what was mentioned in section 2.1 about learning theories. The proposed simulation therefore should incorporate these different levels.
- ▷ *High degree of interactivity*: A high degree of human-machine interaction characterizes good educational software. By interactivity Reichert meant true interaction between the learner and the software and not reading a web page or watching an animation. True interaction was defined by Laurel [21] as follows: “You either feel involved in the computer representation or you do not”. The crucial point is the ability to interact with the representation, and not how often the software feigns communication with you. There are different classifications of interactivity levels. In this thesis a model by Schulmeister [22] is used which defines six levels of increasing human-computer interaction.
 - Level one means no interaction at all, but only a display of information
 - Level two lets users navigate through the representation of information
 - Level three offers multiple representations of the content
 - On level four, the user can modify parameters of the representation
 - Additionally, on level five, the user can manipulate the content itself
 - Level six means the user can create and manipulate objects and watch the system react
 Ideally the simulation should match the simulated object as best as possible. This will be taken into account in the design of the simulation.
- ▷ *Feedback*: The software’s feedback with respect to the actions of the user can assist their learning process. Reichert defined two levels of feedback, “implicit” and “explicit”. With implicit feedback, the learner must interpret the output that the software produced while they interacted with it. Explicit feedback denotes an automated tutor which takes on the role of the teacher. The tutor points the learners to mistakes they make, provides support when the learners stumble or shows them different solutions.
- ▷ *Visualization and usability*: It takes time to familiarize oneself with the user interface of any software. Since the user interface is not the subject itself, it should be as self-explanatory as possible. However, as of yet, there is little if any discussion on usability in learning software context, on what could be called the “learnability” aspects of electronic media.

Increasing problem difficulty (cognitive level) makes the learning more challenging, engaging and effective. It is believed that when increasing the level of difficulty less feedback should be given to

get an effective learning method. This is also called “scaffolding” (figure 2.10). Scaffolding means decreasing the amount of feedback (prompting, guidance) over time and hereby allowing the final skill level to be elicited by naturalistic cues (combination of two of the quality criteria mentioned above).

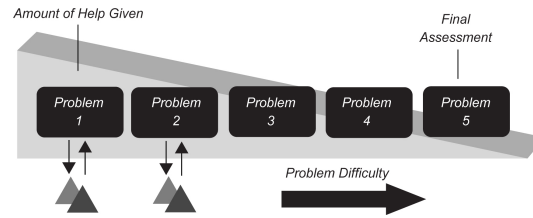


Figure 2.10: “Scaffolding”: *Inversely proportional increase and decrease of difficulty and amount of feedback provided.* Adapted from: David M. Merrill

The implementation of all of these quality criteria should result in an effective virtual learning tool. But first the simulation needs to be developed. For this reason the process of the simulation development will be discussed next.

2.5 Process of simulation development

There are a number of different instructional design methods available in literature [54, 55] but each of these creative processes have roughly the same outline: Analysis, Design, Development, Implementation and Evaluation [56]. This outline is also applicable to the design of training simulation. But the application of this model into the process of training simulation development requires that some more details on the exact stages of the process to be described. A British company, called Epic which develops e-learning, describes the process of developing training using a more useful model (figure 2.11). This model [54] describes the cycle of training development from a performance gap/training need to implementation of the developed training program. The usefulness of this model is due to its clear and functional steps. The phases of this model give a clear overview and insight in what actually should be done to get a training simulation. In this paragraph each of the stages of this cycle will briefly be described.

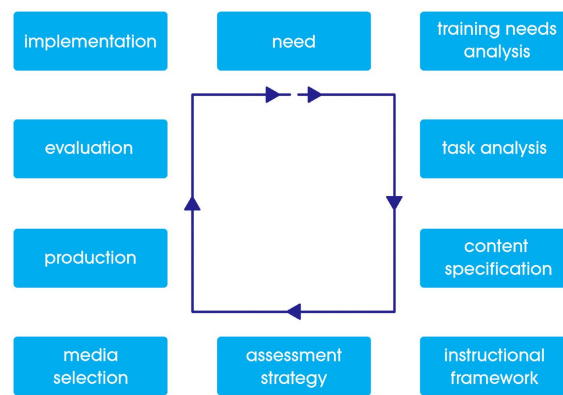


Figure 2.11: *Epics description of the e-learning development cycle [54]*

- ▷ *Need*: A need for training or education first needs to be identified before attempting to design or develop any type of additional training or education. The performance gap is a tool which can give more insight in the current level of knowledge and/or skills of a specific target group. Having identified this gap designers can then determine the instructional goals for the training.
- ▷ *Task analysis*: When the specific needs for the training simulation are expressed, the task(s) that should be taught need to be described very well. The training simulation should be able to teach students a skill without the addition of a mentor or teacher. So the designer of the simulation should know in advance when interventions/feedback is necessary. The designer should consider all possible scenarios in which a learner can interpret the simulation. Furthermore, a detailed description of the tasks should be made. For e-learning a teacher should consider all possible scenarios in which a student can use and interpret the lesson. Furthermore, a detailed description of the task(s) should be made.
- ▷ *Content specification*: With the need and task analysis complete the content of the training can be specified. Questions like *What should be described and how?* and *What other information should be given, and how?* should be answered in this stage. All the information concerning the content of the medical device can be collected from 3 sources: (1) Literature, (2) Manufacturer, and the (3) Hospitals which use the equipment. What kind of information can be adapted from each of the sources is summarized below.
 1. Literature: From literature we can identify the working principle, hazards of working principle, and research done on the use of the device (e.g. effectiveness)

2. Manufacturer manual: There are a variety of manufacturers which produce the same technology of equipment. But each of them has their own design and sometimes even their own additional features. Therefore the user's manual is an important information source. Features which should become clear from the manual include: device interface and interaction (settings and connection ports), effects of selected settings/options (e.g. effects on human tissue), procedural (order of steps for setting up system), and hazards of handling specific device (do's and don'ts for device in question).
 3. Hospitals: Each hospital has its own experiences and/or difficulties with the use of a medical device. Furthermore, cables and other accessories (available and compatible instruments/cables etc) are often hospital specific.
- ▷ *Instructional framework*: The instructional framework describes how the lesson will be taught. Different tasks require different forms of instruction. A number of different instructional models exist, and all are based by addressing the, so called, learning theories. These theories were discussed in chapter 2.2. These instructional frameworks can serve as guideline/checklist for good instructional design.
 - ▷ *Assessment strategy*: Which skills to be trained should now be clear. But how will these be assessed? Will they even be assessed in the training simulation? In this stage, the assessment should be described. What information will be assessed and how will it be done. Will your assessment focus on short term or long term retention? And will your assessment be part of the e-lesson or will it be done differently?
 - ▷ *Media selection*: According to Epic, only now the decision for training simulation or conventional learning should be made and choices should be made about how the simulation content should be displayed. The actual design of the simulation should be done in this stage.
 - ▷ *Production*: In this stage the rough materials for the e-lesson (e.g. pictures, video, audio, text, simulations) are acquired and put together to form the actual simulation. It is important that all the factors concerning the simulation (not only learning, but also teaching, technical specifications etc.) are considered during design.
 - ▷ *Evaluation*: To be sure that the intended effects are achieved with the e-lesson, user tests should be performed. However well designed and thought-out a lesson is, there are always things that certain users will perceive differently. Especially with simulations it is important to find these problems and make changes in the simulation to prevent learners from learning the wrong things.
 - ▷ *Implementation*: Perfection can be the goal, but probably never reached. When the e-lesson has proven to work well enough it can be implemented into the curriculum. It is important that the designed e-lessons are subjected to a testing period, even when testing was done before implementation. After implementation the lesson is taken more seriously and problems that were considered small before can now get a higher level of importance.

2.6 Summary

In this chapter the basic idea behind the actual learning process and skill acquisition was stated. People move through different phases when acquiring knowledge and for humans to acquire skills effectively it is important to expose them to different cognitive levels which increase in difficulty. Just practice does not make perfect. The way the student practices, the amount of instructional feedback, and the level of the student has change. The current applied apprenticeship model is a training method which is effectively applied in a variety of fields. The problem of applying this model in the healthcare sector is the fact that it is not always ethical to train during actual procedures, because this could comprise patient safety. Another problem is the low frequency of training. The training possibilities are also limited to the amount of procedures and the availability of tutors and/or equipment. Implementing the apprenticeship model in a computer simulation can help to resolve these issues. To achieve this, quality criteria proposed for educational computer simulations need to be satisfied: *Content based on fundamental ideas, Incorporation of different cognitive levels, High degree of Interactivity, Provide Feedback to user, Visualization and usability (user friendly)*. To achieve this succesfully the different features of virtual reality technology need to be applied accordingly. Furthermore, to develop a simulation certain steps need to be taken. These steps were described and include determining the need, media selection, and the actual development.

3 Simulation design process

Having discussed the actual learning process and important criteria for the design of an educational simulation, the next step is to actually design and produce the simulation. In this chapter the different stages for designing and producing a training simulation will be followed. These stages include: (1) Identifying the need, (2) Performing a task analysis, (3) Content specification, (4) Choosing an instructional framework, (5) Determining an assessment strategy, (6) Media selection, (7) Production of the simulation, and (8) Evaluation of the simulation. The final step of actually implementing the simulation in the current curriculum for the learners is not subject of this thesis. All the mentioned stages will be discussed in the order of which they are mentioned.

3.1 The need

As mentioned in the introduction, the need for additional training, focused on medical equipment, is definitely present. The need for additional training related to medical equipment was also expressed by the *Leids Universitair Medical Center (LUMC)* in the Netherlands. In collaboration with the LUMC a further depth analysis was made concerning this problem. The steps taken will be discussed in the following sections.

3.2 Content specification and task analysis

In this section of the thesis a task analysis will be conducted to state in detail which tasks should be trained by the simulation. In order to determine the task analysis the following questions need to be answered:

- ▷ Which medical device should be simulated?
- ▷ Which “knowledge” and which “abilities” is the learner supposed to acquire?

In this paragraph these questions will be answered. First the choice of the medical device is explained and subsequently the task inventory is discussed.

3.2.1 Medical Device

The operating room consists of a variety of medical equipment such as ultrasonic devices and insufflators. For this research the medical device chosen to be simulated is an electro surgical device named *ForceTriad* (figure 3.1) produced by the company Valleylab (manufacturer of energy-based medical system). The decision to simulate this specific device was taken in collaboration with the LUMC and is based on their personal experience that users have difficulties understanding and using this device.

Electro surgery & ForceTriad

The ForceTriad is an electrosurgical device. Electrosurgery is the application of a high-frequency electric current to biological tissue as a means to cut, coagulate, desiccate, or fulgurate tissue. High-frequency current passes heats up biological tissue to get a desired clinical effect. The ForceTriad has 3 different power modi to do so. The main difference between these modi is the path the current travels:

- ▷ *Monopolar*: Monopolar is the most commonly used electro surgical modality. This is due to its versatility and clinical effectiveness. In monopolar electro surgery, an active electrode is



Figure 3.1: *Picture of the ForceTriad*

in the surgical site. A patient return electrode is somewhere else on the patients' body. The current passes through the patient as it completes the circuit from the active electrode to the patient return electrode.

- ▷ *Bipolar*: In bipolar electro surgery, both the active electrode and the return electrode functions are performed at the site of surgery. The two sides of the forceps² perform the active and return electrode functions. Only the tissue grasped is included in the electrical circuit. Because the return function is performed by one side of the forceps, no patient return electrode is needed.
- ▷ *Ligasure* The Ligasure mode is a combination of bipolar electro-surgery and mechanical force. This combination makes it possible to seal vessels. The ligasure mode is therefore also called a vessel-sealing technique.

²Forceps are hinged instruments used for grasping and holding objects/tissue

3.2.2 Task inventory

The concept of task inventory is a way to identify the essential items that need to be learned in order to accomplish the particular goal. Although the surgeons are the ones who apply the different power modi (electrical current) to human tissue, it is the operating room nurse who makes the FT ready for use. The OR nurse performs all the necessary steps before the surgeon can use the different possible power modi. The task inventory is focused correctly setting up the FT. Correctly setting up the ForceTriad means being able to start-up the device for the 5 different possible modi:

- ▷ Monopolar Laparoscopic surgery
- ▷ Monopolar Open surgery
- ▷ Bipolar Laparoscopic surgery
- ▷ Bipolar Open surgery
- ▷ Ligasure vessel sealing

To start-up the device a variety of tasks need to be executed. The global tasks for starting up the system for each of the power modi are (according to the user guide from ValleyLab):

- ▷ Turn on the energy platform and verify that the self-test is successfully completed.
- ▷ If using a footswitch, connect it to the footswitch receptacle on the rear panel.
- ▷ In case of monopolar surgery, apply the patient return electrode to the patient and connect it to that patient return electrode receptacle on the front panel.
- ▷ Connect the instrument cable to the appropriate instrument receptacle on the front panel.
- ▷ Verify or change the mode and power settings.

Using this list as basis these tasks have been summarized into an assessment form consisting of 23 items (table 3.1) which has been used for assessing the performance of the OR nurses. Wrongfully or not executing one of these twenty-three tasks means an error has been made. Errors are categorized in the following manner:

- ▷ Identification: Wrongfully identifying cables, instruments, and/or foot pedals
- ▷ Protocol: Not executing tasks in the correct order
- ▷ Connection: Wrongfully connecting cables, instruments, and/or foot pedals

As mentioned in the previous chapter, these two stages of the simulation development answer not only the question *What should be described and how?*, but also *What other information should be given, and how?*. The training simulation should describe a medical device and give trainees the possibility to test and/or train their skills related to the device. This includes being able to select different cables and/or foot pedals, but also selecting the settings and power buttons available on the device. Additionally the simulation should respond accordingly as it would in real life making the simulation as *real* as possible. For this stage video recordings and pictures were made of the device and all the corresponding cables and foot pedals. Using this information the response of the medical device became clear. Additional information about what the learners are required to know was acquired from the expert nurse³ of the LUMC. The participants of this research were certified OR nurses and are only required to know the global working principle of the device. Together with the nurse manager the level of knowledge was determined and summarized into 5 slides showing text and animations about the theory (appendix A). These slides will be presented as part of the total simulation.

³The expert nurse is responsible for providing additional training for OR nurses

Table 3.1: Assessment form

Procedure	Task	Correct	Wrong
Global	Turn on energy platform		x
	Wait for self test	x	
	Connect than settings	x	
Monopolar laparoscopic	Identify adapter		x
	Connect adapter	x	
	Identify cable	x	
	Connect cable	x	
	Identify RE cable	x	
	Connect RE cable	x	
	Identify foot pedal	x	
	Connect foot pedal		x
Monopolar open	Identify cable	x	
	Connect cable	x	
Bipolar laparoscopic	Identify cable		x
	Connect cable	x	
	Identify foot pedal	x	
	Connect foot pedal	x	
Bipolar open	Identify cable		x
	Connect cable	x	
Ligasure	Identify cable	x	
	Connect cable	x	
	Identify foot pedal	x	
	Connect foot pedal	x	

3.3 Instructional framework

For the design of the training simulation no existing instructional framework was used. The design of this simulation is based on the adult learning theory (section 2.3) and the mentioned quality criteria (section 2.4.3). Learners should be able to interact and receive feedback during training. These features together with the incorporation of different cognitive levels (as discussed in section 2.2) are believed to result in an effective training simulation.

3.4 Assessment strategy

The assessment of the learners will be done by using the assessment form presented in table 3.1. The choice for not doing any kind of assessment in the simulation itself was based on the fact that this demands a higher level of programming and increases the complexity of the program. Not only is this time consuming, but the scope of this research is to show that by exposing users with this simulation their performance in real life will improve and therefore the assessment is done in real life.

3.5 Media selection

The simulation was developed in the program Adobe®Flash®Professional CS4. The choice for this program was made on the possibilities this program has and personal preference. For the design of the simulation the results of the task inventory were used (which functions, procedures, and tasks should be learned and which type of errors can occur). Choices in the design are based on the learning theories and quality criteria mentioned in chapter 2.

3.6 Simulation production

After starting up the simulation the user interface gives the learner 3 options (figure 3.2) to choose from:

- ▷ Theory: In this part of the simulation theoretical background knowledge about the ForceTriad is presented. In principle theoretical (declarative; see chapter 2) knowledge can be acquired using words/text [57]. Therefore it was decided to present the theoretical knowledge in the form of a presentation. In addition to the text, animations will also be used to visualize the text presented. This was done because according to the E-learning continuum (discussed in chapter 2) people remember more by seeing than reading.
- ▷ Freestyle: Users can “play” with a virtual presentation of the ForceTriad on a computer screen which looks, reacts, and sounds like the real device.
- ▷ Training: Users are given assignments which need to be completed and receive feedback on their actions using the same virtual representation of the medical device. This interactive virtual model of the device gives the learners the ability to learn by doing as is desired by the adult learning theory.



Figure 3.2: Start up screen simulation

A more detailed description of all these parts of the simulation will be given in the following sub sections.

3.6.1 Theory

The first part of the simulation consists of theoretical background knowledge about the ForceTriad. Theoretical (declarative) knowledge can be very well transmitted through words and be remembered as such. To endure this knowledge more is necessary, for example repetition. Examples are the different functions and abridgments available on the medical device. This part of the simulation is

meant to give the learner a brief refresh course about the theoretical background but was primarily meant to define certain terminologies which the learners should already know. This was done to prevent obscurity in the rest of the simulation. In total 5 subjects were presented: (1) electro surgery in general, (2,3,4) the three different power modes (monopolar, bipolar, and ligasure), and (5) the *return electrode monitoring (REM)* system of the device. Text and animations were used to visualize the information presented on screen. Learners were able to navigate through this information as often as they preferred (figure 3.3). It is also possible to use videos or audio to present the theory, but the choice for textual presentation was done to enable the user to read the information in their own time. Also the simulation focuses on the training of skills and not knowledge acquiring of knowledge (education).



Figure 3.3: The five theory slides available

3.6.2 Freestyle

In the second part of the simulation learners were able to “play” with the simulation. The main goal of this part was to let the learner get used to the interaction and functions of the simulation. In order to achieve this a complete virtual, interactive model of the ForceTriad was developed. This virtual model not only looks like, but also reacts and sounds like the real life device. All the details were artificially reproduced, such as alarm reporting by the device. Users were able to select and connect cables and foot pedals but also switch on and apply settings on the device. This could be done by moving the mouse cursor of the target of choice. The choice of interactive device (computer mouse) was done based on the fact that for most people this is a well-known way of interacting with a computer. Other interactive devices such as joysticks and datagloves are not as prevalent. The cables and foot pedals were photographed and these images were used to visualize them in the simulation. To prevent the user from memorizing each picture by other cues than intended, all the images were taken on 3 different backgrounds and different angles (figure 3.4 and 3.5 show examples of this process). Another possibility of presenting the cables, was to build virtual models for each of the cables, but this demands more time and programming skills, whilst it is believed that the effect of using pictures can be just as effective. The pictures enlarge by scrolling over them with the mouse cursor. In this way the user can get a better view of them before actually making a choice of which item to select. The images are represented next to each other and gradually increase in size when scrolling over them with your mouse.

During freestyle the user is allowed to engage freely with the virtual device as he or she would be able in real life. In this way users can get familiar with the working of the simulation and learn in an *explorative way*. A screen shot of what the virtual ForceTriad looks like is shown in figure 3.6.



Figure 3.4: Pictures of monopolar adapter with different backgrounds

3.6.3 Training

For the training part of the simulation the same virtual model was used. The difference between the freestyle and training part of the simulation is that in the training part users are given assign-



Figure 3.5: Pictures of monopolar laparoscopic cable with different backgrounds

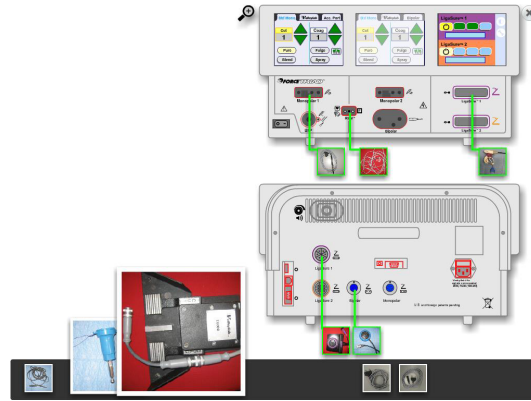


Figure 3.6: Screenshot of Simulation during Freestyle part

ments to complete, whereas in the freestyle part users were free to experiment and play with the simulation. The training part of the simulation is primarily meant to learn the tasks related to the operation procedures (*procedural knowledge*) of the ForceTriad. These tasks are largely motoric patterns with cognitive/visual factors, comparable to tasks needed to drive a car. The tasks and the order in which they need to be performed are practiced in the form of assignments which should finally result in an automatic recalling of the information by the learner. This way of learning is seen as an active process where knowledge is *constructed* (constructivism as discussed in chapter 2). By making it possible for learners to interact with the simulation one of the important features of the adult learning is provided: Active participation. The training part is divided into 3 levels: (1) Beginner, (2) Proficient, and (3) Expert. Increasing problem difficulty makes the learning more challenging, engaging and effective. The higher the level, the less feedback is given. This is the application of the, so called, “scaffolding” mentioned in chapter 2 where effective learning is achieved by decreasing the amount of feedback (prompting, guidance) over time and hereby allowing the final skill level to be elicited by naturalistic cues.

Feedback is given in the form of a pop-up message which states whether or not the assignment has been done accordingly. The feedback given by the simulation is of explicit form [15]. The simulation assists the learner provides explicit feedback and thereby takes the role of tutor, pointing out the learners’ mistakes. Furthermore, the trained assignments are realistic, for learner relevant real life tasks which need to be executed in real life. During the training the learner is not bothered with background literature information or global understanding.

- ▷ *Beginner*: At this level each of the five power modes (as mentioned in the task inventory) are individually trained. Each mode is divided into subtasks which the learner has to complete. Only when the learner has done so can the following subtask be attempted. In a way the learner is guided point by point on how to set-up the ForceTriad for the five different possible interventions. These subtasks were presented in text next to the image of the FT (figure 3.7). Upon completion of each subtask a green check mark was displayed behind the subtask. When the wrong choice has been made a pop-up screen appears stating why the selected item is incorrect (figure 3.8).
- ▷ *Proficient*: At the proficient level the five possible set-ups are still trained individually, but without the addition of subtasks. Learners have to know up front what the steps are and

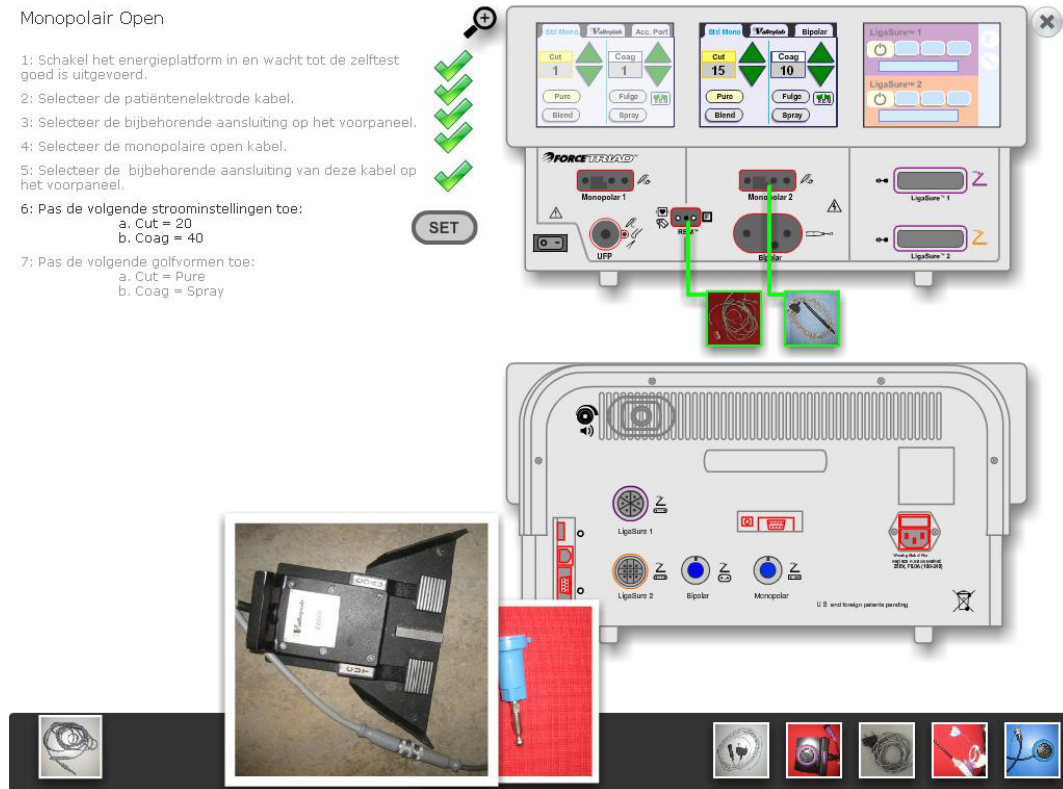


Figure 3.7: Screenshot Simulation during Training at Beginner level

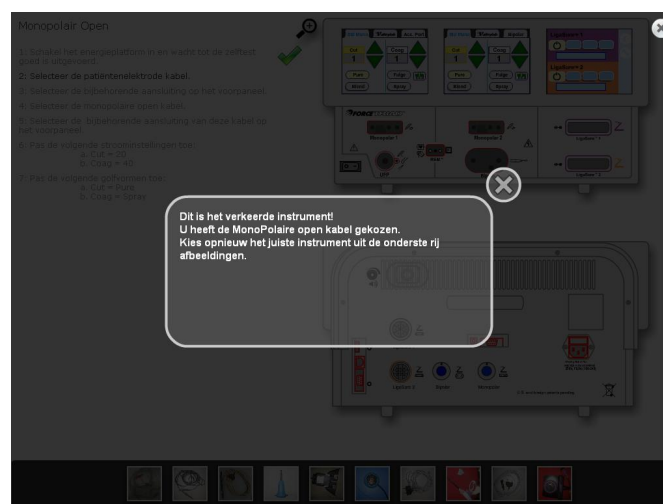


Figure 3.8: Screenshot showing the feedback pop-up when making a wrong selection

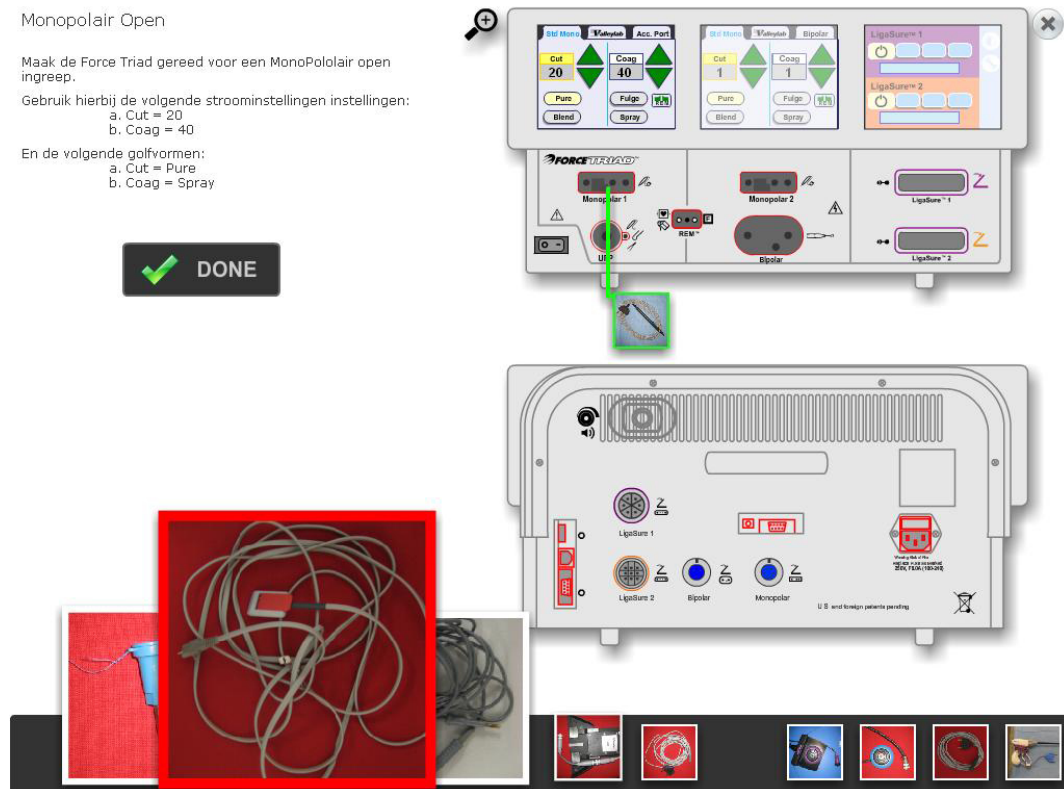


Figure 3.9: Screenshot Simulation during Training at Proficient level

complete the assignment without any feedback during the exercise. Only when the learner thinks he or she has finished the assignment can they *ask* the simulation if it was done correctly. This is done by pressing a “done” button (see figure 3.9). The system then “tells” the learner if everything was done successfully or, in case not, what stills needs to be done (see figure 3.10).

- ▷ *Expert*: At the expert level learners are prompted to set-up the medical device for multiple interventions. Three combinations of three main goals are trained. As in the proficient levels learners only get feedback when they themselves click on the “done” button.

The use of a pop-up message as form of feedback is not the only option for giving feedback. Other options to provide feedback include the use of audio, animations and/or video recordings. The reason why a text-message was chosen above the other options was that by providing the feedback in text form gives the learner an overview of all the incomplete/incorrect actions. The learner can read this at his or her own pace.

Another design choice was the application of different cognitive/difficulty levels. This simulation consists of training the basic skills of setting up the ForceTriad. It does not include elements such as communication with the surgeon, or in between changes of settings. Another option of increasing difficulty is to create a storyline which covers not only the set-up but also a whole surgical procedure where elements such as communication and shutting down the device are included. However, the focus of this research was to validate whether or not the basic skills can be improved by applying a training simulation so no additional story lines were used in the simulation.

In table 3.2 an overview of the specifications related the developed simulation.

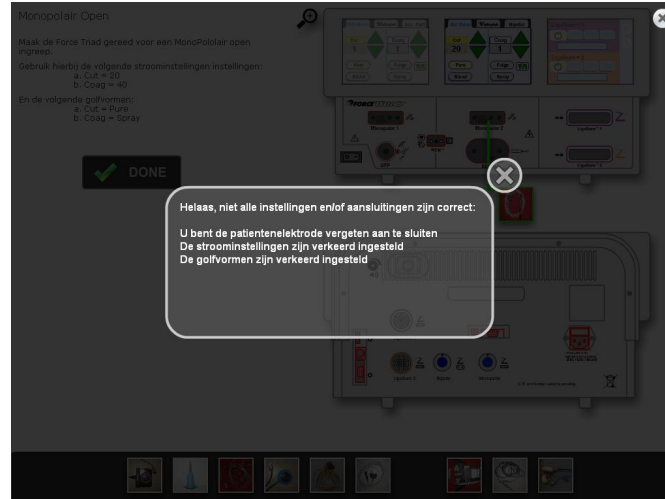


Figure 3.10: Screenshot of feedback pop-up during proficient training

Table 3.2: Specification overview Simulation

Design platform	Adobe®Flash®Player 10.1
Input device	Computer mouse
Output device	Standard high-resolution monitor
Computer requirements	450-mHz processor, 128 MB RAM, and 128MB of graphics memory
Sense of immersion	Non-low
Interaction	Navigate through, modify parameters, and manipulate content
Feedback	Explicit feedback [15] using pop-up text message
Cognitive levels available	Beginner, Proficient, and Expert

3.7 Summary

This chapter discussed the content of the simulation. This included the choice of the medical device and the tasks related to effectively operating the device. The medical device chosen is called the ForceTriad and was done in consultation with the LUMC. The ForceTriad is an electrosurgical device able to deliver three main power modi. Each power mode has its own subtasks which needs to be executed. A task inventory for all the different possible setups resulted in an assessment form consisting of twenty-three possible errors during the handling of the device. This information, together with the quality criteria stated in chapter 2, was then used to develop and produce an interactive simulation of the ForceTriad. This simulation not only looks like, but also reacts and sounds like the real life device. The simulation consists of three main categories: (1)Theory, (2)Freestyle, and (3)Training. Furthermore the training part of the simulation consisted of three difficulty levels. The higher the difficulty the less direct feedback is given. The feedback was given in the form of pop-up screens which stated, in text, what was done incorrectly. In the following chapter the method used for evaluating the simulation will be discussed.

4 Evaluation method

Prior to implementation of a new training tool, evaluation and validation of the tool is mandatory. Subjective approaches to validation include *content* and *face validity*. Examples of more objective and quantitative approaches to validation are concurrent and construct validity. The aim of the current study was to establish content, face, and concurrent validity of the simulation, thereby determining how effective the simulation is for training the skills necessary to handle medical equipment:

Content validity is generally defined as “an estimate of the validity of a testing instrument based on a description of the contents of the test items” or a judgment about what domains the instrument trains (e.g., procedural skills) [24, 25]. Content validity is also defined as the assessment of the appropriateness of the simulation as a teaching modality [62]. According to this definition content validity involves evaluation by experts knowledgeable about the device. This determines whether the simulator can realistically teach what it is supposed to teach.

Face validity refers to whether the model resembles the task it is based on and addresses the questions to what extent the environment simulates what it is supposed to represent and whether it is considered useful for training [24].

Concurrent validity compares the relationship between the test scores on the trainer (training simulation) under evaluation and the scores achieved on another instrument (traditional training method in the case of this research) [24].

4.1 Target group

The target group for determining concurrent and face validity consisted of 18 certified operating room nurses employed at the medical center in Leiden: *Leids Universitair Medisch Centrum (LUMC)*. In this study, a “certified nurse” was defined as having at least 3 years of working experience and possessing a diploma which states he or she has finished the education for operating room nurses. The reason for choosing this specific group is that they are the ones responsible for setting up and closing the OR. This includes handling medical equipment. Connecting, applying correct settings, and following protocol. The characteristics of the group are summarized in the table 4.1.

Table 4.1: Participant characteristics

Total n (male : female)	18 (2:16)
Median age in years (range)	30 (23-56)
Median experience in years (range)	9 (3-31)

These 18 nurses were randomly divided into two groups each consisting of 9 nurses. One group was trained using the designed simulation, whereas the other group was trained by the expert nurse according to the physical, and personal way of training applied at the LUMC. For clarity the group trained using the simulation will be called the Simulation Trained (ST) group while the other group will be named the “Real life Trained” (RT) group for the remainder of this article. The ST group was introduced to the simulation between July 1 and July 27, 2010. During this same period of time the RT group was trained using the conventional training method of the LUMC.

Real life training: The members of the RT group were all individually given a training about the ForceTriad by a mentor nurse as is normally the case for OR nurses. The training they received is part of “refresh course” where the mentor verbally and physically explains and demonstrates the basic tasks related to de FT. This “refresh course” is given once a year, but its effectiveness has not yet been validated. The duration of this training session was about 10 minutes for each OR

nurse.

Simulation training: The nurses of the ST group, individually, followed 2 training sessions using the simulation. The nurses were first all introduced to the simulation by an explanation of the goals of the training system and a hands-on tour of all the components of the program (Freestyle part of the simulation). The first session was done in approximately 20 minutes, while the second training sessions took approximately 15 minutes to complete. During the first session of the simulation training members of the ST group completed the theory, freestyle, and beginner level of the simulation. In the second session they completed the proficient and expert level of the training. The simulation training was performed on computers located in a computer room at the LUMC (figure 4.1).

4.2 Content validity

To determine content validity the information of the FT was obtained from literature (theoretical working principle), the hospital (available protocols), and the manufacturer of the device (the user's manual). Furthermore, the author physically interacted with the device in order to get a better understanding of the device's reaction to certain interactions. To determine the appropriateness of the simulation as teaching modality a demonstration of the simulation was given to the nurse manager and expert nurse⁴. During the demonstration the different features were explained and presented. With their approval content validation can be established.

4.3 Face validity

As mentioned the ST group was trained using the simulation. To determine face validity the opinion of the nurses about the simulation needs to be evaluated. Therefore the participants of the ST group were asked to give their opinion about the training system by completing a questionnaire.

4.3.1 Questionnaire

: This questionnaire consisted of 16 questions about the simulation. The questions were partly adapted from a questionnaire previously used in a study on face validation of another simulation trainer [27] designed for training basic endoscopic skills of surgeons. The first part of the questionnaire comprised three questions about the first impression, design, and user-friendliness of the simulator and three questions about the training capacities of the simulator. The questions in the first part of the questionnaire had to be answered by rewarding a mark on an ordinal scale, ranging from 1 (very bad/useless) to 5 (excellent/very useful). The second and final part presented ten general statements about the suitability to train surgical residents with the simulator. These statements had to be answered with "agree", "disagree", or "no opinion".

⁴The expert nurse is responsible for providing additional training for OR nurses

Table 4.2: Face Validity questionnaire Part 1

PART 1: What is your opinion about... (1 = very bad/useless and 5 = excellent/very useful)	1	2	3	4	5
<i>First impression</i>					
appearance and design of the software	O	O	O	O	O
user-friendliness of the instrument	O	O	O	O	O
level of realism of the software	O	O	O	O	O
<i>Training capacities</i>					
identifying cables / foot pedals	O	O	O	O	O
identifying interface buttons / connection ports	O	O	O	O	O
procedural tasks	O	O	O	O	O

Table 4.3: Face Validity questionnaire Part 2

PART 2: Statement: The simulation...	Agree	Disagree	No opinion
is useful to train skills for the ForceTriad	O	O	O
can become useful to train skills for the ForceTriad	O	O	O
is useful instrument to train procedural skills	O	O	O
can become useful to train procedural skills	O	O	O
is useful for identifying cables / foot pedals	O	O	O
can become useful for identifying cables / foot pedals	O	O	O
is suitable for training at home	O	O	O
is suitable for training at the hospital	O	O	O
could be used as a tool to determine nurses' competence	O	O	O
I would use it in my own time as back up information	O	O	O

4.4 Concurrent validity

To establish concurrent validity the 18 nurses were randomly divided into two groups each consisting of 9 nurses. One group was trained using the designed simulation, whereas the other group was trained by the expert nurse according to the physical, and personal way of training applied at the LUMC.

In order to determine concurrent validity the performance of the ST and RT group needed to be evaluated. This was done two times in the form of a pre and post test. The pre test was performed for all the nurses prior to receiving any additional training. This test was done using the assessment form presented in table 3.1. After having received their training both groups were again tested (post-test) using the same assessment form from the pre-test. By comparing the results (amount of errors observed) one can make statements concerning concurrent validity.

4.4.1 Experiment

: The setting of both the pre-, and the post-test was at the LUMC. The pre test was performed unannounced during working hours. Each of the nurses was individually tested by verbal assignments consisting of setting up the FT for all the five different modes. The amount of errors were tallied according to the assessment form of table 3.1. During the pre- and post-tests errors were tallied for the three categories discussed in chapter 3: (1)Procedural, (2)Connection, and (3)Identification errors. These tests were also captured on video with the consent of the nurses. As mentioned the ST group and RT group received their own type of training and received this training in July 2010. Members of the RT group were all individually given a training about the



Figure 4.1: *Nurses training with the simulation*

FT by a mentor nurse as is normally the case for OR nurses, physically showing and explaining the different functions and tasks related to the ForceTriad. The nurses of ST group followed 2 training sessions using the simulation. The first session was done in approximately 20 minutes, while the second training sessions took only 15 minutes to complete. The introduction to the simulation consisted of an explanation of the goals of the training system and a hands-on tour of all the components of the program (Freestyle part of the simulation). During the first session of the simulation training the nurses completed the theory, freestyle and beginner level of the simulation. In the second session they completed the proficient and expert level of the training. The simulation training was performed on computers located in a computer room at the LUMC (figure 4.1). A month after having received the training all participants performed a post test that was identical to the pre test. During the pretest and post test, the errors (identification, procedural, and connection errors) were tallied.

The collected data was analyzed using the Statistical Package of Social Software (SPSS) version 17.0. The Wilcoxon signed rank test for non-parametric data was used to analyze statistical differences between the amount of errors made during the pre- and post-test by the RT- and ST group. Statistical significance was considered when p was less than 0.05.

5 Results

5.1 Content validity

The tasks given in the training simulation are designed to train procedural and cognitive tasks related to the set-up of the ForceTriad (FT). During the training the nurses were asked to set-up the ForceTriad for each of the different power modes. The tasks could be performed at three different difficulty levels. With the use of a computer mouse users could virtually switch on the device, select and connect cables, and apply settings if applicable as in the real world. This was possible by moving the mouse cursor over the button/cable of choice and selecting them with a single mouse click. The learner was given feedback when a task was not, or incorrectly performed (e.g. not connecting a necessary cable or foot pedal). No error registration was made with the simulation.

Furthermore, a demonstration was given to the nurse manager and expert nurse of the LUMC. The demonstration included a *walk through* of the three parts of the simulation (theory, freestyle, and training). In their opinion the simulation is appropriate to train the basic skills for which it was designed. By their approval, the appropriateness of the simulation, as teaching modality, and content validation was established.

5.2 Face Validity

The results of questionnaires filled out by ST group will now be presented.

5.2.1 Questionnaire results part 1

First impression

Table 5.1 shows the mean values of the scores for the first impression of the simulator. All the given values were at least 4. The highest mean score of 4.4 was given for the appearance/design, and level of realism of the simulation. The lowest value of 4.0 was given for the user-friendliness.

Training capacities

Table 5.1 shows the mean values (including standard deviation) of the scores for the first impression and training capacities. The training capacity of the simulation received a rating, with mean scores, ranging from 4.1 till 4.3. The highest score in the category training capacities was given to training of procedural tasks(4.3). Training of identifying cables received a score of 4.2 and the training capacities related to the interface buttons was given a mean score of 4.1.

Table 5.1: Results Part1 Face validity (1 = very bad/useless and 5 = excellent/very useful)

What is your opinion about...	Mean	SD
<i>First impression</i>		
appearance and design of the software	4,4	0,5
user-friendliness of the instrument	4,0	0,8
level of realism of the software	4,4	0,7
<i>Training capacities</i>		
training of identifying cables / foot pedals	4,2	0,4
training of identifying interface buttons / connection ports	4,1	0,7
training of procedural tasks	4,3	0,5

5.2.2 Questionnaire results part 2

At least 88.8% of the nurses agreed on statements concerning the usefulness of the training simulation. When asked if they would use the simulation in their own time or at home 55.6% chose for the *no opinion* option. All of the nurses agreed on the statement that the simulation is suitable for training at the hospital.

Table 5.2: Results Part2 Face validity statements

Statement: The simulation...	Agree	Disagree	No opinion
is a useful to train skills for the ForceTriad	88.8%	0.0%	11.2%
can become a useful to train skills for the ForceTriad	100%	0.0%	0.0%
is a useful instrument to train procedural skills	88.8%	0.0%	11.2%
can become a useful to train procedural skills	100%	0.0%	0.0%
is useful for identifying cables / foot pedals	100%	0.0%	0.0%
can become a useful for identifying cables / foot pedals	100%	0.0%	0.0%
is suitable for training at home	44.4%	22.2%	33.4%
is suitable for training at the hospital	100%	0.0%	0.0%
could be used as tool to determine nurses' competence	100%	0.0%	0.0%
I would use it in my own time as back up information	44.4%	0.0%	55.6%

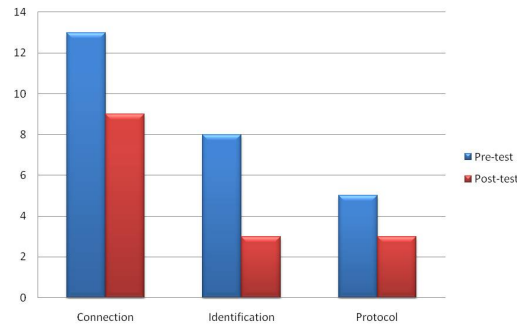
5.3 Concurrent validity

During the pre-tests a total of 26 errors was observed (see figure 5.1). These errors are now divided according to the categories defined by the task inventory of chapter 3:

- ▷ **13 Connection errors:** In 6 of the cases nurses forgot to connect a necessary adapter for the monopolar laparoscopic cable and in 3 cases this adapter was not pushed in deep enough for the system to recognize it. The bipolar laparoscopic cable was connected to the wrong connection port 2 times, and this was also observed 2 times for the bipolar “open” cable.
- ▷ **8 Identification errors:** When asked to identify a certain foot pedal 2 different nurses identified the bipolar foot pedal incorrectly, and 4 nurses did not correctly identify the bipolar laparoscopic cable. In 2 cases nurses wrongfully identified the monopolar laparoscopic cable.
- ▷ **5 Procedural errors:** During the setup 2 nurses did not wait until the, so called, self test of the ForceTriad had been completed prior to taking further steps. In the 3 other cases nurses first applied the settings and than connected the cables, while this should be done in opposite order.

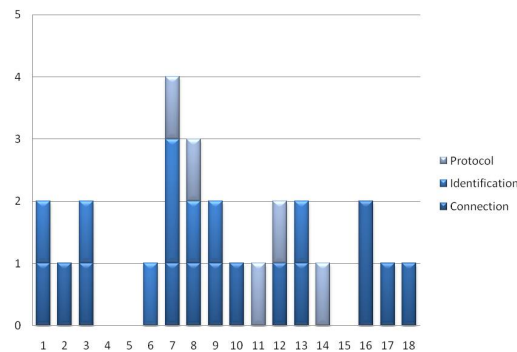
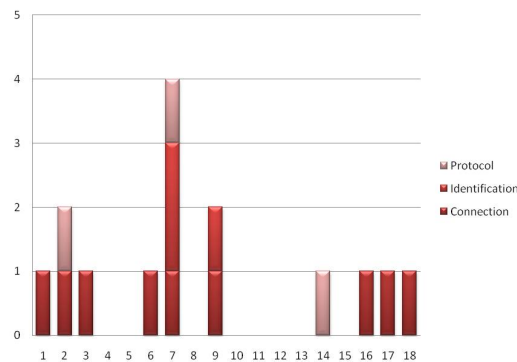
During the post-tests a total of 15 errors was observed (see figure 5.1). Dividing these errors accordingly results in the following errors:

- ▷ **9 Connection errors:** In 1 of the cases a nurse forgot to connect a necessary adapter for the monopolar laparoscopic cable and in the other 8 cases this adapter was not pushed in deep enough for the system to recognize it.
- ▷ **3 Identification errors** The bipolar foot pedal, laparoscopic, and open cable were wrongfully identified.
- ▷ **3 Procedural errors:** In 2 cases the nurses first applied the settings and than connected the cables and another nurses did not wait for the self test to complete.

Figure 5.1: *Number of errors observed during pre- and post tests*

Dividing these results into individual performance of the nurses gave the following result: of the 18 nurses who participated in this research 8 (44%) made less errors after having recieved additional training and 9(50%) of the nurses' performance stayed the same, and only 1(6%) nurse made more errors after having recieved additional training. In figure 5.2 the errors made, during the pre-test, by each of the 18 nurses is shown graphically and subsequently in figure 5.3 the errors made during the post-tests, by each of the nurses, are presented in the same manner.

In total a reduction of 11 errors(42.3%) were observed for the whole target group after having recieved additional training. Details on all the errors made by each individual can be found in appendix B. Next, the results of the pre and post test will be presented separately for both the RT and the ST group.

Figure 5.2: *Pre-Errors made by each individual*Figure 5.3: *Post-Errors made by each individual*

5.3.1 Real life Trained group

For the RT group a total of 15 errors (6 connection, 7 identification, and 2 protocol) were observed. Post tests revealed that this amount declined to a value of 11 errors (6 connection, 3 identification, and 2 protocol).

This means a reduction of 4 errors (27%) for the RT group.

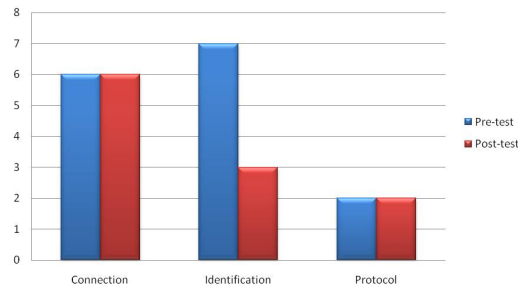


Figure 5.4: *Pre- and Post errors RT group*

Dividing these results into individual performance of the nurses gave the following result: of the 9 nurses who followed the traditional real life training 3 (33%) made less errors after having recieved additional training, while 5 (55%) of the nurses' performance stayed the same, and 1 (12%) made more errors after having recieved additional training. In figure 5.5 the errors made by each of the 9 nurses, during the pre-test, is shown graphically. Subsequently in figure 5.6 the errors made, during the post-tests, are presented in the same manner.

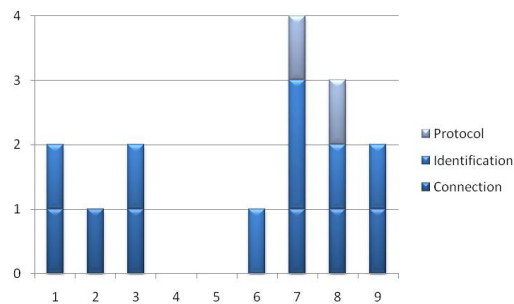


Figure 5.5: *Pre-Errors made by each individual, RT group*

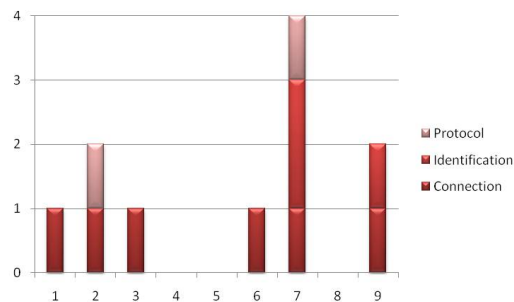


Figure 5.6: *Post-Errors made by each individual, RT group*

5.3.2 Simulation Trained group

The ST group made a total of 11 errors (7 connection, 1 identification, and 3 protocol) during the pre-test. During the post test this number reduced to 4 errors (3 connection, 0 identification, and 1 protocol).

This means a reduction of 7 errors (63%) for the ST group.

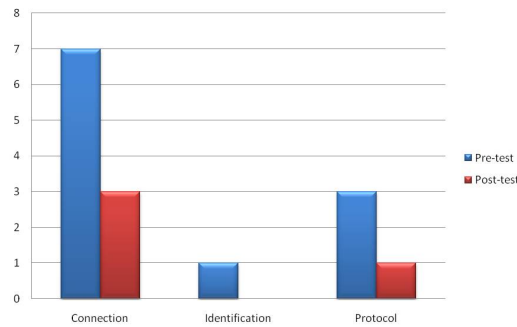


Figure 5.7: *Pre- and Post errors ST group*

Separating these results for individual performance of the nurses gave the following result: of the 9 nurses who followed the simulation training 5 (55%) made less errors after having recieved additional training, while 4 (45%) of the nurses' performance stayed the same, and 0 (0%) made more errors after having recieved additional training. In figure 5.8 the errors made by each of the 9 nurses, during the pre-test, are shown graphically. Subsequently in figure 5.9 the errors made during the post-tests, are presented in the same manner.

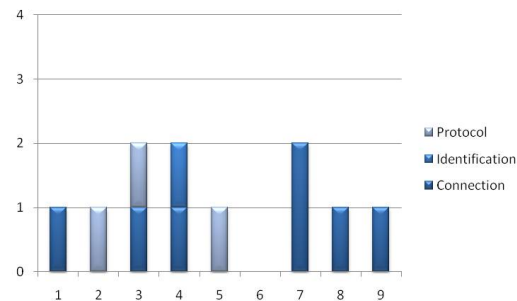


Figure 5.8: *Pre-Errors made by each individual, ST group*

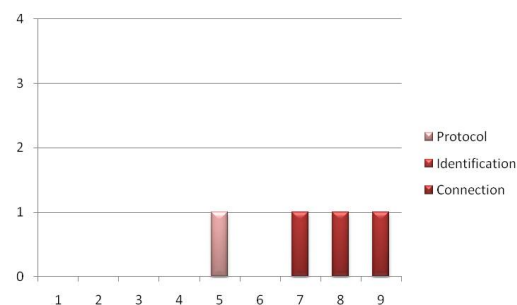


Figure 5.9: *Post-Errors made by each individual, ST group*

5.3.3 Simulation training versus real life training

Table 5.3 shows the mean of the amount of errors made during the pre- and post-test for the RT- and ST-group. Notice that mean value, of errors made, decreases in the RT- and ST group from the pre test to the post test.

Table 5.3: Number of errors observed for the ST and RT group during the pre- and post-tests.

		Pre-test	Post-test	<i>p</i> Value ^a
RT group	mean	1.66	1.22	0.257
	SD	1.24	1.22	–
ST group	mean	1.22	0.44	0.038
	SD	0.62	0.49	–

^a Wilcoxon signed-rank test

In figure 5.10 the results of the error reduction of the RT and ST group are put alongside each other.

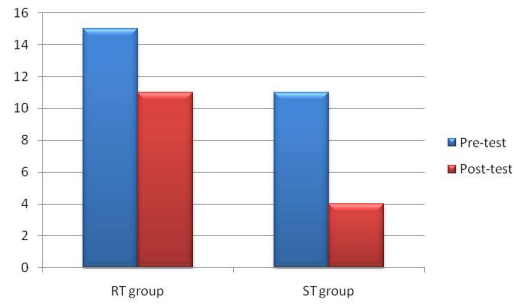


Figure 5.10: *Pre- and Post errors of the RT and ST group*

5.3.4 Errors per power modi

Summarizing these errors for each of the three power modi available on the forcetriad (Bipolar, monopolar, and ligasure) we see that during the pre-test approximately 50%(13/26) of the errors were made during setting up the ForceTriad for monopolar procedures and approximately 42%(11/26) of the errors were made during the set up of bipolar procedures(Fig 5.11). During the post tests approximately 66.6%(10/15) of the errors were related to the monopolar power modi, while 26.6%(4/15) were bipolar related. No errors were observed during the pre- and post-tests setup of the Ligasure power mode.

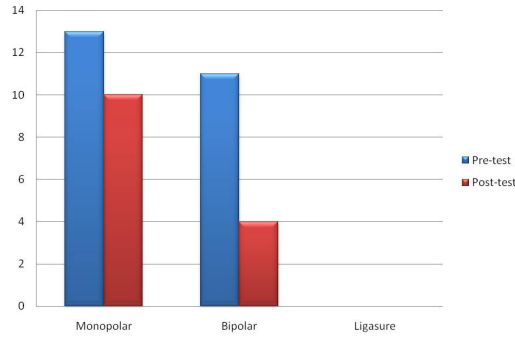


Figure 5.11: *Number of errors per power mode*

6 Discussion

Structured training and assessment of skills, related to medical equipment, is an important issue in healthcare [3]. The occurrence of errors related to medical equipment have been quantified [23] and the lack of proper training and assessment, related to medical equipment, has been identified by several studies as one of the main reasons for this problem [5, 7]. The current training method can comprise patient safety and is limited by the availability of mentors and equipment itself. The application of VR as training simulations could resolve such problems and is already considered and proven to be a valuable training application in other fields such as aviation and surgeons' training of laparoscopic skills [6]. However, the application of VR for the training of skills related to medical equipment has not yet been investigated to the knowledge of the author.

User's performance

The experiment, conducted to determine concurrent validity, showed a significant increase in performance for participants of the ST group (p Value of 0.038). The number of errors observed for the RT group did reduce, but this change was not significant (p Value of 0.257). An explanation for the difference in performance could be the fact that the training of these nurses was not limited to an explanation, but the nurses actually practiced and got immediate feedback when making wrong decisions during simulation training. Whilst during the traditional way of the refresh training the nurses only got a verbal and visual explanation on how the device works. This result does correspond with statements in literature about adult learning (adults acquire skills more effectively by active participation). Also, the members of the RT group got no feedback when actually applying their skills in the OR. During the real life training no "hands on" exercise sessions were included. It should also be noted that the RT group received a training of 10 minutes, while the ST group received 35 minutes of training (spread over 2 sessions). This means it has not been proven that the *active participation* during the ST training results in a more effective training method. But, members of the ST group trained without mentor. Assigning a mentor which coaches and observes the nurses (as was the case for the RT group) is time consuming for hospitals and often logistically problematic to make possible.

Simulation design

Designing a training simulation requires knowledge about how humans effectively acquire knowledge and skills and how to apply this in a virtual world. According to the adult learning theory, adult learners prefer learning that involves active participation, practical experience, variety, feedback, and real world problem solving [12]. To enable this, in a virtual world, the simulation needs to suffice certain design criteria such as a high level of interactivity and the delivery of corrective feedback to the user. Implementing the different quality criteria defined by Reichert [15] can be done in different ways using the available technologies VR has to offer. For example, the use of a pop-up message as form of feedback is not the only option for giving feedback. Other options to provide feedback include the use of audio, animations and/or video recordings. The reason why a text-message was chosen above the other options was that by providing the feedback in text form gives the learner an overview of all the incomplete/incorrect actions. The learner can read this at his or her own pace.

Another design choice was the application of different cognitive/difficulty levels. The developed simulation focuses on training the basic skills of setting up the ForceTriad and does not include elements such as communication with the surgeon, or in between changes of settings. Another option of increasing difficulty is to create a storyline which covers not only the set-up but also a whole surgical procedure where elements such as communication and stress are included. However, the focus of this research was to validate whether or not the basic skills can be improved by applying a training simulation so no additional storylines were used in the simulation.

Although the results of this article show that the application of the simulation training has resulted in an improvement of performance by OR nurses (63% less errors observed for the ST group), the chosen design features might not have been optimal. Future research is needed to find an optimum application of the different features and the effect they have on the learning curve. Examples in-

clude researching the effect of different types of feedback and the addition of a more broad storyline.

User's opinion

The results of this study show that the developed training simulation was well received by the participants. According to the results of the questionnaires filled out by the OR nurses, the first impression and training capacities were rated high (procedural, identification, and connection tasks). The user-friendliness of the simulation got the “lowest” rating (4.0) which is still high on a scale from 1 to 5. There were, however, also complaints concerning the simulation. Two of the nurses complained that the presentation and selection of the images was not optimal. The reason for this dissatisfaction could be the type of image representation used in the simulation. The pictures enlarge by scrolling over them with the mouse cursor. The images are represented next to each other and gradually increase in size when scrolling over them with your mouse. Due to this presentation the user can get a better view of the images before actually making a choice of which item to select. A more “stationary” presentation of the images could be a solution.

The participants also found that the simulation had a high degree of realism and believed that the simulation can become a useful tool in training cognitive and procedural tasks related to the FT. Although the nurses stated that they experienced a high level of realism during simulation training it should not be forgotten that content validation was limited to the training of basic skills related to the FT. Other factors like stress and communication during actual procedures were not taken into account in this simulation. These are also important factors which can influence nurses' performance. Future research could focus on implementing these issues in the form of scenarios and hereby creating a more realistic training environment.

In general a large percentage of the ST group (88.8%) agreed with the statement that the simulation is an useful tool to train. However, only 44.4% agreed that the simulation is suitable to train at home, while 100% agreed that it is suitable to train at the hospital itself. This could indicate that OR nurses do not prefer to train outside working hours or that the simulation is not motivating enough. An in depth analysis of the target group could provide the answers to questions such as these.

Although care was taken to optimize the design of this study, face validity contains weakness because it is based on opinions. In order to reduce this weakness, questions were adapted from a previously used questionnaire [60], which was used to determine face validity for a laparoscopic surgical simulator. Because the tasks to be trained in the developed simulation differ to those of the surgical simulator, the questions of the questionnaire were changed accordingly. However, systemic errors can originate from the questionnaire. For example, the interpretation of questions can differ among subjects because of suboptimal formulations. Also, the enthusiasm of the presenter or the attractiveness of a new training system can bias the answers.

Simulations have many potential benefits, but skeptics also state many disadvantages of applying VR as training environment. Disadvantages of VR simulations which are mentioned include the costs and lack of realism. However, improvements in technology make it possible to design and develop systems which are flexible, affordable, and more realistic. An example of a flexible, and relatively low in cost, training simulation is the SIMENDO (laparoscopic surgical skills trainer) [63]. Moreover, mobile training systems are especially interesting because several studies indicate that VR training is likely to be successful when the training schedule is intermittent rather than condensed into a shorter period of extensive practice [58, 59]. To easily implement such a schedule it is favorable when the simulation is easily accessible (e.g. in every hospital or at home). The developed simulation in this article was designed using the program Adobe®Flash®CS4, which has the possibility to place the designed simulation online so that it is easily accessible on home computers and computers from any place as long as there is an internet connection.

It is also well known that acquired skills can diminish over time if not trained frequently. For example, when nurses do not work with a specific device for a while they could forget the basic skills. These skills can be reinforced using the developed simulation which is relatively simple when compared to the available laparoscopic simulators. The developed simulation is meant to be

low priced, mobile, and especially suitable for training basic skills related to medical equipment for example. It could be used as additional training tool to complement the conventional training method giving the learner the ability to practice individually as often as they like. Training individually is another advantage of the simulation, because they are not dependent on a mentor and/or the availability of the medical device.

Simulation shortcomings

The simulation, however, has some weaknesses. One of these weaknesses is the fact that the tasks performed in the simulation do not require the same physical actions of the OR nurses as it would in real life. Instead, nurses used a computer mouse for connecting and selecting cables, whilst in real life they can touch and feel the cables. In the experiment, for determining concurrent validity, the members of the ST and RT groups were assessed on their competence of executing predefined tasks. One specific task, which was connecting a necessary adapter for the monopolar laparoscopic mode, required the nurse to physically align the adapter correctly with the connection port and apply a significant amount of force before the ForceTriad recognized it. Not correctly aligning and/or not applying significant force to the adapter was not trained in the simulation (making this possible in the simulation would result in a more complex system).

During the pre-tests this type of error was observed 3 times, and during the post-test this error was observed 8 times. A reason for this could be that the nurses correctly aligned the adapter by chance. This observation does imply that, for specific cases of tasks related to medical equipment, more could be needed to train than just a mouse click. The addition of haptic feedback could make the simulation more realistic, but also far more complex and expensive. A less complex solution could be the use of animations. Visualizing the correct placement of the adapter could result in the desired effect. Important to note is that by not correctly taking into account such issues, could result in a negative learning effect. It shows how, seemingly unimportant, design decisions can have a big effect on the learning process.

Summarizing the results for the total amount of errors during the pre- and post-tests, without the addition of the mentioned adapter error (so only focusing on the tasks which were trained), resulted in figures 6.1 & 6.2. From these graphs it becomes clear that the ST group went from 11 to only 2 errors (72% less), whilst the RT group went from 12 to 7 errors (44% less) observed (excluding the adapter error).

In both scenario's (including and excluding the adapter error) the ST group's performance improved more than that of the RT group. Including the adapter error the ST group went from 11 to 4 errors (63% less), whilst the RT group went from 15 to 11 errors (27% less).

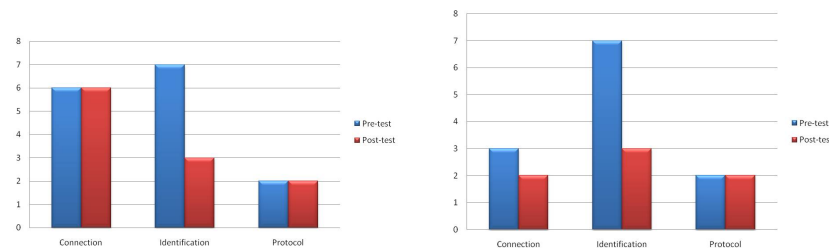


Figure 6.1: *Left: RT Group results including adapter error, Right: RT Group results excluding adapter error*

Another interesting result of this research showed that, of the errors which were observed, 0% were made during the set-up of the ligasure mode (pre- and post tests). During the pre-tests and post-tests most errors were observed during the set-up related to the monopolar power mode (pre: 50%, post: 66%). The bipolar power mode was accountable for 42% of all the errors observed during the pre-test and for 26.6% during the post-test. A possible reason that most of the errors were observed for the monopolar mode is the fact that setting up the monopolar mode requires more steps to complete compared to the bipolar and ligasure mode. More tasks means more possibilities

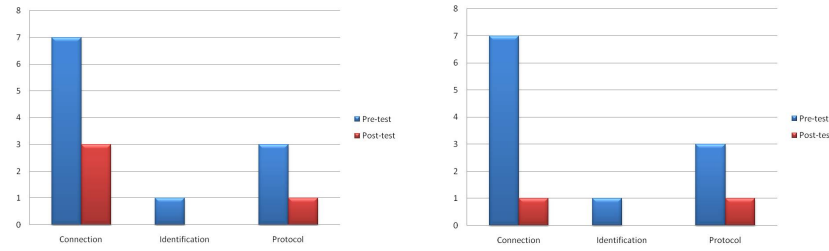


Figure 6.2: *Left: ST Group results including adapter error, Right: ST Group results excluding adapter error*

for errors to occur. No errors were observed for the ligasure. This could be because the ligasure has a prominent design. The colors of the foot pedal, instrument, and connection ports show a lot of resemblance (all of the mentioned parts are purple, or have purple aspects on them). Also the ligasure mode has less options which can be modified compared to the bipolar and monopolar mode.

As mentioned in this article, the design of a medical device can also play an important role in the occurrence of these errors. The ligasure mode of the ForceTriad is a good example, in the authors opinion, of how design features can reduce errors. However, there will always be room for improving equipment design, but this process is expensive. Once bought equipment will not easily be replaced by hospitals.

This research has shown that both groups show a decrease in errors made after having received training. The number of errors for ST group significantly decreased. The reduction of errors for RT group was not significant. However, statements related to quantative measurements of this research are very limited because of the relatively low amount of participants. In total 18 OR nurses participated which makes a quantative comparison of errors not as reliable as one would wish. Nevertheless, this is one of the first times such a simulation was specifically designed to train skills related to a medical device (to the knowledge of the author) and the results show much potential for further research. The results of this study can serve as a first insight for new research projects focused on the same subject of improving skills for the operation of medical equipment.

7 Conclusion and Recommendations

The objectives of this thesis included designing and validating a simulation meant to train basic skills related to a medical device. In this chapter conclusions related to these objectives and recommendations for future research will be stated.

Simulation design:

A working prototype of a training simulation was developed meant to train basic skills related to a medical device. The design was not based on available instructional frameworks, because there are no clear and generally accepted protocols of equipment handling [23]. Instead the design was based on a conducted task analysis, the adult learning theory, and quality criteria stated in literature [15]. Quality criteria, which are believed necessary for good educational software, were implemented in the developed simulation. These criteria included interactivity, incorporation of different cognitive levels, and providing a form of feedback.

Validation:

Content-, face-, and concurrent validity were established. The simulation was found appropriate to train the basic skills related to the FT. This study showed that OR nurses considered the developed simulation to be a useful training device for identification, connection, and procedural tasks. The OR nurses also appreciated the design and user friendliness of the simulation and stated that they found it suitable for training at the hospital. Nurses which were trained using the simulation made significantly less errors ($p = 0.038$) after having received additional training, whilst the nurses trained using the traditional training method applied at the LUMC made 27% less errors made, but this change was not significant ($p = 0.257$).

Recommendations for future research:

The results of this study gave valuable insights into which topics are of importance when designing and developing a training simulation focused on training basic skills related to a medical device. Future research could focus on what kind of effect the implemented different features of VR and quality criteria have on the learning cycle of the OR nurses. Questions like *How much interactivity is necessary?* and *What form of feedback is optimal?* for effectively training basic skills related to a medical device using VR.

The number of participants ($n=9$), for each group, of this research was relatively low. To be able to make a better quantitative analysis of the effect of a training simulation more participants should be included. A quantitative measurement can also be made more objective by comparing the performance of personnel in different hospitals.

The results of this study show great potential for the application of a training simulation for medical equipment, but further research must be done to create a general understanding and accepted training method and protocol related to medical equipment. This, together with quantitative research on the effectiveness of the training simulations are needed before hospitals will consider implementing such a *new* additional training to the existing curriculum.

8 References and Bibliography

References

- [1] Brennan, T.A., *Incidence of adverse events and negligence in hospitalized patients: results of the Harvard Medical Practice Study 1*, N Engl J Med 1991;324:370-6.
- [2] Kohn L.T., *To err is human: building a safer health system*, Committee on Quality of Health Care in America, Institute of Medicine. Washington: National Academy Press, 2000:312 pp..
- [3] Leap L.L., *Errors in Medicine*, Harvard School of Public Health, Boston, MA 02115, United States 2009.
- [4] Reason J., *Human error: models and management*, British Medical Journal 320:768-770. 2000.
- [5] Cooper J. B., *An Analysis of Major Errors and Equipment Failures in Anesthesia Management: Considerations for Prevention and Detection*, American Society of Anesthesiologists, Inc 1984.
- [6] Seymour N.E., *VR to OR: A Review of the Evidence that Virtual Reality Simulation Improves Operating Room Performance*, World J Surg (2008) 32:182-188
- [7] Inspectie voor de Gezondheidszorg, Kwaliteitsborging van medische apparatuur in ziekenhuizen: verbeteringen noodzakelijk, Oktober 2002
- [8] Sternberg R.J., *In search of the human mind* Harcourt Brace & Company, Orlando USA 1995
- [9] Fitts P.M., *Learning and skilled performance in human performance*, Belmont CA: Brock-Cole 1967
- [10] Dreyfus S.E., *A five stage model of the mental activities involved in directed skill acquisition*, California Univ. Berkeley, Operations Research Center 1980
- [11] Anderson J.R., *The architecture of cognition*, Cambridge Mass, Harvard University Press 1983
- [12] Kolb D., *Learning style inventory*, Boston, MA: McBer & Company 1981
- [13] Issing L.J., *Information und Lernen mit multimedia*, Psychologie Verlag, Union, Weinheim 1997
- [14] Glasersveld E., *Wissen, Sprache, Wirklichkeit-Arbeiten zum radikalen Konstruktivismus*, Vieweg, Braunschweig 1987
- [15] Reichert R., *On the Learning in E-Learning*, Proceedings of EDMEDIA 2004 World Conference on Education Multimedia, Hypermedia and Telecommunications, pp. 1590-1595. June 23-26, Lugano, Switzerland, 2004
- [16] Schwill A., *Fundamental Ideas of Computer Science*, EATCS-Bulletin 53, 274295. 1994
- [17] Cannon-Bowers J. A., *Synthetic learning environments: On developing a science of simulation, games and virtual worlds for training*, In S. W. J.Kozlowski & E. Salas (Eds.), *Learning, Training, and Development in Organizations*. Mahwah, NJ: Erlbaum. 1995
- [18] Thavikulwat P., *The architecture of computerized business gaming simulations*, Simulation & Gaming, 35, 242-269. 2004
- [19] Teach R.D., *Designing business simulations*, In J. W. Gentry (Ed.), *Guide to business gaming and experiential learning* (pp. 93-116). East Brunswick, NJ: Nichols/GP. 1990
- [20] Jones, K. *Who is who, who sits where*, Simulations & Gaming, 29, 328-330. 1998

- [21] Laurel B., *Computers as Theatre (second ed.)*, Addison-Wesley Publishing. 1993
- [22] Schulmeister R., *Taxonomy of Multimedia Component Interactivity. A Contribution to the Current Metadata Debate*, Studies in Communication Sciences. Studi di scienze della comunicazione. 3(1), 61-80. 2003
- [23] Verdaasdonk E.G.G., *Problems with technical equipment during laparoscopic surgery*, Surg Endosc, 21: 275279. 2007
- [24] Aggarwal R., *Laparoscopic skills training and assessment*, Br J Surg 91: 1549-1558. 2004
- [25] Gallagher A.G., *Fundamental principles of validation and reliability: rigorous science for the assessment of surgical education and training*, Surg Endosc 17:1525-1529. 2003
- [26] Duffy A.J., *Construct validity for the LAPSIM laparoscopic surgical simulator*, Surg Endosc 19: 401405. 2005
- [27] Schijven M., *Face-, expert, and referent validity of the Xitact LS500 laparoscopy simulator*, Surg Endosc 16: 1764-1770. 2002
- [28] Dankelman J., *Fundamental aspects of learning minimally invasive surgical skills*, Minimally Invasive Therapy and Allied Technologies, 14:4, 247 - 256. 2005
- [29] Rasmussen R., *Skills, rules and knowledge; signals, signs and symbols, and other distinctions in human performance models* IEEE Trans. Systems Man Cybernetics. 1983;13:25766.
- [30] Reason J., *Human error* 1st ed. Cambridge University Press. 1990.
- [31] Birkmeyer J., *Hospital volume and surgical mortality in the United States*, N Engl J Med 2002;346: 1128-37.
- [32] Begg C., *Variations in morbidity after radical prostatectomy*, N Engl J Med 2002;346:1138-44.
- [33] Hall J., *Surgeons and cognitive processes*, Br J Surg 2003;90(1):10-6.
- [34] Polet P., *Modelling border-line tolerated conditions of use (BTCU) and associated risks*, Saf Sci 2003;41(2-3):111-36.
- [35] Cooper J., *Preventable anesthesia mishaps: a study of human factors*, Qual Saf Health Care Sep 2002;11(3):277-82.
- [36] Hadjianastassiou V., *Surgical mortality score: risk management tool for auditing surgical performance*, World J Surg Feb 2004;28(2):193-200.
- [37] Ganong W., *Review of medical physiology*, Cambridge: Appleton & Lange; 2003
- [38] Verdaasdonk E., *Can a structured checklist prevent problems with laparoscopic equipment?*, Surg Endosc (2008) 22:22382243, DOI 10.1007/s00464-008-0029-3.
- [39] Gaddis T., *Virtual reality in the school. Virtual reality and Education Laboratory*, East Carolina University. 1998
- [40] Fitzgerald M., *Virtual reality*, In: L. Beolchi (ed.), Telemedicine glossary. European Commission-DG INFSO, pp. 327-329. 2001
- [41] Durlach N., *Virtual Reality: Scientific and Technological Challenges*, National Academy Press, 1995.
- [42] Milgram P., *A Taxonomy of Mixed Reality Visual Displays*, IEICE Transactions on Information and Systems, E77-D(12), 1994, pp.1321-1329.
- [43] Azuma R., *A survey of augmented reality*, Presence 1995;6(4):355-85.

- [44] Riva G., *Applications of Virtual Environments in Medicine Applied Technology for Neuro-Psychology Lab*, Istituto Auxologico Italiano, Milan, Italy 2003
- [45] McGuire E., *Knowledge representation and construction in hypermedia and environments*, Telematics and Informatics 13:251-260. 1996
- [46] Brown J., *Situated cognition and the culture of learning*, Educational Researcher 18:32-43.
- [47] Lave, J., *Situated learning: legitimate peripheral participation*, Cambridge: Cambridge University Press. 1991
- [48] Crane M., *Knowledge constructing through hypermedia authoring*, Educational Technology Research and Development 47:29-50. 1999
- [49] Winn W., *A conceptual basis for educational applications of virtual reality*, Technical Report TR 93-9. Available: www.hitl.washington.edu/publications/r-93-9/. 1993
- [50] Dede C., *Science-Space: virtual realities for learning complex and abstract scientific concepts*, Presented at the IEEE Virtual Reality Annual International Symposium (VRAIS '96). 1996
- [51] Satava R., *Virtual environments for medical training and education*, Presence 6:139-146. 1997
- [52] Slater M., *A Note on Presence Terminology*, Presence-Connect, Jan. 2003; <http://presence.cs.ucl.ac.uk/presenceconnect/articles/Jan2003/melslaterJan27200391557/melslaterJan27200391557> 2003
- [53] Bowman D., *Virtual Reality: How Much Immersion Is Enough?* Virginia Tech. 2007
- [54] Fox M., *Learning design and e-learning*, Epic, Brighton, United Kingdom 2006
- [55] Dick W., *Dick and Carey Model*, The systematic design of instruction (4th ed.), New York: Harper Collins College Publishers, 1996
- [56] Carliner S., *ADDIE Model*, Training design basics, Alexandria, Virginia: American Society for Training & Development. 2003
- [57] Cnossen F., *Adaptive strategies and goal management in car drivers*, Proefschrift Rijksuniversiteit Groningen, 2000
- [58] Gallagher A., *Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training*, Ann Surg 241: 364372. 2005
- [59] Ali M., *Training the novice in laparoscopy. More challenge is better*, Surg Endosc 16: 17321736. 2002
- [60] Schijven M., *Face-, expert, and referent validity of the Xitact LS500 laparoscopy simulator*, Surg Endosc 16: 17641770. 2002
- [61] Müller D, *Mixed reality learning spaces for collaborative experimentation: A challenge for engineering education and training*, iJOE International Journal of Online Engineering - www.i-joe.org. 2007
- [62] McDougall E., *Construct Validity Testing of a Laparoscopic Surgical Simulator*, Departments of Urology and Family Medicine, University of California, Irvine, Orange, CA. 2006
- [63] Verdaasdonk E., *Validation of a new basic virtual reality simulator for training of basic endoscopic skills*, Man Machine Systems Group, Faculty of Mechanical, Maritime & Materials Engineering, Delft University of Technology, Surg Endosc, 20: 511518. 2006

A APPENDIX: Theory slides simulation

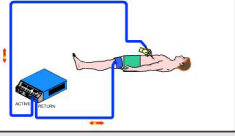
1. Electro chirurgie

De ForceTriad is een electrochirurgisch apparaat. Bij elektro chirurgie wordt hoog frequent elektrische stroom gestuurd door weefsel om een gewenst klinisch effect te krijgen. Tijdens passeren van stroom door het weefsel warmt deze op.
Er zijn 2 type electro-chirurgie nl. bipolair en monopolair. Het verschil tussen monopolaire en bipolaire electro chirurgie wordt gekenmerkt door het circuit van het stroomverloop.

Monopolair

Bij monopolaire electro chirurgie gaat stroom vanuit de generator via een actieve elektrode door het weefsel van de patient. Hierna gaat de stroom via het lichaam van de patient naar een "return elektrode" (geplaatst op de patient) die het vervolgens veilig terugleid naar de generator.
De patient is hier WEL deel van het circuit!

play animation



Bipolair

Bipolaire chirurgie is het toepassen van hoog frequente wisselstroom waarbij het circuit zich beperkt tot een instrument met twee naastgelegen elektroden (een plus en een minpool). Het stroomverloop beperkt zich tussen deze aangrenzende twee polen.
De patient is hier GEEN deel van het circuit!

play animation

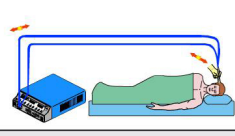


Figure A.1: Theory slide #1

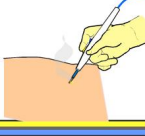
2. Monopolair (functies)

play animation

CUT



100% on



Cut (snijden)

Lage voltage / hoge stroom
sterkte
Constante of kort onderbroken
toevoer van stroom
Temperaturen > 100 C
Verdampen van cellen
Weinig of geen hemostase

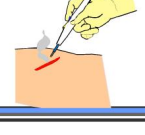
Beschikbare "Cut" golfvormen:
Pure: verzorgt een precieze snede. Er is sprake van een constante toevoer van energie aan de cellen, deze "exploderen" en er is geen of een klein hemostatisch effect.
Blend: verzorgt een "langzamere" snede met additionele hemostase. Er is sprake van een onderbroken signaal waar er tijdens de pauze de cellen drogen wat resulteert in een hemostatisch effect.

play animation

COAG (Fulguration)



6% on



Coag (coaguleren)

Hoge voltage/ lage stroom sterkte
Onderbroken toevoer van stroom
Temperaturen < 100 C
Coaguleren van cellen
Hemostase

Beschikbare "Coag" golfvormen:
Fulg: Er is sprake van een langer onderbroken signaal waar tijdens de pauze de cellen droge. Deze functie coaguleert weefsel door middel van "vonken" die gaan van de elektrode, door de lucht, naar het weefsel!
Spray: Wijzige fulguratie. Groter oppervlak maar minder diepe weefsel penetratie

Slid Mono

Cut	Coag
6	1
Pure	Fulg
Blend	Spray

Figure A.2: Theory slide #2

3. Bipolair

De Bipolaire functie wordt vooral gebruikt voor dessicatie van weefsel. DESSICATIE is een vorm van coagulatie waarbij contact gemaakt wordt met het weefsel en electrode(n). Een relatief kleine hoeveelheid weefsel wordt tussen "klem" van het bipolaire instrument vastgehouden waarna er een continue wisselstroom stroom door het weefsel wordt gestuurd. Hierdoor droogt het weefsel uit. Tijdens dessicatie zijn de elektroden in direct contact met het weefsel en ontstaan er geen vonken.

De beschikbare modi voor de bipolaire stand:

- Low:** Biedt precisie en nauwkeurige controle over de hoeveelheid dessicatie
- Standard:** Conventionele dessicatie instelling met lage voltage
- Macro:** Hogere voltage instelling waardoor er ook bipolair "gesneden" kan worden

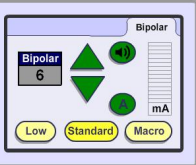


Figure A.3: Theory slide #3

4. Ligasure

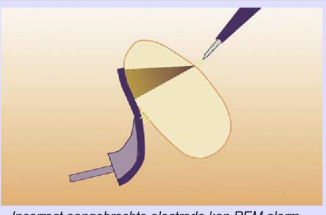
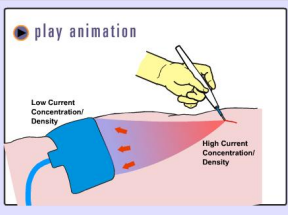
The ligasure is een combinatie van bipolaire electrochirurgie en mechanische kracht. Deze combinatie zorgt ervoor dat een bloedvat "gesealed" kan worden. Het "seal" mechanisme gebruikt lichaams eigen collageen om het karakter van de bloedvatwand te veranderen en om vaatlumen uit te wissen. De Ligasure weefselfusie modus kan worden gebruikt bij slagaderen, aderen en lymfevaten met een maximale diameter van 7mm. Afhankelijk van de diameter kan de instelling voor stroomtoevoer aangepast worden door het drukken op de groene balkjes.



Figure A.4: Theory slide #4

5. REM Alarm

REM staat voor: Return Electrode Monitoring system. Dit systeem meet continu weefsel impedantie (weerstand) tussen het grensvlak van het lichaam van de patient en de "return electrode". Dit alarm gaat af wanneer de contact kwaliteit en/of quantiteit wordt aangetast.



Incorrect aangebrachte electrode kan REM alarm veroorzaken

Voer deze stappen voor het oplossen van een REM-alarm:

1. Controleer de stekker en kabel van de dispersieve elektrode. Bij zichtbare schade dient u de stekker of kabel te vervangen
2. Controleer of de dispersieve patienten elektrode goed is aangesloten op het energieplatform
3. Controleer of de patientenelektrode goed contact maakt met de patient

Figure A.5: Theory slide #5

B APPENDIX: Individual performance results

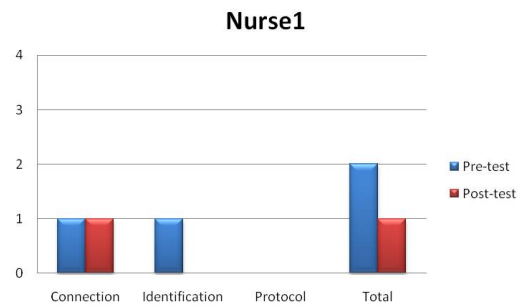


Figure B.6: Errors nurse 1(RT)

PRE-TEST

1 Connection: No adapter placed for monopolar laparoscopic procedure

1 Identification: Did not correctly identify the monopolar laparoscopic cable

0 Protocol:

POST-TEST

1 Connection: No adapter placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

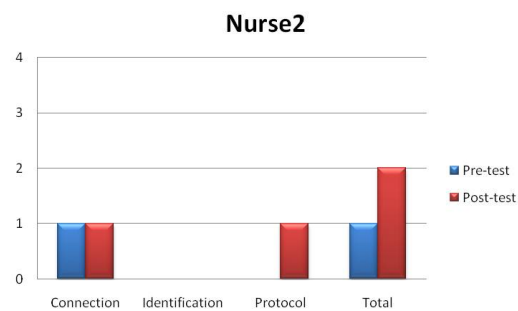


Figure B.7: Errors nurse 2(RT)

PRE-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

1 Protocol: First applying settings than connecting cables

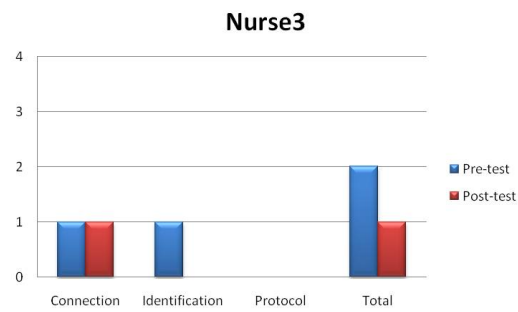


Figure B.8: Errors nurse 3(RT)

PRE-TEST

1 Connection: The bipolar open cable was connected to the wrong port

1 Identification: Did not correctly identify the monopolar laparoscopic cable

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

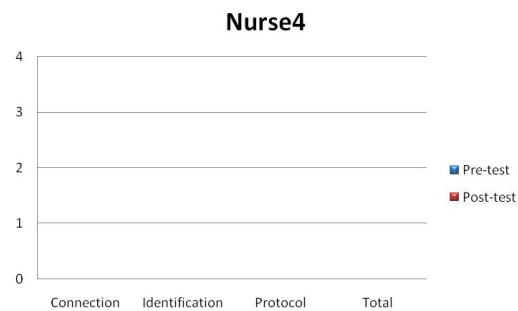


Figure B.9: Errors nurse 4(RT)

PRE-TEST

0 Connection:

0 Identification:

0 Protocol:

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

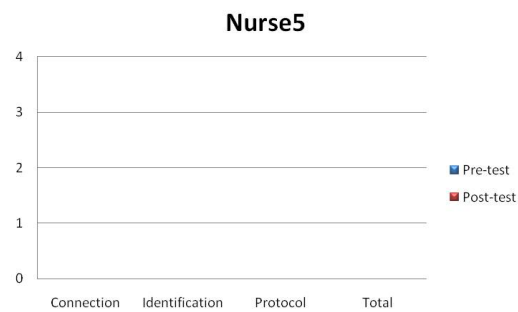


Figure B.10: Errors nurse 5(RT)

PRE-TEST

0 Connection:

0 Identification:

0 Protocol:

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

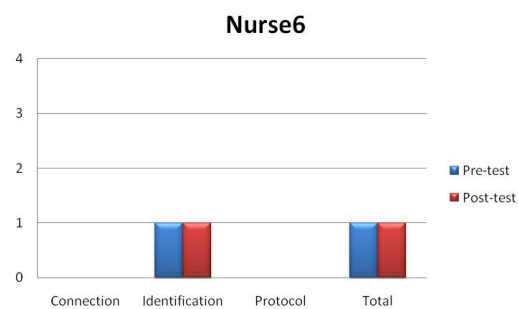


Figure B.11: Errors nurse 6(RT)

PRE-TEST

0 Connection:

1 Identification: The bipolar foot pedal was not correctly identified

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

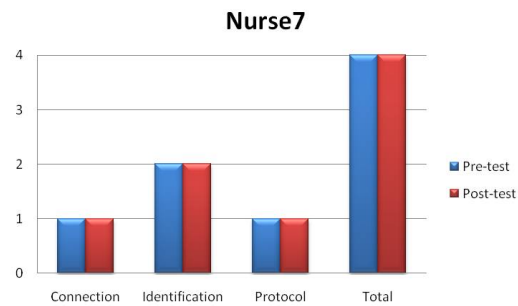


Figure B.12: Errors nurse 7(RT)

PRE-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

2 Identification: The bipolar foot pedal & laparoscopic cable were not correctly identified

1 Protocol: Nurse did not wait for self test to complete

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

2 Identification: The bipolar foot pedal & laparoscopic cable were not correctly identified

1 Protocol: Nurse did not wait for self test to complete

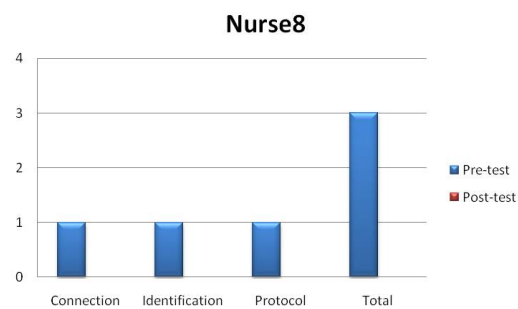


Figure B.13: Errors nurse 8(RT)

PRE-TEST

1 Connection: No adapter placed for monopolar laparoscopic procedure

1 Identification: The bipolar laparoscopic cable was not correctly identified

1 Protocol: Nurse did not wait for self test to complete

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

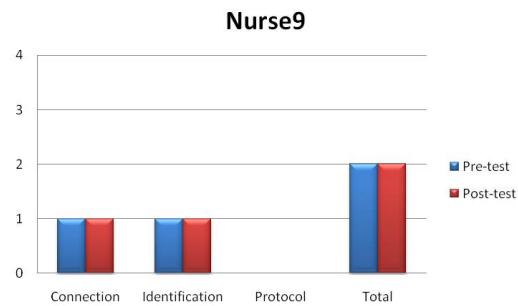


Figure B.14: Errors nurse 9(RT)

PRE-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

1 Identification: The bipolar laparoscopic cable was not correctly identified

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

1 Identification: The bipolar open cable was not correctly identified

0 Protocol:

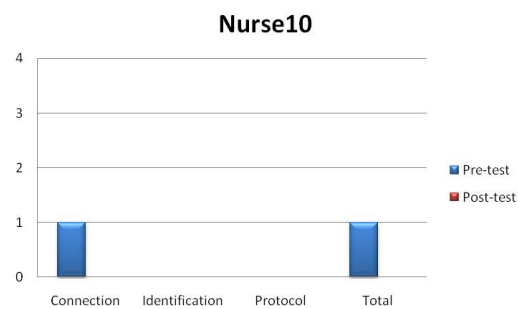


Figure B.15: Errors nurse 10(ST)

PRE-TEST

1 Connection: No adapter placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

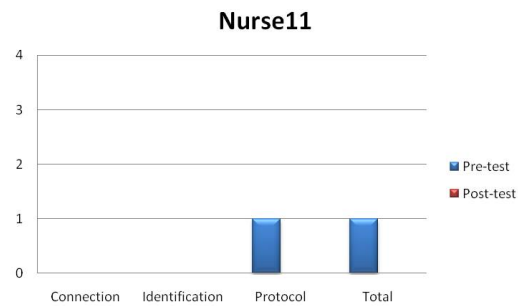


Figure B.16: Errors nurse 11(ST)

PRE-TEST

0 Connection:

0 Identification:

1 Protocol: First applying settings than connecting cables

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

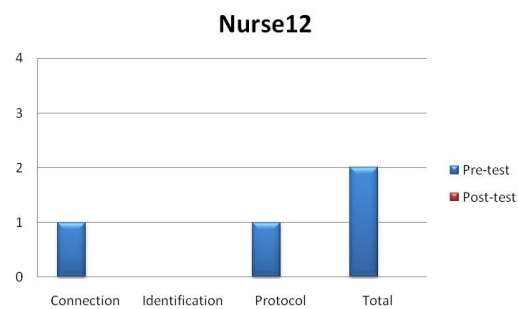


Figure B.17: Errors nurse 12(ST)

PRE-TEST

1 Connection: The bipolar open cable was connected to the wrong port

0 Identification:

1 Protocol: First applying settings than connecting cables

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

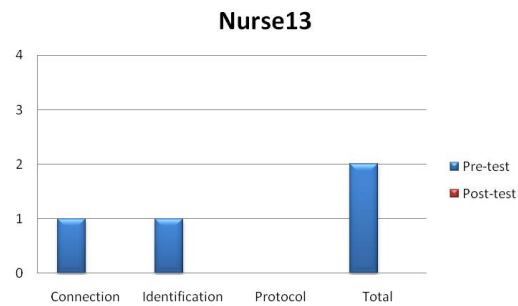


Figure B.18: Errors nurse 13(ST)

PRE-TEST

1 Connection: No adapter placed for monopolar laparoscopic procedure
 1 Identification: Did not correctly identify the bipolar laparoscopic cable

0 Protocol:

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

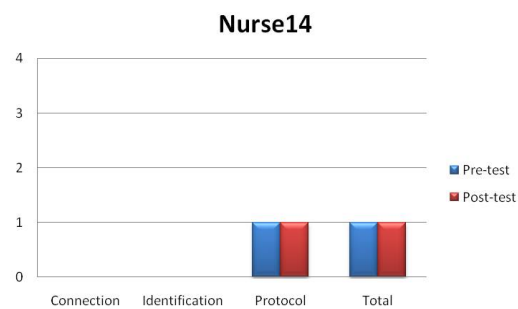


Figure B.19: Errors nurse 14(ST)

PRE-TEST

0 Connection:

0 Identification:

1 Protocol: First applying settings than connecting cables

POST-TEST

0 Connection:

0 Identification:

1 Protocol: First applying settings than connecting cables

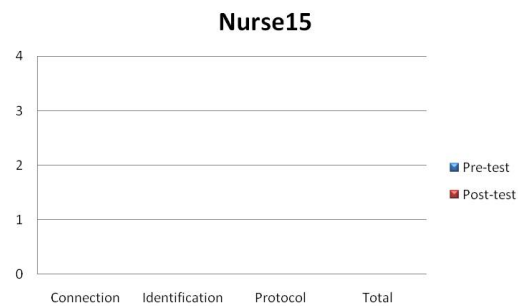


Figure B.20: Errors nurse 15(ST)

PRE-TEST

0 Connection:

0 Identification:

0 Protocol:

POST-TEST

0 Connection:

0 Identification:

0 Protocol:

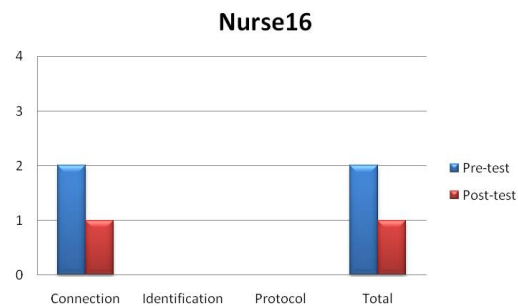


Figure B.21: Errors nurse 16(ST)

PRE-TEST

2 Connection: No adapter placed for monopolar laparoscopic procedure & The bipolar laparoscopic cable was connected to the wrong port

0 Identification:

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

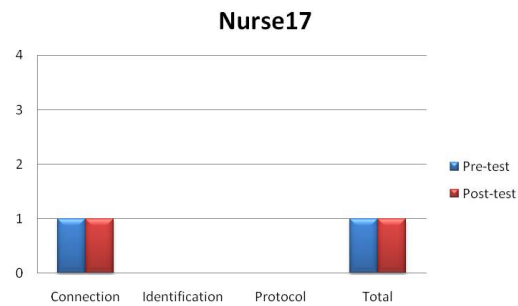


Figure B.22: Errors nurse 17(ST)

PRE-TEST

1 Connection: No adapter placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol:

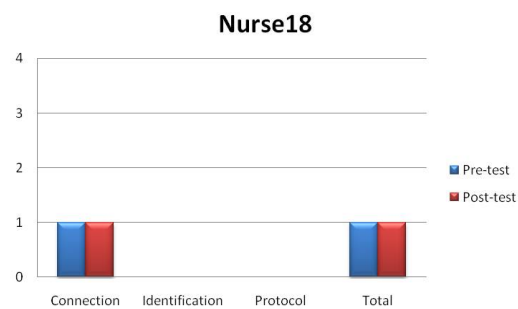


Figure B.23: Errors nurse 18(ST)

PRE-TEST

1 Connection: The bipolar laparoscopic cable was connected to the wrong port

0 Identification:

0 Protocol:

POST-TEST

1 Connection: The adapter was not correctly placed for monopolar laparoscopic procedure

0 Identification:

0 Protocol: