

MSc Thesis in Interaction Design

# Individualising Surgical Training in a Virtual Haptic Environment

Jenny Christensson

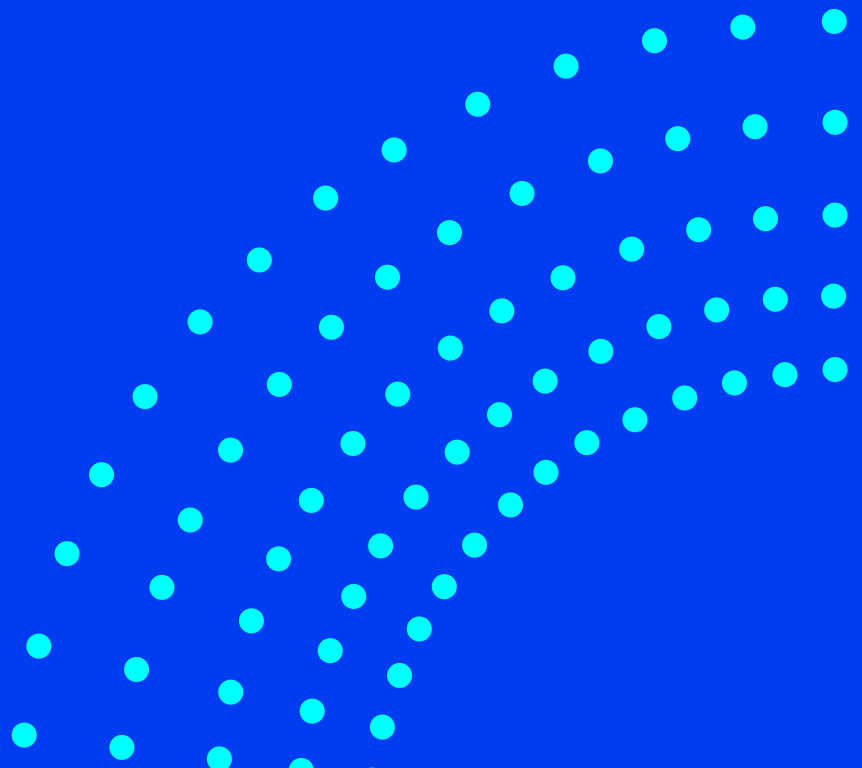
Göteborg, Sweden 2005



IT University  
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Department of Computer Science



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# Individualising Surgical Training in a Virtual Haptic Environment

- Design of flexible teaching strategies to support individuals

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### **ABSTRACT**

Since safety and patient outcome are the most important criteria in surgery, training effectivity should be of primary importance when educating surgeons. Traditional surgical training focused on motor skills has today a number of limitations. Those can be overcome by using computer based training. Using a virtual environment and haptic force feedback, the training environment can be interactive looking like reality. This MSc thesis focuses on how to optimise the learning by individualising the training.

To make the training as effective as possible, the teaching strategy must be best possible. Teaching strategy can be divided into a variable amount of demonstration, instruction and feedback and how this is presented for the user. Today there are no surgical training environment at the market providing individualised adjusted demonstration, instruction and feedback.

Building on arguments from literature, discussions with experts and a product survey, the thesis present how to individualise surgical training in a virtual haptic environment. The thesis suggests and presents how teaching strategies can be designed to be flexible and support individuals. The demonstration, instruction and feedback are designed from knowledge about the trainee, previous result and actual performance. The thesis uses arguments that were found in literature and led to the design of teaching strategies. Further work should have been to include users as a next step in the process.

**Keywords:** Teaching strategies, motor skill training, individualised learning environment, effective and efficiency learning.

## PREFACE

This paper is a master thesis report in Human Computer Interaction and Interaction Design, written for the IT-University of Gothenburg, being a part of Chalmers University of Technology and Göteborg University, Sweden. The writing was done in Sydney, Australia, within the Australia's Commonwealth Scientific and Industrial Research Organisation, science area Information and Communication Technology, CSIRO ICT. CSIRO is one of the world's largest and most diverse scientific global research organisations with 6500 staff members. The focus is on providing new ways to improve Australian quality of life, as well as the economic and social performance of a number of industry sectors through research and development. These sectors are agribusiness; energy and transport; environment and natural resources; health: information, communication and services; manufacturing and finally mineral resources.

The CSIRO ICT Centre contributes to powering Australia to compete in global ICT innovation, applying research results to challenges across all industry sectors, both internationally and in Australia. The aim is to develop an internationally competitive ICT research program that will generate leading-edge ICT solutions. The Centre also cooperate and collaborate with CSIRO researchers across the full breadth of CSIRO science. The Centre has a research staff of around 170.

My interest for CSIRO ICT started when I was browsing Internet looking for interesting project within Human-Computer Interaction and Interaction design. I got in contact with the organisation asking by e-mail if it was possible for me to write my MSc at CSIRO ICT. Eight month later I arrived in Sydney for a four month long stay.

Dr. Christian Müller-Tomfelde was my supervisor at CSIRO and he gave me invaluable input through informal discussions and meetings. Dr. Müller-Tomfelde introduced me to the subject field and has been highly supportative during the work with the thesis. Thank you for everything you taught me, all time you have spent and for being so patient!

I am very thankful to CSIRO ICT, Information Agility Stream and group leader Cécile Paris who gave me the opportunity to write the thesis in a world class science organisation. Being a part of the stream gave me good view over what interaction design is and how it can be applied. Thank you, the whole stream, for taking so good care of me.

Fang Chen was my supervisor at the IT-University in Gothenburg, Sweden. Thank you for assuring the science quality of the thesis and your thoughts and ideas of improvements.

Jenny Christensson

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# 1. INTRODUCTION

The technology is rapidly evolving now days and the affects of how human can use these improvements has effects for the education and training arena in medicine. The ‘future of surgery’ is now but the future of any new technology depends upon how well the training is, i.e., no matter how good the technology is, the overall outcome of surgical performance requires always training and exercise. The literature mentions that the surgeons’ dexterity constitute 25% of a skilfully performed operation, common sense suggest that technical skill does affect the outcome. Today surgical training takes place according to the apprenticeship model which is characterized by a mentor-student relationship in close supervision in a series of one-on-one situations. This model has work well in the past but a number of recent developments and incidents have started to question the model. On the one hand the method is expensive and slightly flexible since the trainer and the trainee is required to be at the same place, at the same time. On the other hand the recent elucidation of the fundamental principles of adult education, which emphasize individual development and a learner-centred approach in an environment, conductive to learning with almost continual high-quality feedback on performance.

In surgical training the focused motor skills belong to the category of implicit knowledge. The learning methods have therefore their respective limitations. Books are not interactive and cannot portray anatomy in three dimensions. Reading is not equal to performing; dexterity as implicit knowledge has to be trained by doing. Training with live animals are ethical problematic, expensive and can not demonstrate the changes resulting from disease as well as the anatomy are not the same as the human. Vitro training models made of synthetic materials are to some extent useful, but it is difficult to maintain a library of models with the important anatomical variations and changes resulting from disease. These models have, as well, limited lifetime because of dissection. The usage of human tissue is, as well as use of animals, ethical problematic and causes problems in respect to legislation. Looking at computer-based training, many potential advantages can be identified. It can be presented looking like reality and being interactive. Since an instructor’s presence is not necessary, the students can practice in a larger span of time and get more total training time. Changes can be made that demonstrate variations in anatomy or disease state. Students could also try different techniques and look at the tissues from perspectives that would be impossible during a real operation.

The thesis suggests a design of a training system in a virtual environment aiming to reach an optimised learning curve when training surgical motor skills. The training system will be based on flexible teaching strategies and individualised instructions and feedback. The aim is to design guidelines for teaching and training strategies of motor skill tasks.

Within the CSIRO ICT, two technologies are available to develop an enhanced haptic training environment for surgical training of motor skills: The Haptic Workbench, (HWB) and the Virtual Document Planner (VDP). Those technologies are used as framework to this study. The study will focus on motor skill training and not consider the mental benefits (or advantages) of the training.

This thesis is based on literature search, product survey and discussions with experts at CSIRO. Since the environment at CSIRO ICT Centre still is under development it was not possible to make a relevant user survey in the relatively short time allocated for doing a MSc thesis

Products on the market today, addressing mostly issues of simulation and interaction devices, but these systems are rarely evaluated out from an educational effectiveness point of view. Those are not supporting individualised training in terms of giving the trainee appropriate instructions and feedback. The products are still expensive and an effective use of the system is recommended. Individualised training is to prefer to receive an efficient learning rate and optimisation of the learning curve.

Chapter 2 is the theory chapter and is aiming to give the reader a wide insight in a number of knowledge fields relevant for a virtual training environment. Chapter 3 summarise the previous chapter and gives a motivation to the used methods, outlined in chapter 4. Chapter 5 is the result of the product survey and chapter 6 discuss the result of chapter 2 and 5. In chapter 7 a proposal to the design of teaching strategy is presented. The conclusion of the thesis is in chapter 8 and finally chapter 9 suggests further work to be done.

## 2. THEORY

The important theoretical background for this thesis is collected from four different domains: Surgery, Training, Virtual Environment (VE) and Intelligent Tutorial Systems (ITS). The framework used is Usability to ensure a design out from usability guidelines. The domains are considered to be the main subject areas of how to learn motor skills for surgery in a virtual environment in an optimal way. The four domains have respective sub-domains. The sub-domains to Surgery are, e.g., decision making respective dexterity. Training has Knowledge, Learning methods and Motor skills; the Intelligent Tutorial System has Virtual Document Planner (VDP) and the Virtual Environment has Virtual Learning Environment (VLE) and Haptic Workbench (HWB) as sub-domain. See Figure 1. The chapters are not consistent to this model but are instead split up according to introduce the reader to the subjects in a reasonable order.

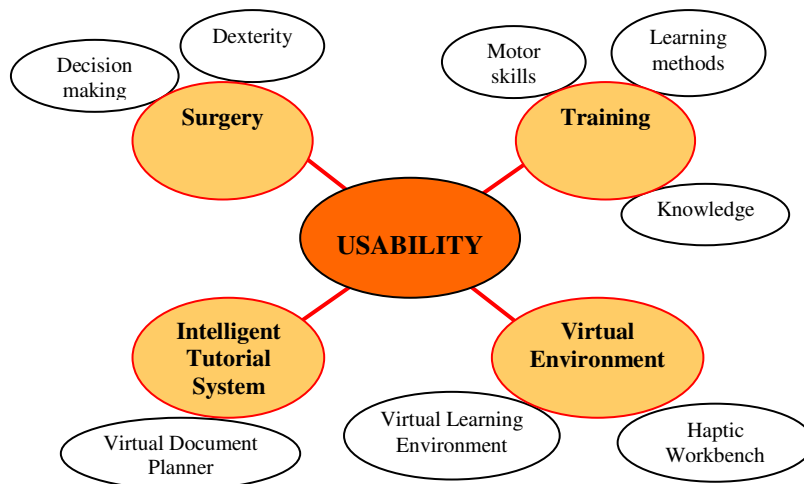


Figure 1. The four domains to consider and there respective sub-domains. There is an overlap between some domains, e.g. dexterity and motor skills, but the thesis aims to use usability as an overall connection or framework. The domains are Surgery, Training, Intelligent Tutorial System (ITS) and Virtual Environment (VE).

### 2.1 SURGICAL TRAINING

Although many factors influence surgical outcome, the motor skills of surgeons in the operating theatre are very important. A skilfully performed operation is 75% decision making and 25% dexterity [2,3]; in some specialties, such as minimally invasive surgery, dexterity becomes even more important. Reduced access, as the surgeons get in minimally invasive surgery, limits perception, increases strain and the likelihood of error, and lengthens procedure time [10,32]. Though surgeons have formal examinations in surgical knowledge, there is no such requirement to show operative dexterity. Instead traditional surgical training is based on an apprenticeship model, where residents learn by watching and participating, taking more active roles in the operation as their experience increases [25]. Surgical procedures are taught on the basis of the mentor's interpretation of current standards, and an objective assessment of motor skills is not considered [11]. Common sense suggests that technical skill does affect outcome [3] and one of the most obvious training needs of laparoscopic residents is the training of manual skills [6]. The 'future of surgery' is now but the future of any new technology depends upon how well the training is [32].

The technology in medicine is rapidly evolving and this has effects for the education and training area. With the introduction of minimally invasive techniques, perceptual-motor relationships become unfamiliar [25]. Direct vision (hand-eye coordination) is replaced by a video image. Because endoscope and instrument positions are continuously changing, the relationship between visual and instrument coordinates also changes continuously. Skilfulness is diminished and kinaesthetic feedback of the interaction forces

between instruments and tissue is also reduced [25]. Tactile sensation, which is especially useful to feel, e.g., hidden lesions or vessels embedded in fat, becomes unavailable. Consequently, there are fundamental changes in the required perceptual motor skills [25]. Because new instruments are being developed at a rapid pace, procedures are also changing rapidly. Simultaneously, new procedures are becoming popular. As an example, the reduced pain, scarring, and recovery times associated with minimally invasive methods have made surgery the treatment of choice for diseases that were most often treated medically [25]. The skills necessary to perform these operations can not be acquired in one or two day courses in the animal laboratory [25], therefore an alternative training environment are necessary.

Graphical and haptic interfaces are used to provide feedback to the operator, may also be used to generate simulations of the operative environment that are useful for training candidates in surgical procedures [14]. Training of skill-based behaviour in laparoscopic surgery is highly desired as laparoscopic combine's unusual hand-eye coordination with the use of complex instruments [6].

Early results suggest that virtual environment simulators have an important role to play in the future of surgical training [14].

## 2.2 MOTOR SKILLS

Motor skill is an action or task that has a goal and that requires voluntary body and/or limb movement to achieve the goal [19]. For instance has the skill of a surgeon has a goal of interaction with organs, tissues and muscles in the proper sequence, appropriate time and with a certain force that requires the surgeons finger and hand movements to achieve the goal. This section gives an introduction of the concept motor skills, a classification of motor skills and finally an overview of three important aspects when training motor skills; goal setting, demonstrations and instructions, and feedback.

### 2.2.1 Concept

The term *skill* has several connotations. Action goal often used in motor learning, means that the skill has a purpose or a goal. Skills are also performed voluntarily, which indicates that in this thesis, reflexes are not considered as skills. However skill-based human behaviour performed tasks can take place without conscious control [6]. Task execution is for an experienced performer highly automated and based on fast selection of motor programs which control the appropriate muscles [6]. The thesis definition of a *skill* is; capability of accomplishing something with precision and certainty; practical knowledge in combination with ability; cleverness, expertness [2]. Also, an ability to perform a function acquired or learnt with practice [2]. A motor skill requires body and/or limb movement to accomplish the goal of the action or task [19] which exclude cognitive skills from this thesis definition of a *skill*. The thesis's main interest is in motor skills that have in common that they need to be learned in order for the skill to be successfully achieved, for example riding a bike, playing the piano, swimming or to perform surgery.

An important characteristic of motor skills, when viewed from a perspective of motor learning and control theory, is that skill is synonymous with the term action [19]. As a consequence, an action can be accomplished in a large number of different ways. If the goal is to stretch the gallbladder from A to B to get a better overview of this gallbladder artery and bile duct to be clipped, there are no exact patterns of movements to the surgeon to achieve this goal, even though some are better than others. The better once are those that give the least damage on other surrounding tissues and gives the surgeon best possible working ergonomic.

Somehow the outcome of an action must be measured in a learning environment. In this use, skill is a qualitative expression of performance [19]. Often this is subjectively determined or compared with others competitors. One way of establish a degree of productivity that would characterize a skilled performer [19] which can be compared with the usability term *efficiency*. Another way of expressing that an individual is a skilled performer is on the basis of certain characteristics of the person's performance [19] which includes the consistency of the performance, anticipating and use of meaningful cues.

## 2.2.2 Classification of motor skills

To be able to present motor learning concepts, motor skills is classified into groups. Classification systems are based on the general nature of motor skills relating to some specific feature of the skills [19]. In the thesis three systems is considered in which motor skill classification is based on: (1) the precision of the movement (which muscles/muscle groups are used); (2) defining the beginning and end points of the movement (when is a task, solved by motor skills, completed); and (3) the stability of the environment (the characteristics to the environment in which the task is performed) [19]. These categories have each sub-category, see Table 1:

Precision of the movement		Defining the beginning and end points			Stability of the environment	
Gross motor skills	Fine motor skills	Discrete motor skills	Serial motor skills	Continuous motor skills	Closed motor skills	Open motor skills

**Table 1. Overview of classification of motor skills and sub-classification.**

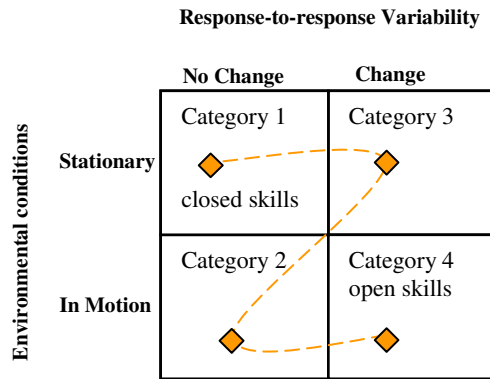
Note that skills can be classified as being more closely allied with one category than with the other without having to fit into one category exclusively.

Classifying motor skills on the basis of *precision of the movement* led to development of two categories: gross- and fine motor skills [19]. Gross motor skills are characterized as involving large musculatures and a goal where the precision of movement is not as important. Fundamental motor skills as walking and throwing are considered to be gross motor skills. Fine motor skills are skills that require control of small muscles of the body to achieve the goal of the skill. Laparoscopic surgery is an excellent example of a task that requires fine motor skills. Other examples are playing the piano, writing or sewing. Generally, these skills involve hand-eye coordination. Classifying motor skills on the basis of precision of the movement is among others often used in education or adapted physical education [19]. From surgery point of view this classification is thus interesting. Most motor skills used in surgery, and in laparoscopic surgery in particular is classified as fine motor skills.

Classifying motor skills on the basis of how clear *defined the beginning and end points* of a movement, are especially popular in motor skills research literature and where motor skills are viewed from a human engineering perspective [19]. The sub-categorization is in discrete-, serial- and continuous motor skills [19]. Discrete motor skills have got clearly defined beginning and end points. Examples are flipping a light switch, depressing the clutch when driving a car or clipping the artery and bile duct to a gallbladder before this is removed. Discrete skills can be put together in serials to reach a certain goal; we then consider the skill to be a serial motor skill. The serial of motor skills required when starting and driving away with a car is a good example, the clutch must be depressed, the key turned, the gear put into first gear and the accelerator must be properly depressed at the same time as the clutch is let out. Another example of serial motor skills is when a gallbladder is removed; the gallbladder is grabbed, stretched and moved. The artery and bile duct must be strangled and than finally clipped. The last sub-classification is continuous motor skills. This type of skill has rather arbitrary beginning and end points. The performer of the skill determines the beginning and end points of the skill. These include skills as running, steering a car or do overall surgery.

*Stability of the environment* is the last classification model of motor skills. The basis for the classification is the stability of the environment in which the skill is preformed [19]. If the environment is stable and predictable, fixed and unchangeable the motor skill is defined as closed. Environments like this are a bowling hall, where the pins stand waiting to be hit, or perform a post-mortem. If the environment instead is temporally and/or spatially changing the motor skill is defined as open. Catching a ball, driving a car or perform surgery can be considered to be open motor skills, based upon that the environment is not stable.

An extension the open-closed classification system is a four-category system [19]. It involves two types of variations from one respond to the next; change or no change; and two types of environmental conditions during the execution of the movement; stationary and in motion, see Figure 2.



**Figure 2. Stability of the environment according to a four-classification system of motor skills and where the diamond shaped squares and dashed line indicates how the system can be seen linear [19].**

The categories in the four-classification system is; (1) the object of the response remains stationary, and there is no change in response requirements from one response to the next. (2) The object of the response is in motion, and there is no change in response requirements from one response to the next. (3) The object of the response remains stationary, and the response requirements change from one response to the next. (4) The object of the response is in motion, and the response requirements change from one response to the next. The system can also be seen linearly, as the orange squares and line indicates. The category one is a closed skill and category four is an open skill, category three is more a closed than an open skill while category two is a more closed skill than open.

Surgery is somewhere between open and closed motor skills. All humans have a basic anatomy but are at the same time individuals. Also an injury that requires surgery has a basic procedure but two operations are not an exact copy of each other. However, from the four-classification system (figure 2), use of laparoscopic surgery to remove the gallbladder is of category 3; the environment is stationary, the gallbladder is located in the abdomen [33], but the response requirements change from operation to operation, the size and shape of the gallbladder (and reason to remove it) is individualized for each case.

The stability of the environment classification has a large degree of popularity in instructional methodology contexts and can also be found in teaching methods of physical education and motor skills learning [19].

With a starting point in laparoscopic surgery and the remove of the gallbladder, the motor skills required can be classified as fine motor skills in serials where the environment is more closed than open; the environment is stationary but the response requirements change from operation to operation.

### 2.2.3 Goal setting

Goal setting is a potent form of motivating achievement in both performance and learning situations of motor skills [19]. Achievement goals can be either master related, where the focus is on improving the skill being performed, or competition related, where the goals are based on comparison with others who are also performing the skill. In general, mastery goals are preferable for most motor learning and performance situations [19]. In terms of surgical training this has the impact that the tasks should not be compared to what others perform, instead the task should be evaluated as successfully performed, or not, out from predefined goals. How reach a goal is planed in a long term plan know as a *strategy* [29].

It is shown that setting performance goals, or challenging goals, can increase performance and be more effective than when no specific goal has been provided or the individual is told to “do their best” [19]. Also, appropriately set goals can increase the likelihood of a person remaining involved in an activity [19] which can be compared to ratio behaviour providing a trainee with enough support and a challenging task at the same time [4]. The goal that an individual will establish in a situation can be related to the person’s achievement orientation and the individual’s past experiences of success or failure in attempting goals.

Setting goals can be critical and some specific guidelines are important to keep in mind when setting goals to assist in effectively using goal setting as a means of enhancing motor skill performance and learning.

Goal-setting guidelines for motor skill learning [19]:

1. Set goals that will enhance skill mastery.
2. Set objective goals.
3. Set goals that are meaningful.
4. Set goals that are attainable.
5. Set goals according to individual differences.
6. Set goals on the basis of past experiences.
7. Set both short-term and long-term goals.

Increase the commitment among the individuals to achieve the motor skill goals by [19, 21]:

1. Explain the benefits of setting goals and of pursuing goals systematically.
2. Do not threaten or intimidate people to set goals at a certain level.
3. Be highly supportive of people striving to achieve their goals.
4. Reward progress and attainment of goals.
5. Provide regular feedback about progress in achieving goals.
6. Help people with their plan of action for achieving goals.
7. Provide clear pre-practice information about the task goal, whether this is a particular movement pattern or a particular outcome.

There is however a difference between the goal to a sportsman and to a surgical trainee. The sportsman can more out from his own wish set a goal to achieve (for example set world record (competitive goal) or run under ten seconds at 100 meters (mastery goal)), if he fail he will still be a sportsman but without reaching his goals. A surgical trainee can not set his own goals in the same way. The overall goal is to be a doctor but to get there he must pass a curriculum and fulfil goals set up by teachers. The curriculum is a plan learning/teaching both in terms *what* to learn but also *how* to learn this (e.g. classroom teaching or practising). If he fails to fulfil the curriculum/reach these goals he will not be a doctor or a surgical trainee for so much longer.

#### **2.2.4 Demonstration and Instructions**

As goal setting and feedback, demonstration and instruction of motor skill learning is critical and very depending upon which type of motor skills is learned. The effectiveness of demonstration and instructions is dependent on the existing skills of the learner and is related upon the type of tasks or skills that are taught [21]. The effectiveness of demonstrations as a teaching tool in motor skill learning has been mixed, it seems to help to highlight the ordering of task components, but not necessary the teaching of movements components [21]. If the task is rather simple, the movement response is not an existing part of the learner's repertoire or the learner has some prior knowledge of the criterion information to be conveyed - instructions and movement demonstrations, which specify the correct or optimal method for performing a skill, have little learning benefit [21]. Demonstration does have a benefit for motor skill performance if the skills are on a higher mental level e.g. dancing, figure skating, because this gives the learner a mental view of the goal to achieve, and is not at a lower muscle level [21]. These lower muscular levels are necessary to ensure quality in the movement response, whereas the higher level is required to shape, plan and guide the movement [21]. Laparoscopic surgery is on lower muscular level and according to the theories presented by Hodges and Franks [21] motor skill demonstration (i.e. the teacher guides the trainee physically) should not have a benefit for learning of motor skills used in laparoscopic surgery. However a demonstration of the task, i.e. *what* to do, not *how* to do it, might be of benefit, depending upon the users pre-knowledge.

If demonstrations are used, the instructor and the learner should be cautious and consider what information is conveyed [21]. This requires an appreciation of the goal a motor skill have, and the understanding that this might be in conflict with other motor skills. In addition, an appreciation of the learner’s existing skills and potential limits in understanding the pre-practice information would also help in predicting what behaviours might be tried, or indeed, avoided as a result of instruction. Demonstrations and instructions for novice are not necessary the same for experts, often they are dealing with different motor problem. To sum up: if demonstration and instructions should be used for motor skill learning it should considering all influence aspects and be done correct, otherwise it will have little learning benefit.

Demonstration and instruction guidelines for motor skill learning [21]:

1. Demonstrations and instructions for novice are not necessary the same for experts, often they are dealing with different motor problem.
2. Demonstrations that are varied in content are recommended to engage observers in the learning process and to inform them of possible solutions to the motor problem.
3. Attention should be directed towards the external effects of the action, rather than the limbs.
4. Instructions that build upon stable, pre-existing movement behaviours early in practice do not facilitate the acquisition of skills that are not part of the movement repertoire.
5. Some individuals may be predisposed to focus attention onto the mechanics of the movement, thus hindering acquisition. For these, the amount of explicit instruction pre-practice should be kept to a minimum.

### 2.2.5 Effect of feedback on motor skill learning

If skill learning shall occur, it is important that the performer of the skill gets feedback [19]. In communications, feedback is a type of message which a receiver transmits back to a source in response to having received a message [29]. There are two types of feedback that can be identified among others. The first one is the performer’s sensory feedback system which is the result of the action that just has taken place. Translated into surgical training this is if the gallbladder is grabbed and stretched, the performer can see what is happening and if he stretch the gallbladder too much; it will burst. The second type of feedback is the one the observer or instructor of performance, provides which is an assessment of the result or outcome, this is called augmented feedback. Augmented feedback can be defined as intensified [2] feedback, i.e. to high light the outcome of an action. The two types have both sub-types [19], see Figure 3.

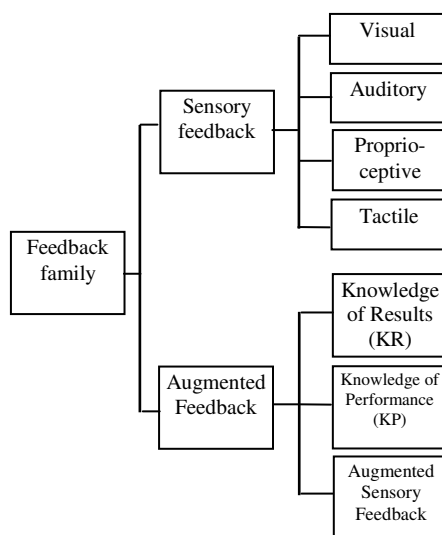


Figure 3. Different types of feedback that is related to learning and performing motor skills [19].

Sensory feedback is given visual, audible, proprioceptive feedback (which is, e.g., how we can tell how much our knee is bent even with our eyes shut [2]) and tactile feedback (the perceptible to the touch; the main tactile qualities are heat, cold, dryness, moistness and hardness [2]). Augmented feedback can be given out from three different focuses. The knowledge of result (KR) tells how hard the gallbladder was stretched or how far the ball was thrown. The knowledge of performance (KP) tells about the movement characteristics e.g. the left arm was held in perfect height or the hand was too shaky. The third type is augmented sensory feedback in which an external device is used to enhance sensory feedback. In a laparoscopic surgery training environment this can be that the surgeon gets a sound feedback when he is pointing or grabbing the correct organ [11, 19].

The augmented feedback plays two roles in learning process; one role is to provide the learner with performance information about the success of the movement in progress or just completed and/or what must be done on a succeeding performance attempt [19]. The second role played by augmented feedback is to motivate the learner to continue striving toward a goal [19]. There is little doubt that augmented feedback plays a critical role in the process of learning motor skills [19, 21]. Bad augmented feedback is worse than no feedback but good feedback is better than no feedback, so the critical part is to give “correct” feedback which varieties from person to person receiving the feedback. There are no clear directions about augmented feedback, the feedback can be essential, not essential, detrimental and an enhancement for learning skills, the effect varies according to the skill being learned [19].

Feedback guidelines for motor skill learning [21]:

1. Provide error information to encourage the trainees to try new behaviours on the next attempt. If no new behaviours are attempted on the basis of intrinsic feedback alone, then some instruction may be necessary.
2. Feedback related to the movement should be as simple as possible and convey important information about the goal attainment.
3. The feedback should be compatible with the pre-practice information.

In the surgical field, there are few textbooks or established methods for teaching fundamental technical skills, so techniques and teaching methods vary among instructors [25].

## **2.3 DIDACTICS LEARNING METHODS**

Learning is the process by which we receive and process sensory data, encode such data as memories within the neural structures of our brain, and retrieve those memories for subsequent use. Didactic is having the character or manner of a teacher or instructor; characterized by giving instructions [2]. Or straight forward: pedagogic.

Surgical training is characterized of a mentor-student relationship in close supervision in a series of one-on-one situations, in which principles and procedures are taught on the basis of the mentor’s interpretation of current standings of practice [14]. This model is also called the apprenticeship model. This model has work well in the past but a number of recent developments have started to question the model [14]. One aspect is the elucidation of the fundamental principles of adult education, which emphasize individual development and a learner-centred approach in an environment conducive to learning with almost continual high-quality feedback on performance [14].

### **2.3.1 Behaviourism versus Constructivism**

Behaviourism respective constructivism represents two theories of learning. As theories both trying to explain the same thing but they are bipolar based on their respective views of how knowledge is acquired and the intervention of tools of learning [59].

*Behaviourism* approaches to psychology based on the proposition that behaviour is interesting and worthy of scientific research [29]. There are different emphases among the behaviourists [29] but from a learning point of view behaviourism is defined as a sequence of stimulus and response actions in observable 'cause and effect' relationships. The concern or emphasis of behaviourism is observable indicators that learning is taking place, the process whereby a human learns to respond to a neutral stimulus in such a manner that would normally be associated with an unconditioned stimulus [30]. A classical example on behaviourism is Pavlov's dog.

The theory concept is directed instruction, whereby a teacher is providing the knowledge to the students either directly or through the set up of contingencies [30]. Exams are used to measure observable behaviour of learning and the use of rewards and punishments are in line with behaviourism. Contrasting this view of learning is the emphasis of cognitive psychologists who equate learning with the mental processes of the mind - Behaviourists do not deny the existence of these mental processes, but they acknowledge their existence as an unobservable indication of learning [30].

*Constructivism* is a cognitive learning theory because of its focus on the mental processes that construct meaning [30]. The theory holds that knowledge is not transmitted unchanged from teacher to student, but instead that learning is an active process [29]. According to constructivism, learning is essentially interactive; knowledge (or knowing) does not arise solely from the entities of the environment nor from the learner but from the interactions between them [24]. Constructivism tries to improve the behaviouristic theories and claims that the design of instruction must be undertaken with suitable attention to the conditions under which learning occurs [30]. With reference to the learner, learning conditions are both external and internal. These conditions are in turn dependent upon what is being learned. Constructivist learning theory is focusing on the motivation and ability for humans to construct learning for themselves and in groups; in opposite to behaviourism which is teacher centred and focus at the individual [30].

Constructivists believe that all humans have the ability to construct knowledge in their own minds through a process of discovery and problem-solving. The extent to which this process can take place naturally, without structure and teaching is the defining factor amongst those who advocate this learning theory.

Traditional surgical learning environment builds upon the apprehension model [28], which is inspired by behaviourism. A view that is emerging from constructivist theories of learning emphasises four aspects as holistically coexisting in any learning process [24]; (1) context, an essential part of what is learned is the situation in which learning takes place, which refers to the physical as well as to the social environment in which the learner is engaged in activity, and might include physical entities, tools, and other people. (2) Activity, all knowledge is constructed by the learners through actively interacting in situations in which they experience a domain and interpret their own experiences. (3) Cognitive structures, previously constructed knowledge influences the way learners interpret new experience and affects their thinking and acting. (4) Time-extension, the construction of knowledge occurs over time from the learners' attempts to connect their previously developed experiences to the new ones.

To take these four aspects into consideration in a holistic way means to assume inseparability between context, physical and psychological phenomena, and the flow of experience, in order to understand learning [24]. It implies a focus on the relationships that develop between these four aspects in a process of learning, rather than on their independent characteristics. Support for this view is found in recent research on education that has pointed to the need for developing theoretical frameworks in which psychological and environmental aspects are integrated [24].

Training of motor skills in a haptic environment dominates of a constructivistic learning approach. For this thesis which aims to have with usability as a central point, motor skill training is definitive more towards a constructivistic approach than a behaviouristic. Motor skills are something that must be learnt "by doing" (constructivism) and require motivation from the learner (also constructivism) to be performed.

### **2.3.2 Implicit knowledge versus explicit knowledge**

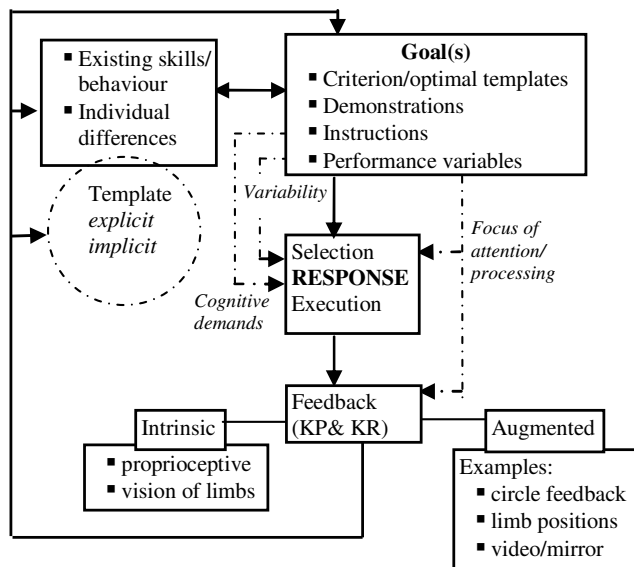
Explicit knowledge is knowledge that can be easily expressed in words or numbers, and can be shared through discussion or by writing it down and putting it into documents, manuals or databases. Examples might include a telephone directory, an instruction manual, or a report of research findings.

Implicit knowledge, also called tacit knowledge, is the knowledge or know-how that people carry in their heads, the silent knowledge. Compared with explicit knowledge, implicit knowledge is more difficult to articulate or write down and so it tends to be shared between people through discussion, stories and personal interactions. It includes skills, experiences, insight, intuition and judgment. Some authors draw a distinction between implicit and tacit knowledge, defining tacit knowledge as that which cannot be written down, and implicit knowledge as that which can be written down but has not been written down yet. In this context, explicit knowledge is defined as that which has already been written down.

Experts in different fields often refer to “the right feeling”. They can not always explain why they take the decisions they do or act in a particular way, it just “feels right”. An everyday example, that is relevant for most people, is to try to explain how you do to tie a shoe. This is implicit knowledge; you “have it in the bones”. For the experts in surgery, training over long time has made them good in what they do. They have trained their motor skills over and over again. This is comparable with an excellent musician; the implicit performance is by many called a piece of art.

Implicit and explicit knowledge can also be applied on motor skill learning. Explicit processes are directed towards goal attainment and developing the appropriate mapping between the learner and the task [21]. Implicit processes concern the acquisition of the appropriate force-generation patterns that enable efficient movement production [21]. Pre-practice information focuses the trainee on being explicitly aware of certain aspects of the task. These aspects may relate to the movement response characteristics, or to key markers necessary for successful goal attainment.

Figure 4 illustrates how the process of skill acquisition is influenced by various performance goals that serve to act upon the response, both its selection and execution and associated processing of feedback. The goals, in turn, are influenced by pre-existing movement skills and the result of practice attempt. Both an explicit and implicit representation of the task is believed to develop with practice, with the implicit representation encompassing pre-existing movement habits and skills, and the explicit representation having a more direct influence on the choice and perception of the task goal.



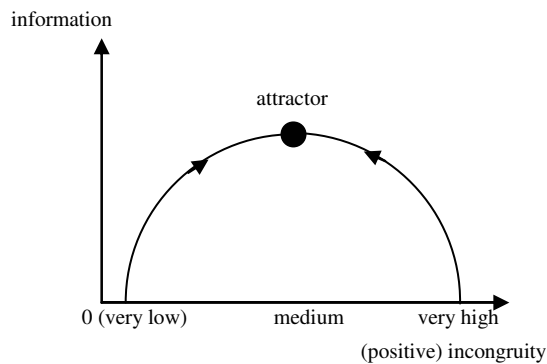
**Figure 4.** Flow diagram to illustrate how the process of skill acquisition is influenced by various performance goals. Dashed arrows are postulated mechanisms underlying the effects of various performance goals. Feedback is given by knowledge of performance (KP) and knowledge of result (KR) [21].

For learning systems that interact with their environments, the more primitive concept of ‘variety’ will have to be used, instead of probability (likelihood of being realized [2]). Humans have a fundamental need for variety [4]. A task to be learned e.g. a motor skill, needs to be practiced and iterated many times but to accommodate the learners need for variation small changes in the task approach or task context can help to keep the motivation and interest up.

### 2.3.3 Incongruity

The aim with learning system is to be as effective as possible. Research on student learning has shown that students must construct knowledge themselves to learn most effectively [5]. In interactive learning environment there is need for variety, this in relationship between a learning system and its context can be expressed as incongruity [4]. Incongruity is the relationship between internal complexity of a learning system and external complexity of the context [4]. The optimal incongruity level depends on the complexity of the cognitive structure [4].

The optimal incongruity is reached at the top of a reversed U-shaped function; see Figure 5 [4]. The optimal area for learning is the sphere around the attractor point. If the complexity is too high for the trainee, he will drop to left of the optimal position. If the complexity gets too low, the trainee will get bored and drop to the right. In both case the incongruity must start to increase. This can be done on two different ways: (1) increasing the complexity of the context or the perception of it, and/or (2) reducing the complexity of the mental model [4].



**Figure 5. The summarized coherence between positive incongruity and information [4].**

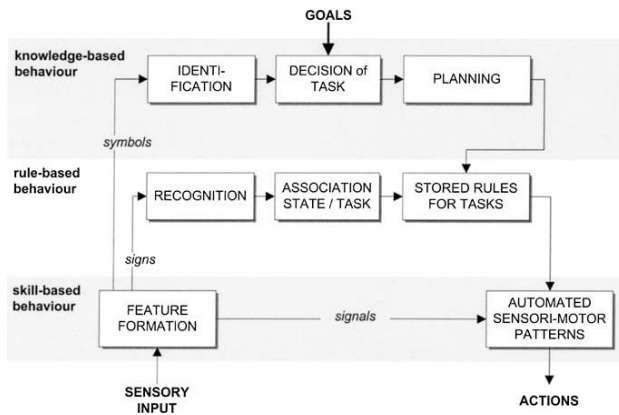
The attractor point is at all times dynamic and individualised for each trainee. The trainers experience of what is too high respective too low complexity changes all the time with as more knowledge the trainee adapt, which is highly individualised. The challenge for the learning environment designer is than how to individualise a system and how to measure if the trainees is at the attractor point at all times.

### 2.3.4 Skill-Rule-Knowledge model

The Skill-Rule-Knowledge model (SRK-model) was proposed by Rasmussen in 1986. He developed the model in the context of system engineering to control complex processes by mapping them in a simple manner in a display.

Effective training ensures that all training objectives are met, efficient training ensures that the training means are cost effective and that the required training time is minimized [6]. Since safety and patient outcome are the most important criteria in surgery, training effectivity should be of primary importance [6].

Rasmussen classifies the human behaviour into three levels; skill-, rule-, and knowledge based behaviour, see Figure 6. As much as in conventional surgery, the laparoscopic surgeon must effectively combine the three levels of behaviour.



**Figure 6. Human behaviour model of Rasmussen with three levels of human behaviour: skill-, rule-, and knowledge-based behaviour [6].**

Instrument handling and dissection techniques require skill-based behaviour. Skill-based behaviour represents human behaviour that takes place without conscious control [6]. Task execution is highly automated at this level of behaviour and is based on fast selection of motor programs or motor skills which control the appropriate muscles.

The recognition of human anatomy is rule-based behaviour [6]. During surgery task, execution is controlled by stored rules or procedures. These may have been derived empirically from previous occasions or communicated from other persons' expertise as instructions.

In unfamiliar situations, faced with a task for which no rules are available from previous encounters, human behaviour is knowledge based [6]. Complications such as uncontrollable bleeding or unsuspected situations such as the encountering of aberrant anatomy require problem solving on a knowledge-based level. During knowledge-based behaviour the goal is explicitly formulated, based on an analysis of the overall aim [6].

### 2.3.5 Collaboration model and CSCW

Computer supported cooperative work (CSCW) is a research area that aims to support use of computing and communication technologies to assist group and organizational activity in terms of location and time [22]. The important features of CSCW systems are the mode of interaction they support and the geographical distribution of the users [39]. Table 2 shows the different alternatives in which context people communicates.

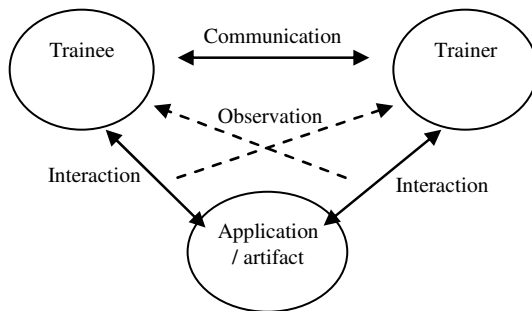
<i>CSCW model</i>	Same time	Different time
Same place	Face-to-face	Asynchronous interaction
Different place	Synchronous, distributed	Asynchronous, distributed

**Table 2. CSCW model for human communication [39].**

The mode of interaction can be either asynchronous (occurring at different times) or synchronous (occurring at the same time), and geographical distribution can be local (the users are co-located in the same environment) or remote (the users are at different locations) [39]. The model can be interpreted in terms of education and learning; synchronous-local, i.e. same time, same place is classroom education. For

synchronous-remote, i.e. same time, different place is education supported by shared editors or video. Asynchronous interaction, i.e. different time, same place is distinguished by self-studying and project reports and papers. Finally asynchronous-distributed communication, i.e. different time, different place is supported by e-mail, note boards and other tools that help the teacher to follow up the learner. Surgical training, in particular motor skill training, is today dominated the apprenticeship model, by face-to-face training. This is both times consuming and not optimal out from an effective point of view (see session 2.1). Training of motor skills in a virtual haptic environment has no requires to take place in any particular of above mentioned context which make the environment very flexible. The training can take place in an asynchronous, distributed mode when the trainee and the trainer have not to be at the same place at the same time.

The collaboration model was born in the artificial intelligence field and later on modified to be, among other things, a software component that mediates the interaction between a software interface agent and a user [23]. In the thesis the model is a little bit modified and used with the components trainee, trainer and application (instead of user, agent and application [23]). The communication stream is not changed. Figure 7 shows the collaboration model as it is used in traditional education (where there is an interaction included) and surgical training. Later on the model will be discussed from a virtual environment training point of view.



**Figure 7. Collaboration model adapted to surgical training environment.**

The collaboration model can be used in all stages of the computer supported cooperative work (CSCW) model. The collaboration model used in a virtual training environment, can take place in the same or different location, at the same or different time, i.e. it can be both synchronised and asynchronous. In terms of surgical training, the effect of this learning method is that the training must not be according to the traditional apprenticeship model [25] where the education takes place synchronous, instead the learning gets more flexible in terms of time and geographical distance. The trainee can, in a virtual environment, perform his tasks and the trainer can make the assessment asynchronously.

## 2.4 VIRTUAL ENVIRONMENTS OF TRAINING

Virtual environments (VE), also sometimes called virtual reality, describe an [environment](#) that is simulated by a [computer](#) [29]. Most virtual environments are primarily visual experiences, displayed either on a computer screen or through special [stereoscopic goggles](#), but some simulations include additional sensory information, such as sound through speakers or haptic feedback [29].

Users can often interactively manipulate a VE, either through standard input devices like a [keyboard](#), or through specially designed devices like a PHANTOM haptic devise or a [cyber glove](#). The simulated environment can be similar to the real world; for example, in simulations for pilots and training of surgeons, or it can differ significantly from reality, as in VE games [29]. In practice, it has for a long time been very difficult to create a convincing virtual reality experience, due largely to limitations on processing power [29], but in the growth rate of developing of processors VE is steady evolving.

The field of surgical knowledge is becoming increasingly complex: more pathology become candidate for surgical treatment and more specific techniques for these cases are being developed. Development of the virtual environments, from scientific prototype to affordable technology that now starts to reach the market.

Two practices in conventional surgical learning are recognized [7]; (1) a daily working relationship is established between the experienced surgeon and the trainee. This places an unrealistically high time load on both the surgical expert and the trainee. (2) Surgeons signal new techniques and decide to implement these techniques in their own practices. A steep learning curve is moved on the patients.

The disadvantages of both training methods could be overcome using Virtual Learning Environments (VLE) in surgical training [7]. A virtual learning environment is a designed information space and integrates a variety of tools supporting multiple functions as information, communication, learning and management [37]. VLE, especially those who are web based, have three main components: a schedule of activities, a set of communication resources and a repository of learning material [38]. Also a VLE contain obvious affordances for collaborative learning [37].

A constructivistic approach, in which the trainees are free to explore the material presented in non-linear ways, might prove beneficial to a deeper understanding of the material presented [7]. Simulators are an ideal environment to train tasks that are too dangerous to be performed in the real world (such as complex surgery) and simulators can be efficient by presenting a wide variety of scenarios in an optimal order for learning [31]. Supporting knowledge representation, reasoning, and decision making in intelligent systems, that are attuned to the values of constructivist views of learning, point to the importance of the context of learning, stress that learning involves active interaction, and emphasise the *process* rather than the product of learning [24]. This approach enables the learning environment to be evaluated according to four properties of constructivist learning processes [24]; (1) cumulateness, which adds elements of previous experiences and current experiences are interpreted in the light of previous ones. (2) Constructiveness refers to new information that is perceived and interpreted by the trainee in a unique way, must be elaborated and related to other information in order that it can be learned. (3) Self-regulatedness, which is the aspects of the learning experience that are analysed and used to drive the trainees' actions. (4) Reflectiveness which involves the trainees being aware of the process by which they are developing activities, and to take this process as the object of their thinking. The VLE is time effective since the trainee can practice without an experienced surgeon to be present and the experienced surgeon can follow several trainees at once, the training can be, according to the CSCW model (see session 2.3.4) asynchronous. Cases where new surgical techniques are to be used the surgeons can practice how to perform the operation before apply it on the patient.

However, the educational value of the simulation will require assessment, and comparison to current available methods of training in any given procedure [14]. It is also necessary to determine, by repeated trials, whether a given simulation actually measures the performance parameters it purports to measure [14]. This raises the question on what constitutes good surgical skill, and how to objective measure this.

Many experimental and commercial prototype environments for training have tried to simulate entire operations, resulting in low fidelity in each of the component tasks comprising the operation [25]. This is an inefficient and probably ineffective approach [25]. It is relatively easy to learn most steps of a procedure by watching and participating according to the *see one, do one, teach one* strategy where medical students, that practical clinical procedures are learned by first observing it, then performing it, and then finally teaching it to another [35]. In every procedure, however, there are a few key steps that are more likely to be performed incorrectly and to result in complications [25, 34]. The significance of these steps might not be obvious, even to an experienced surgeon, until situations arise such as unusual anatomy or uncommon manifestations of disease. The value of a surgical simulator is analogous to the value of a flight simulator. In current practice, pilots are certified to fly by confronting simulated situations, such as wind shear or engine emergencies, that happen only once in a lifetime, if at all [25, 34]. A surgical simulator should train surgeons for the principal pitfalls that underlie the major technical complications. Such training an assessment could be used by medical schools, health administrations, or professional accrediting organizations to enforce standards for granting surgical privileges and for comparing patient outcomes with surgeon skill [25].

### 2.4.1 Haptic

The term *haptic* is relating to the sense of touch or tactile sensations; having a greater dependence on sensations of touch than on sight, especially as a means of psychological orientation [2], *haptic* means pertaining to the technology of touch [29]. The term *haptics* is referring to the study of touch and tactile sensations, especially as a means of communication [2]. One of the earliest forms of haptic devices is used in large modern [aircraft](#) that use [servo](#) systems to operate control systems [29]. The system provides *haptic feedback*, a force that would be felt in actual operations [29]. Since the objects being manipulated do not exist in a physical sense, the forces are generated using haptic (force generating) operator controls [29].

The underlying processes of relevance to haptic training include mechanisms such as kinesthesia and proprioception, which mediate our haptic interaction with the world [28]. Kinesthesia is the human sense of position and movement, which is created from proprioceptive cues arising from receptors in the joints and muscles. Kinesthesia is crucial in haptic training, because this is the information pathway in the perception of incoming stimuli [28]. Haptic training can be used as motor skill training [28]. Another important aspect is kinesthetic memory or implicit knowledge which is the ability to remember limb position, velocity, etc [28]. It is shown that humans have a very good ability to remember positions of their limbs quite accurately and for long periods and this ability to remember motor patterns that is exploited by haptic training [28].

Haptic training is different from visual training in the sense that training occurs in body centered, or motor, coordinates as opposed to visuospatial coordinates [28]. This may be especially helpful when learning motor tasks with complex kinematics, where a haptic presentation removes the need for complex sensor motor transformations [28]. This approach may also be useful for complex, three or more dimensional, motor skills that are difficult to explain and describe verbally or even visually [28]. The term *learn-by-doing* is representative here. An example is to tie shoe laces “can not” be explained, it must be experienced. In particular tasks that are hard to find a metaphor for when explaining visual or verbal can have a benefit of haptic or learn-do-doing training. This may explain why, for some learning, physical practice is better than observational learning. Studies have shown that haptic training in combination with visual perception creates the most effective training (with respect to position and shape measures) [28].

Haptic technology creates a sense of touch in a multi-modal media. The technology relates to an apparatus and software cooperatively providing a haptic virtual environment wherein a user may create an object which is converted into a virtual object with graphics/animation hardware and software and can be “touched” using a haptic device. The object can be manipulated via configurable view-ports allowing the object touched to be modified such that a user can create a wide variety of volumetric objects with a wide variety of characteristics, for example stiffness and friction, without having to resort to generating code.

Haptic training is used for medicine and surgical training (Mentice and Reachin, Sweden; SensAble, Novint Technologies and Immersion, USA; et al.), Flight simulators (SensAble), Teleportation (SensAble), Oil and gas (Reachin, Novint Technologies), Gaming (Immersion; et al.) Molecular modelling and nano-manipulation (SensAble), and is a rising technology in the Automotive Industry and Digitizing (Immersion; Novint Technologies).

### 2.4.2 Haptic Workbench

The Haptic Workbench (HWB) is stereoscopic workspace which combines stereo images, co-located force feedback and 3D audio to produce a small-scale hand immersive virtual environment system [8]. The user is allowed his/her hand in the same apparent volume as computer-generated 3D graphics, providing direct correspondence between the 3D input and the 3D output volumes. The HWB arose in the early 1980s from the needs of application users to work with objects and data in a fundamentally three-dimensional manner [8, 27].

The initial approach of a Workbench used by Schmandt created in the early 1980s [27], see Figure 8, is rather similar to the HWB existing today at CSIRO.



**Figure 8. A sketch from Schmandt of his Workbench. A cutaway view of the work station, showing the view through the half silvered mirror of the video monitor and the user's hand [27].**

The initial approach is a conventional frame store is used for 3D display, with left/right eye views interlaced in video and viewed through PLZT shutter glasses. The video monitor is seen reflected from a half silvered mirror which projects the graphics into a workspace, into which one can reach and manipulate the image directly with a “magic wand”, a Polhemus magnetic six degree-of-freedom digitizer developed by Polhemus Navigational Sciences. The wand uses a magnetic six degree-of-freedom digitizer. In an alternative configuration, a graphics tablet was placed within the workspace for input intensive tasks.

CSIRO's Haptic Workbench has replaced the “magic wand” with a PHANTOM 1.5 haptic force feedback device, a robotic arm from SensAble Technologies Inc., the Polhemus magnetic six degree-of-freedom digitizer is replaced with a Polhemus FASTRAK tracking system with both a stylus and a standard receiver, and the “Virtual Workbench” is from the Systems of Science, National University of Singapore [8]. The glasses used are 150 Hz stereo shutter glasses.

A haptic software toolkit, Reachin API is used which is a C++ application programming interface for creating multi-sensory application [45] Reachin API handles complex calculations required for the touch simulation and the synchronization with graphic rendering [45]. It is based on a scene-graph that borrows a lot of its structure from VRML (virtual reality makeup language) and addresses the issues in designing a multi-threaded programming environment that integrates haptics and graphics [8].

### **2.4.3 Disadvantages with surgical training in VE**

Virtual simulators for surgical training are still under developing. At present, most commercially available simulators enable training in a single task only and it has not yet been determined whether this feature enhances learning on such simulators [14]. Haptic feedback adds substantially to the cost and complexity of a simulator, and some institutions may have difficulty in justifying such gross expenditure on a simulation of a single task, particularly when it has not yet been demonstrated to be of any greater benefit than cheaper and more accessible, low maintenance alternatives [14]. Many of the surgical simulators described in the contemporary literature, or those available commercially, have been fully validated in adequate trials [14]. Indeed, there are currently no broadly accepted guidelines for the validation of simulators, partly because there is no consensus on useful performance parameters, and no way, at present, to relate performance to ultimate outcome [14].

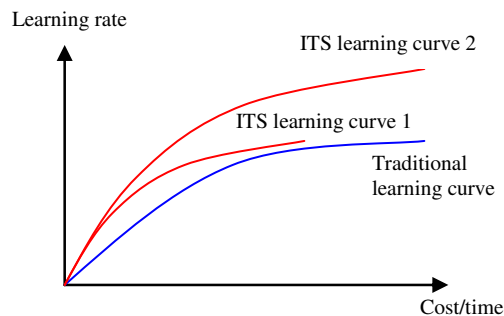
From a learning point of view it is also important to consider the risk of negative transfer of training. Transfer of training refers to how well the learning that has occurred in one environment, such as training in simulators, enhances performance in a new environment [31]. Negative transfer occurs when task performance in one environment cause performance to be worse in the second environment, as compared to performance without the prior experience [31]. This seems to occur most frequently when the two simulations have highly similar stimulus (i.e. display or environmental) cues, but different response are required [31]. For a haptic training environment where the main profit aims to be training of motor skills, the avoidance of negative feedback is rather critical and demands the environment to be adoptive to the

reality. The haptic input or response to a certain stimuli must be identically or very like the reality. The stimuli or graphical representation of the task is then, according to this theory, less critical.

## 2.5 INTELLIGENT TUTORIAL SYSTEMS

Intelligent tutorial systems (ITS) are sprung out from artificial intelligence (AI) and the adoption of a human tutor as an educational model in the early 1970s [22]. ITS have a tutorial task to achieve, where the definition of a *task* is part of a set of actions which accomplish a job in the sense that “useful work is getting done” [29]. A *tutorial task* is a set of action that provides learning and a *domain task* is a set of action in a specific subject field. Intelligent systems to support learning have emphasised the use of AI in education with three main purposes: representation of the knowledge to be learned, inference of the learner’s state of knowledge, and planning of instructional steps to be followed by the learner [24]. The goal of ITS are to enlarge the students in sustaining reasoning activity and to interact with the student based on a deep understanding of the students behaviour [22]. Personal human tutors provide a highly efficient learning environment and have been estimated to increase mean achievement outcomes but, unfortunately ITS have had relatively little impact on education and training in the real world [22]. There are several reasons for this lack; the systems are expensive but the main reason might be that ITS are developed in the AI environment and not among education specialists [22]. Intelligent tutorial systems are therefore, so far, generally evaluated out from artificial intelligence criteria and rather than with respect to cost/benefit analysis of educational effectiveness [22].

The essential measure of educational effectiveness is learning rate as a function of cost [22,60], see Figure 9.



**Figure 9. Traditional learning cost compared to learning cost with use of ITS. Cost/time is in terms of efficiency, how much effort the trainee must uses to reach a goal. Graphical visualisation of reference 22, how to increase learning.**

Educational software environments are effective to the extent that they enable students to increase learning efficiency by (1) reach higher achievement levels in the same amount of learning time or to (2) reach the same achievement levels with less learning time [22,60] (see Figure 9). There is also important to consider that the ITS are not only used by students, teachers are also users [22]. Teachers should be able to author the learning environment by entering new problems, structure the curriculum, request report of the state to the student, etc. It is important that concern usability goals for the teachers as well as the student. To make computer mediated learning more flexible, teachers should have possibility to administrate the system, according to the CSCW model, asynchrony.

Research on student learning has shown that students must construct knowledge themselves to learn most effectively [5]. Use of an ITS support this when the ITS can be designed to give different types of instruction and feedback in different situations. An appropriate *strategy* should be used, a long term plan of action designed to achieve a particular goal [29]. An experienced human tutor balances on the line between allowing the trainees to perform as much as possible themselves and providing the trainees guidelines to

keep them from losing the grip. For an ITS to imitate these successful tutors, it must support [5]; (1) unconstrained natural language input and (2) extended tutorial strategies; when the tutor constructs a plan it does not have an accurate model of the student, the tutor might plan to teach a trainee some information but later on finds out that the trainee knows it. Then the plan must be modified. A computer tutor must also be able to deal with [5]; (1) failure – the tutor may not understand a trainee response, the trainee may answer a question in an unexpected manner or the tutor’s teaching tactic may not be working. (2) Interruption – the trainee may be interrupted with a question. (3) The need to revise tactics – the trainee may skip steps in an explanation (or series of sub-tasks). (4) The need to disambiguate student meaning. Reactive planning techniques from robotics can be used to allow modification of tutorial plans and adapting them to student input [5].

To analyse the use of teaching strategies in a tutorial dialogue system, three dimensions are used; extent, generality and representation [5]. By extent is meant: do the tutorial strategies extend solely over single turn, multiple turns or both. A teaching strategy is specific to a domain if it is not separate tutorial knowledge from domain knowledge. To explain the generality and representation of the teaching strategies, the notion of curriculum script needs to be introduced. The curriculum script is a sequence of topic formats, each of which contains a main focal question and an ideal complete answer [5]. The ideal complete answer consists of several sub-answers, called aspects. Tutorial planning is concerned with constructing effective tutorial dialogue from a set of strategies [5].

### 2.5.1 Virtual Document Planner

While the Haptic Workbench enables users to interact with the simulation of tangible objects, the Virtual Document Planner (VDP) is used to support the user interaction in the training environment [9]. The interaction of the user with the simulation is captured and the VDP delivers appropriate information to help and assist the user. Such a system can be characterized as an intelligent system and, in the special case of training, as an intelligent tutoring system.

The Virtual Document Planner was originally designed to produce documents dynamically, by integrating several data sources and customizing the content for a user [9]. The planner has been extended to handle both textual and graphical information. The architecture used is a typical Natural Language Generation (NLG) architecture, where the linguistic resources are separate from the engines [9], e.g., the resources are domain specific but the engine is general and not depending upon in which context (domain) it is used. A *communicative goal* (or *discourse goal*) is given as input to the document planner. The communicative goal is to answer an information need of the user. The planning engines then strive to achieve this goal, using sets of discourse, and design rules, using traditional goal/sub-goal decomposition. This approach uses *rhetorical relations*, based on the Rhetorical Structure Theory (RST) and guarantees coherence behaviour, e.g., between parts of a text [9].

The Virtual Document Planner can be used in a Tutorial System or as an Intelligent Tutorial System on its own. Used in motor skill training with the aim to optimise the learning curve the ITS can have a basic architecture shown in Figure 40.

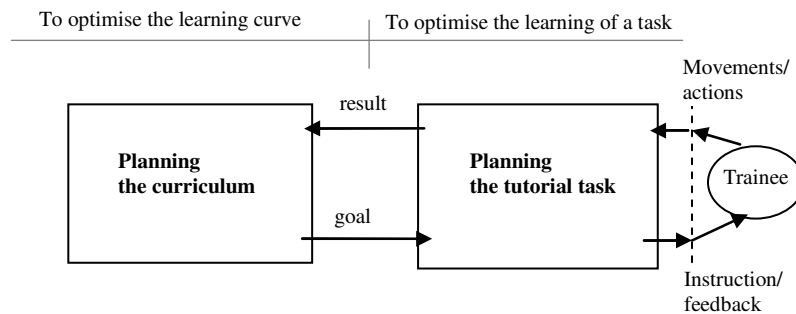


Figure 10. Intelligent Tutorial System in motor skill training where the aim is to optimise the learning curve.

The VDP can be used beyond the original use to plan the curriculum and the domain task and the tutorial task so that coherence emerges and support for the training. Figure 10 illustrates that in motor skill training there are two types of intelligence tutorial systems involved; (1) Planning of the curriculum which is focusing on the long term goal to learning motor skills. This is a part of e.g. the overall medicine studies where the goal is to handle the required motor skills when performing reality surgery. The planning is decomposed from the overall goal to learning motor skills into lesions and exercises. The other part (2), the tutorial task planning is focusing on the task performance. How to guide the trainee to fulfil a task, e.g. to remove the gallbladder. Which learning strategy to use and how to present the instructions and feedback.

The content of the curriculum and tutorial task planning are designed based upon the context in which the training takes place. This is included concern about the user and context model, the domain task, the curriculum and the discourse history.

### **2.5.2 Essential skills to be learned in surgery**

Yet there are no standardized training methods in surgery, there is little information concerning the essential skills that must be trained and assessed [25]. However there are work going on to provide a foundation for communication and a standardization of definition, measurement and criteria in the surgical virtual environment [26]. The *Metrics for Objective Assessment of Surgical Skills Workshop* 2001 [26] resulted in five domains; definitions, taxonomy, list of systems, levels for curriculum development and research opportunities. The four definitions that was meant to be essential was [26]; (1) ability, the natural state or condition of being capable, aptitude. (2) Skill, a developed proficiency or dexterity in some art, craft, or the like. (3) Task, a piece of work to be done, a difficult or tedious undertaking. (4) Procedure, a series of steps taken to accomplish an end. The taxonomy is a classification of the abilities, skills, tasks and procedure respectively [26]. Existing systems was analysed to see which exercises measured fundamental abilities, technical skills, complex tasks and full procedure [26]. Developing a curriculum was not completed but questions to considering what use would be made of the curriculum, for whom was it developed and who would decide the correct performance criteria was discussed [26]. Finally three distinct areas for research were identified; (1) the need for a skill called “tissue handling.” (2) Identification and validation of fundamental abilities. (3) The need to compare and integrate the various available exercises of the different systems into a single coherent “core curriculum” and the entire area of haptic abilities and their role in the fundamental abilities (psychomotor, visiospatial, and perceptual) [26].

This is aspects to be concerned carefully when designing the ITS. How to learn is debated but the alternative are still well known, what to learn, in terms of motor skill training, might be harder to find out. Some skills, most notably laparoscopic intracorporeal suturing and knot tying are complex tasks that must be explicitly trained [25]. Other important skills might be harder to define.

## **2.6 USABILITY**

Usability is the extent to which an artefact can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [12]. Usability is not simply a property of an isolated product, but rather it is also dependent on who is using the product, the goal that they are trying to achieve and the environment in which the product is being used. Usability is a property of the interaction between a product, a user and the task, or set of tasks. The usability may change over time.

Effectiveness can be measured in terms of the extent to which a goal or a task is achieved [1]. In a surgical environment this is translated to if an operation is succeeded. If for example a gallbladder should be removed by laparoscopic surgery, effectiveness is if the gallbladder was removed successfully and the patient after the circumstances is alright. Effectiveness in a haptic motor skill training environment is if the trainees adapt the skills they will have use in reality surgery.

Efficiency is the amount of effort required to accomplish a goal [1]. The less effort required, the higher the efficiency [1]. Efficiency can be measured in terms of cost or use of time. If a gallbladder removal took five

or eight hours or required two or five surgeons are examples of factors that are measured in efficiency. To get more time to practice for the trainees and require less time to follow up for the experienced surgeon gives a haptic motor skill training environment high efficiency (comparing to the alternative with one-to-one teaching or teaching according to the apprenticeship model [11]).

Satisfaction is the level of comfort that the users feel when using a product and how acceptable the product is to users as a means of achieving their goals [1]. Satisfaction is very much depending of the effectiveness and efficiency to a system. It is hard to measure since this is the user's subjective feelings to a system. How the surgeons did experience that the liver transplantation went. Do the trainees and experienced surgeon experience that a VE system is relevant to achieve their goals?

### 2.6.1 Principles of Usable Design

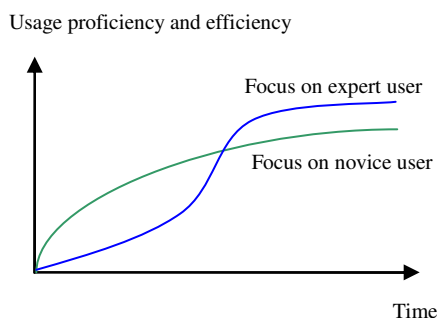
There are many properties of usable design. Also how to combine and rank the properties vary from author to author. The thesis has, to above mentioned effectiveness, efficiency and satisfaction, chose to include rather more than less properties, to get a wide perspective to possible important factors in the design of a haptic training environment. The examples given how the respective property could be translated into surgery and haptic training environments is most times given at an overview level and are not broken down into detail of the design.

The term ability is often used and defines the general capacity of the individual [20].

*Learnability* is concerned with the cost to the user in reaching some competent level of performance with a task, but excluding the special difficulties associated with completing the task for the first time [1]. Particularly important in situation where training time is short or where a user is to be self-taught with a product [1]. It is well known that people do not like spending a long time learning how to use a system. However, to a certain extent, people are prepared to spend longer learning more complex systems that provide a wider range of functionality [18].

In a haptic training environment, it is important to be aware of that there are two aspects of learnability. First it is the user interface to the environment, the hardware and the GUI. This must be learned or at least understood to a certain level before entering the second aspect, the actual task to perform. The task is the training of motor skills, which aims to “sit in the bones” when finished training.

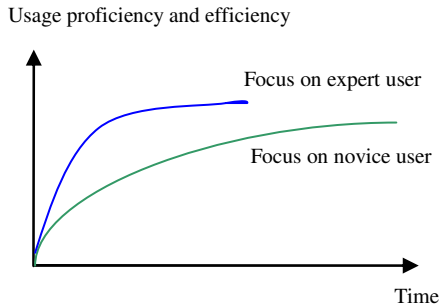
Ease of learning refers to the novice user's experience on the initial part of learning curve; see Figure 11 [17]. The standard learning curve does not apply cases where the users are transferring skills from previous systems.



**Figure 11. Learning curve for a hypothetical system that focuses on the novice user, being easy to learn but less efficient to use, as well as one that is hard to learn but highly efficient for expert users [17].**

The two different types of users in Figure 11 can be translated into the novice trainee respective the experienced surgeon in a haptic training environment. The experienced surgeon does have more background in motor skill training (from reality surgery) than the novice trainee and therefore he/she will get less out of the training to start with. To keep his/hers interest to the system is to include *accelerators*

[17] in the user interface to achieve “best-of-both-worlds”. It should be possible for experienced users to perform frequently used operations especially fast, using dialogue shortcuts [17]. This shortcuts can be seen as an individualized training plan where, in this example, the surgeons can be challenged earlier (in a time perspective) and quite the training earlier than a trainee, see Figure 12.



**Figure 12. Expected learning curve for a hypothetical system when the tutorial is individualized.**

Initial ease of learning is probably the easiest of the usability attributes to measure, with the possible expectation of subjective satisfaction [17].

*Guessability* is a measurement of the cost (time on the task or error) to the user in using a product to perform a new task for the first time [1]. The lower the cost is, the higher the guessability is. To get guessability is a question about considering the users perception and mental view to the system and to the context where the system is running in. Good guessability can be designed out from metaphors, relevant for the user group. The system should be designed so the user recognize herself and need as little effort as possible to get familiar with the interface, and instead can be able to concentrate on the actual task to be performed.

However it could be argued the main factor that makes this solution guessable is that the user is already aware of it. The time taken in guessing the system has therefore not actually been reduced, but spread out, since this learning time has been taken up in the past. As a result the system only seems to be more guessable. Either way consideration must be given when a system is designed to make it more guessable, thereby reducing the time and the effort needed to use it [15].

In the context of a haptic surgical training environment guessability should be considered at two levels, the interface to the hardware and the graphical user interface (GUI). The hardware should remind of the tools used in the real surgical world and invite to interaction of those. Factors to consider are e.g. the ergonomic posture and operation tools like scissors and forceps, etc. If the aim with the GUI is to remind of the real world (see session 2.4.3) the graphical presentation of e.g. a liver should look like real organ. In this context, however, it is important to consider the different type of users, there might be both medicine students and surgeons with long experience, using the surgical training environment.

*Memorability* refers to how easy a system is to remember how to use, once learned [18]. This is especially important for systems that are used infrequently. Even if the user has not used a system or an operation for a few months or longer, the user should be able to remember or at least rapidly be reminded of how to use it [18]. To support this, the design should consider structure of operations, menu options, names, icons, etc. Thus are the memorability aspects mainly concerning the interface, the tools that make the training of the task, motor skill training, possible.

A haptic training environment is probably frequently used by a trainee but for an experienced surgeon it might be longer time he/she uses the system to practice. Also the trainee might have use of the environment after finishing there student training.

*Consistency* is when similar tasks are done in similar ways or things that are related are presented in a similar way and things that are not related are made distinctive [1, 16]. Consistency should apply across the different media which form the total user interface [17]. This is including not just the application screens

but also the documentation, help-systems and tutorials. Input and output should be consistent (stimulus-response compatibility): if a certain force is needed to interact with an organ of a special type in one part of the trainee tutorial, further on in the tutorial, the same force should be needed for that type of organ. An application should behave consistently with the metaphor that it presents: muscles are connected to bones but bones are never connected to muscles (bone has muscles connected). What one person sees should be consistent with what another person sees, so that they can effectively communicate about it (this is of special interest for making communication over geographical distance possible). Finally, an application should behave consistently in any context and on any platform (cross-platform compatibility).

In virtual environments and simulations, consistency to reality is the main focus. When building a training environment for training of motor skill memory, it is of highest concern that the tasks represented, or the application, are relevant for reality surgery.

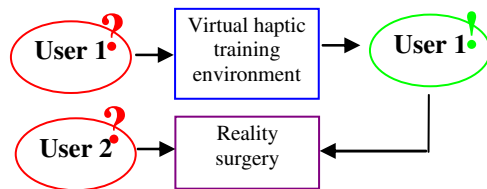
*Compatibility* offers a measure of the degree to which operations fit in with expectations based on the user's real-world experiences [16] and experience of other products. Another term for this is affordance, at a very simple level this means "to give a clue" [18] or to offer possibilities of actions. For example, a door handles afford pulling, a cup handle affords grasping and a mouse button affords pushing.

To design compatibility is to use relevant metaphors and recognition attributes. In a surgical training environment the metaphors is often to remind of a reality environment, both from a hardware and GUI point of view. For example there is the VIST™ product from Mentice illustrating a vascular intervention system, Figure 13.



**Figure 13. Mentice vascular intervention system trainer, VIST**

In general the system should be compatible with users expectations, however some times we must be presented for an odd, new environment, like operation of a human body. So compatibility can also be seen the other way around. That a system might not be compatible to the outside world but when the user is presented for the environment in reality, the user can feel comfortable; he/she has been in the same situation earlier and know what to expect. See Figure 14. The training environment shall be, from a haptic point of view, as like reality as possible so when the trainees perform reality surgery, they should feel comfortable in the context and know what to expect.



**Figure 14. A rough sketch over the relationship between two novice surgeons where user 1 has been trained in a virtual haptic training environment and user 2 has not. User 1 is assumed, especially by him-/herself, to be better prepared for reality surgery.**

*Consideration of user resource* means to design a product so that its method of operation takes into account the demands placed on the user's resources during interaction [1]. To consider the users perception and cognition, mental stress, number of hands, etc. For surgery this is a very important point since surgery can be critical and require dexterity. The resources to a surgeon shall make it easier for him/her to concentrate

on the critical task and not the surrounding. For example so must the surgeon get enough assistance, light, tools, etc.

In a haptic training environment, the assistance to the trainee might differ out from how far the trainee has come in the learning environment. What is the goal of the training? To train a specific motor skill task is done in different stages, from novice to expert, from much assistance to no assistance with time limit.

*Feedback* is about sending back information about what action has been done and what has been accomplished, allowing the user to continue with the activity [18]. The feedback of the user's actions should be acknowledged and a meaningful indication should be given to the user about the results of his/her actions [1]. For interaction design there is various kind of feedback – audio, tactile, verbal, and visual and combinations of these [18].

In the surgical training environment there are three types of feedback. The trainee gets two types of feedback: The overall system feedback and guiding through the learning environment is one type of feedback. The other one is the haptic or tactile feedback given by the PHANTOM™ device [8]. When the trainee is touching an imager organ the feedback should be as the touching a real organ. The third type of feedback from the surgical training environment is the feedback the author or supervisor of the trainee is receiving.

Some times there is an idea to have a delayed feedback. In a surgical haptic training environment, the delay might be useful from a learning point of view, for example get the result of the performance after finishing the task and not at once. From the haptic point of view there should not be a delay since training of motor skills require immediately response.

*Error prevention and recovery* is reached if a product is designed so that the likelihood of user error is minimized and so that if errors do occur the user can recovered quickly and easily [1, 16]. According to Murphy's Law will everything that can go wrong do so in the worst possible moment.

In reality surgery and design of surgical robots error prevention and recovery is a very important question since that environment are dealing with human lives and can be very critical. However in terms of haptic training environment, this will be prevented in the soft- and hardware developing and is of major concern in a real-time learning point of view. But of course the design of the learning environment must be investigated so not the incorrect motor skills will be trained.

*User control* give users as much control as possible over the interactions that they have to produce. This means, for example, giving control over the pacing and timing of interactions [1]. In the haptic training environment the user should have a large degree of freedom in the physical interaction with the PHANTOM device [8] but this might not be the case out from the learning point of view. The steps or procedure in the interaction is decided out from an Intelligent Tutorial System that consider the previous result to the trainee and out from that decide what interaction to be present for the user next.

*Visual clarity* is requirement to GUI. It is important that information is displayed in such a way that it can be read quickly and easily and without causing any confusion. This includes both labels and information displayed as feedback [1, 16]. The visual clarity criteria rate the degree to which information is organized so that the user knows quickly, and without confusion, how he/she should use it [16].

For the haptic learning environment there will be two types of visual feedback, the feedback related to the haptic interaction and the feedback related to the tutorial system. Those must be displayed so they will not cause conflict with each other. This can have several solutions, either the two types of feedback is not displayed at the same time or they are displayed in different areas or, finally, the two types of feedbacks are synchronized (displayed at the same time) in the same visible area.

*Prioritization of functionality and information* so that the most important functionality and information are easily accessible to the user [1, 16]. In reality surgery and design of surgical robots this is, together with other critical systems, a very important question. The system must consider the users perception and cognition and also decide what is most important to present at the time. What information does the user need and that information is not/less important. Here is also to consider what does the user thinks he/she needs? Out from the user's expectations (consistency and compatibility) there might be information the user thinks is useful and spends energy in looking for it instead of concentrate at the task.

For a haptic training environment prioritization of functionality and information is decided out from a learning perspective. In this environment it is important to tell the user the underlying philosophy to why some information is visible and other is not, why some functionality is available and others are not.

*Appropriate transfer of technology*, it is important to making appropriate use of technology developed in other contexts to enhance the usability of a product, to both look for advantages and disadvantages. For example has head-up display technology has provided successful in aircraft, but less successful in road vehicles [1].

The virtual training environment used to improve in surgery skills, can be compared with similar environments for example aircraft simulators. Both environments have one basic similarity - the human and the human factors, but nevertheless the aircraft focus more on decision making and the haptic training environment on motor skills training. However, to look into other environments lessons can be learned without being experienced, something saving both time and money.

*Explicitness* to a product is when the design to the product gives a cue of its functionality and method of operation [1]. Explicitness is the degree to which it is clear how the site should be used [16]. The product is intuitive for the user and the user understand the basic functionalities. Explicitness can be compared with guessability. However both explicitness and guessability must be considered out from who are the users.

In a haptic training environment it is not the point that the solution to the actual task should be explicit but how to interact with environment to solve the task is of more interest to be explicit.

### 3. SUMMARY OF THE REVIEW

In the outcome of the literature search, four parts can be identified; (1) today's status in the surgical training of motor skills environment and needs for tomorrow. (2) Motor skills that needs to be trained and recommended training of those. (3) Recommended design of the learning environment with the aim to optimise the learning curve. (4) Principles of usability design translated into terms of surgical motor skills training.

The literature mentions, that dexterity, or motor skills, constitute 25% of a skilfully performed operation [3]. It is especially clear that invasive surgery or laparoscopic surgery which combine's unusual hand-eye coordination with the use of complex instruments, have an obvious need of training of manual skills [6]. However today there is no objective assessment of motor skills [11]. The technology in medicine is rapidly evolving and there are fundamental changes in the required perceptual motor skills [25]. There are not just novice trainees that have a use for training motor skills; also experienced surgeons have use for motor skill practise, training new or modified surgeon techniques. The 'future of surgery' is now but the future of any new technology depends upon how well the training is [32]. The ability to use advanced technology in surgery, which is available, is depending of how well the surgeons can manage it. To increase their ability to use the technology they need training.

The definition of a motor skill is, in this thesis, an action or task that has a goal and that requires voluntary body and/or limb movement to achieve the goal [19]. Motor skills are a qualitative expression of performance and can be measured in terms of efficiency [19]. With the starting point in laparoscopic surgery, required motor skills can be classified as fine motor skills in serials where the environment is more closed than open; the environment is stationary but the response requirements change from operation to operation. How to train these types of motor skills is not clear among the experts but the most important guideline; to set appropriate goals that will enhance skill mastery [19, 21]. For the type of motor skills the thesis dealing with, demonstrations and instructions should consider *what* to perform in terms of the final outcome of the task, and not *how* to perform it in terms of the trainee's limb movements. Giving feedback is a critical part where sometimes no feedback is better than bad augmented feedback but good feedback is better than no feedback. Motivation of the trainee plays an important role in learning motor skills [19].

Yet there are no standardized training methods in surgery, there is little information concerning the essential skills that must be trained and assessed [25]. Experts often refer to "the right feeling", they can not always explain how they perform a task, they just implicitly do it [21]. However, early results suggest that virtual environment simulators have an important role to play in the future of surgical training [14]. There is work going on to provide a foundation for communication and a standardization of definition, measurement and criteria in the surgical virtual environment [26]. The Rasmussen model applied to the performance of surgical tasks, points out three levels of knowledge that needs to be leaned; skill based (instrument handling and dissection techniques), rule based (recognition of human anatomy) and finally knowledge based (unfamiliar and unsuspected situations, faced with a task for which no rules are available from previous encounters) behaviour [6].

The motivation to the trainees is an important part in the learning process. Constructivist learning theory is focusing on ability for humans to construct there own learning which has show to be an effective way of learning, [5, 30]. Motivation can help to support this kind of learning [5, 30]. The training should take place in a learning environment where the balance between challenge and support is reached, in terms of incongruity; at the attractor point in the incongruity curve [4]. The relation (communication/interaction) between trainee, trainer and application/artefact is visualised in the collaboration model (Figure 7) and in the CSCW model (Table 2) the relation between time and space is illustrated.

There are some terms used in this thesis which meanings are important to define; a *strategy* is a long term plan of action designed to achieve a particular goal [29]. A *teaching strategy* is a long term plan of how to train to reach a certain goal. A *task* is part of a set of actions which accomplish a job in the sense that useful work is getting done [29]. A *tutorial task* is a set of action that provides learning out from a teaching point of view, and a *domain task* is a set of action that provides learning in a specific subject field. There is a strong relation between the teaching strategy and the tutorial task; the tutorial task changes after which teaching strategy is used.

Instead of training motor skills in a real environment, a simulation environment can be used. Motor skill training can be reached by performing haptic training [28]. Several disadvantages in today's training methods of motor skill training could be overcome using Virtual Learning Environments (VLE) in surgical training [7]. A VLE is a Virtual Environment (VE) e.g. a simulator which supports learning. A VE can be combined with an Intelligent Tutorial System (ITS). The combination is meant to be a system where the VLE constitutes as the domain task and the ITS constitutes of the tutorial task. The goal of ITS is to enlarge the students in sustaining reasoning activity and to interact with the student based on a deep understanding of the students behaviour [22]. Educational software environments are effective to the extent that they enable students to increase learning efficiency [22].

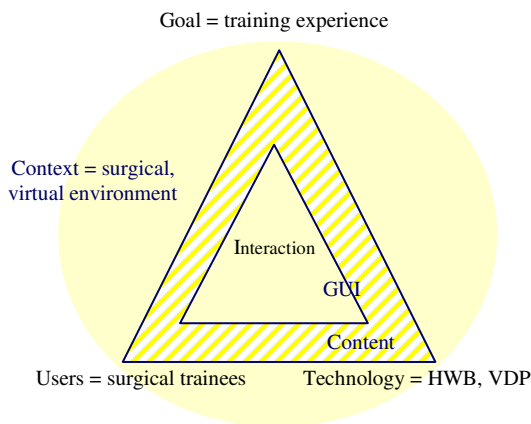
At CSIRO a Haptic Workbench (HWB) enables users to interact with the simulation of tangible objects and a Virtual Document Planner (VDP) can be used to add support to the environment [9].

Usability is the extent to which an artefact can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [12]. Effectiveness is whether which a goal or a task is achieved [1], if an operation is succeeded. Efficiency is the amount of effort required to accomplish a goal, the less effort required, the higher the efficiency [1]. Satisfaction this is the user's subjective feelings to a system [1]. There are several properties in principles of usable design where some plays a large role than others in terms surgical training. Since safety and patient outcome are the most important criteria in surgery, training effectivity should be of primary importance [6].

## 4. METHODS

The training environment at CSIRO ICT Centre is on the level of a prototype and the thesis will mostly address the issue on a conceptual level in combination with a literature study. The review is focused to give a wide, rather than deep, outline of the aspects included in a virtual training environment that is of importance to consider. To confirm these aspects to be relevant, talks and discussions with experts at CSIRO took part. Products on the market was surveyed and classified whether they fulfilled the needs for optimised individual training, recommended by the thesis. Since the environment still is under development it was not possible to make a relevant user survey in the relatively short time allocated for doing a MSc thesis.

The main methodology is based on triangulation [13] where requirements to products and their characteristics comes up in a context. The products are tools that are used in an attempt to achieve a goal. Figure 15 is a graphical representation of the working environment for this thesis. The overall context is surgical training in a virtual environment. The goal is the outcome of training, the training experience the trainees get. The users are the surgical trainees (not necessary at novice level) and the Haptic Workbench (HWB) and the Virtual Document Planner (VDP) main technology in use. The thesis aims to investigate the design of the content of the system, with focus on teaching strategies. The interaction and GUI will be briefly described and not deeper investigated.



**Figure 15. Triangulation adapted to the environment of surgical training.**

### 4.1 LITERATURE STUDY

The goal with a literature study is to collect and receive knowledge in the subject field and in that way increase the understanding of the concept. The published information should favourably influence the designer's output and should be obtained without unacceptable cost and delays [57]. To take part of published material is a good way to get input in the design work. To do this in a most effective way, the overall field is divided into sub-fields. The literature study for this thesis has been concentrated on two types of knowledge; (1) learning the principles, and know the state-of-art, in an unfamiliar area that already been codified by others [57]. In this thesis this has been knowledge about motor skills, learning principles and usability. (2) To take samples over the whole of an area in which the knowledge is at present fragmentary and disorganised [57]. This is represented in the thesis by surgical training in simulators and with haptic tools.

Out from the two knowledge types above, the searches was directed; (1) on reputable review articles and textbooks, original research papers [57]. (2) On theoretical and technical articles over an area a little bit larger than the final framework [57] to get ideas from other knowledge fields. The material to the literature study in this thesis was composed of books, articles, papers and internet pages. The precision (see Figure 16)

is estimated to 50 percent for books and articles, which means that around half of all books and articles read have been used as reference material. The precision for internet pages is significantly lower. This is because internet pages are easily accessible, you can look at many pages in a short time but it is harder to find relevant pages. The precision for internet pages is estimated to 15-20 percent.

$$\text{Precision} = \frac{\text{Number of relevant documents retrieved}}{\text{Total number retrieved}}$$

**Figure 16. The definition of precision in literature study [57].**

The method is a relatively cheap method in terms of money but the method can be time consuming in terms of finding relevant material and reading it through.

## **4.2 PRODUCT SURVEY**

The goal with a product survey is to find technology- and design solutions that are already on the market. By finding those valuable inputs about good and poor design, good solutions can be received and less good solutions can be avoided. The product survey will also indicate if there is a lack of a solution/product to a known problem. The method was carried out by browsing the Internet. The search was divided into two main parts; existing surgical training environments and existing haptic devices. This was done to get an idea of what is existing in the subject field, i.e., surgical training but also to get an idea that is existing in other subject fields. One part of the thesis focusing on the learning environment, however, the product survey was not specified to find learning environment products without motor skill training since the literature study indicated that motor skill learning is synonymous with the term action [19] and should not be compared with cognitive skill learning.

The information about the products is according to the developers' own homepages and the correctness was not able to be inspected because of lack of access to the products. Dr Müller-Tomfelde and I discussed contacting the producers but we estimated that this would not give us more objective information about the products than what was found on the respective homepage.

## **4.3 TRY IT YOURSELF / SELF EXPERIENCE**

Try It Yourself [61] focuses on the design team, who explore the artefact/system/prototype. The goal with the method is to give the designer a clue how the interaction environment works to get a better understanding of suitable design. The purpose is to test the artefact/system/prototype, rather than just talk about it. The self-experience in this case was the use of the CSIRO's Haptic Workbench. The system allows the user to interact with shapes and geometric figures and to get force feedback.

## **4.4 SCENARIOS**

A scenario is a personalised, fictional story with characters, events, products and environments. [39] It aims to help the designer to explore ideas and the ramifications of design decisions in particular, concrete situations [39]. A scenario can be written (as in session 7.2.7) to clarify the communication between human and computer. What type of input and output that are possible, might take place or are convenient. Rather than dealing with abstract representations, a scenario approach provides concrete, situated representations of the design which help the designer to focus on many aspects of a possible interaction at once [39].

A scenario can, as well as, make the situation clear for the designer, explain how a system is used for the reader of a design document to be able to participate in the design process [58]. The scenario is written with vocabulary and phrasing.

#### 4.5 DISCUSSIONS WITH EXPERTS AT CSIRO

At my time at the Australia's Commonwealth Scientific and Industrial Research Organisation, science area Information and Communication Technology, CSIRO ICT [58], I have taken part at the every day work and got an insight in the research institute. I was working with the Information Agility Theme and this gave me a more complete view over what interaction design is and how it can be applied.

The most valuable input was the informal discussions and meetings with Dr. Christian Müller-Tomfelde who is working on the *skill* project that focuses on effective training of motor skills using the Haptic Workbench and tailored information delivery, like instructions and feedback. Dr. Müller-Tomfelde's research interests are is on the fields of human-computer interaction, multimodal interfaces, auditory display, computer-supported cooperative work and disappearing computer. Dr. Müller-Tomfelde introduced me to the subject field and has been highly supportative during the work with the thesis.

The weekly group meetings and seminars, gave me an insight in what the other researchers do and ideas of how I could apply their knowledge on this thesis.

Taking part in two conferences, the ICT Center Conferences [58] and the OzCHI 2004 [36] gave an insight in what other researchers and research institutes are working at. This gave new ideas and references used in this thesis.

## 5. RESULT

The result chapter consist of the outcome of the product survey which is focused on both surgical training environment and haptic devices.

### 5.1 EXISTING SURGICAL TRAINING ENVIRONMENTS / PRODUCT SURVEY 1

A review and classification of several surgical training environments, aiming to get an overview of existing products and what is available on the market. The products where classified according to criteria's found in the literature study and to interesting criteria's relevant for this thesis survey. Please note that the abstract and functionality to the products is according to the developers own homepages, the correctness have not been possible to inspect because of lack of access to the products.

#### 5.1.1 Abstract of surgical training environments products

The functionality to a number of surgical training environments is described shortly. The fact of the products are according to the developers own homepages.

**Immersion CathSim Vascular Access Simulator** [40] is a haptic force feedback hardware device that was developed to avoid that nurses and phlebotomy students had to learn how to start a needle insertion or draw blood using rubber arms, oranges or each other. Healthcare professionals learned only by practicing on patients. CathSim supports skills acquisition, skills maintenance, skills measurement, and IV certification. It combines cognitive and motor skills training into an integrated learning experience. It provides a variety of patient types encountered in real life and can simulate complications. With the AccuTouch Tactile Feedback device, the student is able to feel the needle and catheter insertion from the “pop” as the needle enters the skin through entry into the vein lumen. See Figure 17.



**Figure 17. Immersion CathSim Vascular Access Simulator.**

**Immersion AccuTouch Endoscopy Simulator** [40] is a software system which includes three types of endoscopic procedures: flexible bronchoscopy, upper and lower gastrointestinal flexible endoscopy. The AccuTouch Endoscopy Simulator is a computer-based system using the virtual environment for teaching and assessing motor skills and cognitive knowledge, enabling novices and experienced physicians to practice in a safe environment and get objective assessment of the performance. The system use real-time computer graphics, including anatomic models developed from actual patient data and a robotic interface device, force is transmitted through the flexible scope to provide tactile sensations mimicking the actual feel of a procedure. See Figure 18.



**Figure 18. Immersion AccuTouch Endoscopy Simulator.**

**Immersion AccuTouch Endovascular Simulator** [40] is a software system that allows clinicians to practice endovascular procedures in a virtual environment and receive objective assessment of the performance. Endovascular procedures require careful attention to interpretation of the fluoroscopic image as well as the subtle feel transmitted through guide wires, catheters and other interventional devices. The AccuTouch Endovascular Simulator, which duplicates the look and feel of the actual procedure, provides clinicians the ability to develop their skills, prior to performing the procedure on a patient and to return to maintain their skills. See Figure 19.



**Figure 19. Immersion AccuTouch Endovascular Simulator.**

**Immersion Laparoscopic Surgical Workstation** [40] is a hardware interface designed to simulate laparoscopic surgery. This interface has two fully instrumented tools - providing haptic feedback. Procedures possible to train are cholecystectomy, tubal ligation, oophorectomy, endometriosis treatment, nissen fundoplication, etc. See Figure 20.



**Figure 20. Immersion Laparoscopic Surgical Workstation.**

**Immersion Virtual Laparoscopic Interface** [40] is a hardware system for tracking the instrument motions associated with minimally invasive surgical procedures. High-speed optical tracking technology accurately

monitors the motions of two surgical instruments simultaneously enabling simulations of these types of procedures. See Figure 21



**Figure 21. Immersion Virtual Laparoscopic Interface**

**Mentice Procedicus MIST** [41] is a simple-to-use computer based software system designed to teach and assess minimally invasive surgical skills. The system comprises a frame holding two standard laparoscopic instruments electronically linked to a low cost personal computer. The screen displays the movement of the surgical instruments in real time 3D graphics, i.e., in a virtual environment. Trainees are individually guided through a series of tasks of progressive complexity, enabling them to develop the skills for clinical practice. Each task is based on a key surgical technique employed in laparoscopic cholecystectomy, using simple geometrical shapes rather than tissue to allow the trainee to concentrate on the development of key psychomotor skills. Performance assessed objectively by time, number of errors, and the efficiency with which the exercise is performed. This information is available to the trainee on completion of the tasks.

Course administrators can adapt the training programs to the needs of individual trainees and Procedicus MIST provides access to the performance scores of individuals throughout the training program. The system provides data on the performance of groups and individual trainees for comparative analyses. See Figure 22.



**Figure 22. Mentice Procedicus MIST.**

**Mentice Procedicus VIST** [41] is a combined soft- and hardware vascular intervention system trainer which reproduces the physics and physiology of the human cardiovascular system such that a person can learn to perform various procedures such as cardiac catheterisation. The virtual environment simulation is

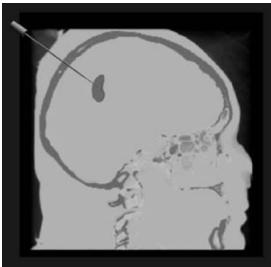
combined with a haptic interface, providing force feedback and there is an instructional system coupled to the simulation that provides a framework for learning from the simulation. See Figure 23.



**Figure 23. Mentice Procedicus VIST.**

**Mentice Procedicus KSA** (Key Surgical Activities) [41] family is made for laparoscopic training. Different types of procedures like triangulation, scope navigation, cutting, suturing, needle passing, diathermy and other essential key skills are trained in this software system. The anatomy database is an abdomen and consists of a complete realistic 3D anatomic virtual environment including stomach, gallbladder, liver, and the surrounding anatomies. Surgeons are able to train to overcome orientation and instrument handling problems as well as hand-eye coordination difficulties. The laparoscopic trainer reduces the need for animals in the surgical education. The skill level of surgeons can be improved by being able to practice techniques repeatedly, and they can develop their skills on the trainer instead of patients. Surgeons can thereby bring more experience to the operating table.

**Novint voxelNotepad** (VNP) [42] software application allows 3D medical data to be felt as well as viewed in real time, i.e., provides a virtual environment. It makes it possible to interpret MRI, CT, and 3D ultrasound data completely in 3D. Novint's needle insertion simulator allows a user to feel what it is like to take a needle biopsy see Figure 24.



**Figure 24. Novint's needle insertion simulator.**

**Polhemus** [43] is the industry leader of 6 Degree-of-Freedom (6DOF) motion tracking, digitizing, eye-tracking and handheld 3D scanners, using the latest electro-magnetic technology. Polhemus hardware products like FASTRACK, LIBERTY and PATRIOT are used by most virtual environment and motion tracking applications.

**Radionics** [44] are mainly developing high technological products for performing and planning surgery. The products are a hard- and software systems providing virtual environments. The company designs neurosurgical and radiation therapy products and provides quality assurance tools, training, and service to ensure reliability and safety.

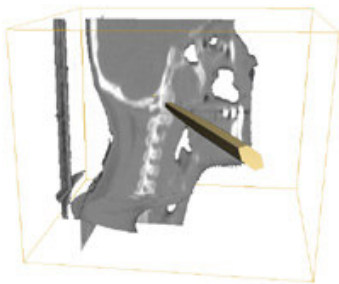
**Reachin Laparoscopic Trainer 2.0** [45] is a complete laparoscopic virtual environment simulator which can provide haptic force feedback and aims to prepare and qualifies the surgical trainees on their way from the classroom to the operating theatre. The forceback training mode guides the trainee through the lesson by recorded movements and speech from a tutor. This provides flexibility in composing individual training courses for varying difficulty levels through a number of basic and progressively more advanced skill training modules as well as lessons for specific procedures. Every movement in the simulator is recorded which makes it possible to objectively measure and assess the progress of each trainee. RLT 2.0 has easily adjustable acceptance limits and enhanced graphic presentation of results. Web-access for administration and pre-training puts less constrains on the actual simulator, hence more people can be trained on one device. See

Figure 25.



**Figure 25. Reachin Laparoscopic Trainer 2.0.**

**Reachin API** (Application Programming Interface) [45] is a software interface for creating real world touch applications with an unprecedented fidelity and sense of reality. Reachin API manages the technology of multi-sensory rendering, freeing the user to focus on application behaviour and interaction and receive objective assessment of the performance. The product provides haptic force feedback application in a virtual environment with an extensible library of shape nodes, surface nodes, simulation and scripting nodes, and control nodes for the different haptic and tracking devices. Reachin API can also be used as a learning environment for teaching haptics in the classroom, building on students existing knowledge in computer graphics. University teaching packages are available that includes teaching support. See Figure 26.



**Figure 26. Reachin API.**

**The Reachin Display** [45] is a similar artefact to CSIRO's Haptic Workbench [8]. It is a hardware system combining a stereo-visual display, a haptic force feedback device and a 6-degree-of-freedom positional. The user interacts with the virtual world using one hand for navigation and control and the other hand to

touch and feel the virtual objects. The use of a semi-transparent mirror creates an interface where graphics and haptics are co-located realistic simulations with force-feedback and stereo viewing. See Figure 27.



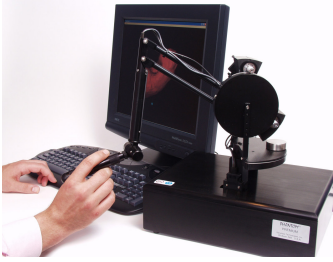
**Figure 27. Reachin Display.**

**The Select-IT VEST system** (Virtual Endoscopic Surgery Trainer), VSOne [46, 47], is a combined hard- and software product with a virtual environment and haptic force feedback, designed to support the training in minimal invasive, endovascular, surgery. As a surgeon-computer interface, a Trainer Input Box (TIB) is used as an artificial cavity together with the correct instrument set, maintaining the realistic environment of a laparoscopic operation. Inside the box, mechanical guidance systems are used for each instrument and a camera. Additionally, two foot switches are implemented providing surgical (coagulation) functions. It uses the Kismet software with extension for “deformable objects” and interactive object manipulation and force feedback devices. See Figure 28.



**Figure 28. Select-It VEST system, VSOne.**

The **SensAble Technologies PHANTOM** [48] is a hardware product line of haptic devices. The PHANTOM Premium models are high-precision instruments, some offer 6DOF (degree of freedom) capabilities and some device offer complete desktop solutions. The PHANTOM is the basic haptic device part of many surgical training products. See Figure 29.



**Figure 29. SensAble PHANTOM 6DOF.**

**SensAble** offers a range of software toolkits and haptic devices for haptic application development, including the **OpenHaptics** [48] which enables software developers to add haptics and true 3D navigation to a broad range of applications, including 3D design and modelling.

**Simbionix GI Mentor** [49] simulator is a complete training environment designed for medical experts and trainees. GI Mentor simulators are interactive computerized simulators that provide haptic force feedback in endoscopic procedures in a virtual environment. The learning environment in the simulator allows an instructor to build a medical program for each individual trainee: Select from the 20 different cases that come with the Mentor to prepare a custom built tutorial. The tutorial can be objectively assigned to a specific trainee and/or save it as a template and feedback of performance is available. See Figure 30.



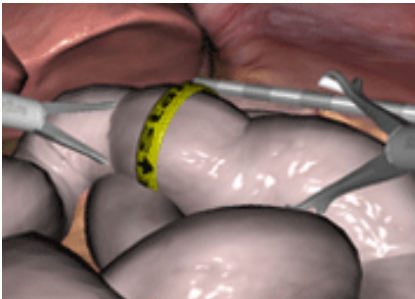
**Figure 30. Simbionix GI Mentor.**

**Simbionix URO/ANGIO/PERC/LAP Mentor** products [49] are virtual environment simulators with hands-on training and practice opportunity for diagnostic and therapeutic procedures of surgery (endourology, interventional endovascular, fluoroscopy and complete laparoscopic surgery respectively). The products provide a learning environment with the opportunity to work with a variety of scopes, tools and visual images on a true to life system. URO Mentor has coordination games and basic tasks for review of anatomies provide the introduction to the use of endourology scopes and tools. From these introductory exercises trainees can get their individual program and move on to a variety of virtual patient cases, each with its own unique anatomy and pathologies. See Figure 31.



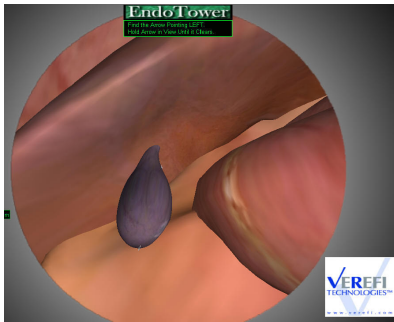
**Figure 31. Simbionix URO Mentor to the left and Simbionix ANGIO.**

**Surgical Science LapSim Basic Skills 2.0/3.0** [50] utilizes 3D technology, including interactive live video, to provide the student with a realistic virtual working environment. Nevertheless, the interface is kept as simple as possible. Practice sessions can vary in graphic complexity as well as in the level of difficulty. Appropriate courses for the individual trainee can be created or modified by the teacher to fit student's specific needs, or the requirements of a training curriculum. Objective assessment of the performance, course saving, import and export functions facilitates course sharing between educators and institutions. As learning environment, LapSim offers the teacher comprehensive student and course administration functions, keeping track of each individual student's progress, as well as groups of students. The system can be closely adapted to offer the right level of challenge to each student. Course curriculum may be saved, imported and exported. See Figure 32.



**Figure 32. Surgical Science LapSim Basic Skills 3.0.**

**Verefi EndoTower** [51] is a surgical software simulator that uses a digital virtual environment to provide instruction in surgical navigation using an angled laparoscopic lens/camera combination. Proper manipulation of the angled laparoscope in the complex 3D environment of the human body is possible. Also to simulating an actual 30, 45, or 70-degree laparoscope. EndoTower is designed for doctors, nurses, residents, physician's assistants, OR (operation room) technicians and students. The camera driving skill is essential and arguably the most basic yet critical skill for video-assisted procedures. See Figure 33.



**Figure 33. Verifi EndoTower.**

**Xitact LS500 Laparoscopy Simulation Platform** [52] is a hardware platform for the simulation and training of laparoscopic procedures such as motor skills. The system is an open platform, providing haptic force feedback training and is compatible with software from major laparoscopic surgery simulation vendors. Together with the Xitact LC3.0 software, the system provides a haptic-enabled simulation and training system for the laparoscopic cholecystectomy. See Figure 34.



**Figure 34. Xitact LS500 Laparoscopy Simulation Platform.**

**Xitact ITP** [52] is a hardware device designed to track the motion of an instrument during the simulation of a minimally invasive surgical procedure. One or more surgical instruments with genuine handles can be inserted and withdrawn freely, as during the performance of a real operation. A Xitact ITP can be upgraded to a **Xitact IHP** [52] incorporating haptic force feedback. See Figure 35.



**Figure 35. Xitact ITP/IHP.**

**Xitact CHP** (Catheter Haptic Port) [52] system is a hardware simulation platform for intravascular procedures. It supports the simulation of all types of interventional procedures; cardiology, peripheral interventions, and interventional radiology. The Xitact CHP provides simultaneous tracking and force feedback and tracking for up to three coaxial instruments. See Figure 36.



**Figure 36. Xitact CHP.**

**Xitact LC3.0 simulation software** [52] is a platform for unsupervised curriculum-based medical training which got possibilities to collect and analyse assessment data.

### **5.1.2 Classification of surgical training environments**

Table 3 shows an overview and classification of surgical training environments and tools. The products are classified into the properties; individualised training, haptic force feedback, learning environment, objective assessment of skills, virtual environment, hardware and software. The properties are in order of interest for thesis. It is hard to define if the product should be classified as hardware or software, in some cases. The software is most commonly depending upon a particular hardware, and the hardware is not useful without software.

Criteria / Product name	Individualised training	Haptic force feedback	Learning environment	Objective assessment of skills	Virtual environment	Software	Hardware
Reachin Laparoscopic Trainer 2.0	x	x	x	x	x	x	x
Simbionix <b>GI Mentor</b>	x	x	x	x	x	x	x
Reachin API	x	x	x	x	x	x	-
Simbionix URO/ANGIO/ PERC/ LAP Mentor	x	-	x	x	x	x	x
Mentice ProceDicus MIST	x	-	x	x	x	x	-
Surgical Science LapSim Basic Skills 2.0/3.0	x	-	x	x	x	x	-
Mentice ProceDicus VIST	-	x	x	-	x	x	x
Select-IT VEST system	-	x	-	-	x	x	x
Immersion CathSim	-	x	-	-	-	-	x
Immersion Laparoscopic Surgical Workstation	-	x	-	-	-	-	x
Reachin Display	-	x	-	-	-	-	x
SensAble OpenHaptics	-	x	-	-	-	x	-
SensAble PHANTOM	-	x	-	-	-	-	x
Xitact LS500	-	x	-	-	-	-	x
Xitact CHP	-	x	-	-	-	-	x
Xitact ITP/IHP	-	-/x	-	-	-	-	x
Xitact LC3.0	-	-	x	x	-	x	-
Mentice ProceDicus KSA	-	-	x	-	x	x	-
Immersion AccuTouch Endovascular	-	-	-	x	x	x	-
Radionics	-	-	-	-	x	x	x
Novint's voxelNotepad VNP	-	-	-	-	x	x	-
Verefi EndoTower	-	-	-	-	x	x	-
Immersion Virtual Laparoscopic Interface	-	-	-	-	-	-	x
Polhemus	-	-	-	-	-	-	x

Table 3. Classification of surgical training environments and tools.

### 5.1.3 Study of the individual learning environments

Four companies is state to support in individualized training. It is Mentice, Reachin, Simbionix and Surgical Science. To be able to compare with this thesis and theory's definition of an individualised learning environment in terms of efficient learning environment a study of the companies individualized learning environment was made.

For all companies and their respective products, the individualized learning environment is in reality that a teacher or author of the system can adapt or create a training program according to the needs of individual trainees [41,45,49,50]. The individual training program consists of a mix of training modules supplied by the product. These types of individualized learning environment are thus administrated between the training sessions and are not flexible during the performance.

## 5.2 EXISTING HAPTIC DEVICES / PRODUCT SURVEY 2

There are some other fields, except from medicine and surgical training, where haptic force feedback is used to train motor skills. It is quite often the same companies involved in both surgical training and training in other fields – the companies got the technology and applies it where it is suitable.

### 5.2.1 Abstracts of haptic devices

A number of haptic devices from different companies are presented to get an overview what kind of device is available and in which application context haptic force feedback is used. The facts of the products are according to the developers own homepages.

*Immersion MicroScribe* [40] products let you quickly construct detailed computer models and accurate part inspections. Using the MicroScribe stylus simply traces over the contours of a physical object to build complex 3D data sets in a matter of minutes. The 3D digitizing and inspection process is fast, accurate, and easy, see Figure 37.

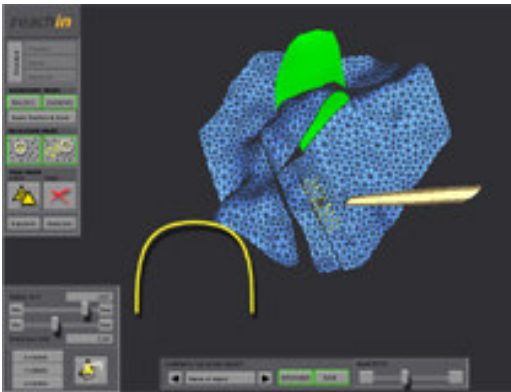


Figure 37. Immersion MicroScribe.

*SensAble FreeForm Concept* [48] solution is a unique touch-enabled system that gives designers a quick, easy way to develop realistic 3D conceptual designs. By creating a robust linkage between conceptualization and engineering, the FreeForm Concept system accelerates the transition from sketches to model, thereby shortening the product development cycle. The solution applies the power of haptic, which allows designers to use their sense of touch to transform images in the mind's eye into 3D models. With the FreeForm Concept software, users can rough out models, combine parts, and then apply paint, images, and other details. FreeForm Concept output includes photorealistic renderings, files for rapid prototyping, and selected 3D formats for downstream processes.

*Reachin GeoEditor* [45] is a tool for oil and gas industry Teams consisting of geologists, geophysicists, petrophysicists and reservoir engineers using 3D seismic data and advanced computer tools to build an accurate model of the underground geology that predicts what a drill bit will find. Well logs and other well information make it possible to characterize the reservoir and make informed decisions on the cost-effective placement of wells, maximizing the flow of oil and gas in the reservoir through the life of the field. Haptic technology can improve the existing tools for visualization and creation of seismic data,

editing of subsurface models, and planning of well paths, to name only a few exciting applications, see Figure 38.



**Figure 38. Reachin GeoEditor.**

*Modeling of Macromolecular Assemblies* adapt visuo-haptic rendering for hybrid modeling of macromolecular assemblies [53]. This describes an immersive visualization system for structural biology using real-time load balancing of virtual reality and haptic rendering. In structural biology a variety of image reconstruction techniques are employed to determine geometric aspects of large macromolecular assemblies at various levels of resolution. During critical load conditions the error metric of a dynamic mesh simplification technique is coupled to the force-update rate of the kinesthetic feedback, thereby providing an instantaneous adaptation of the rendering to the modeling efficiency. This enables the construction of nano-scale bio-molecular architectures while avoiding unwanted haptic blackouts during peak modeling demand.

There are several projects going on with *flight simulators* including haptic force feedback. The American Federal Aviation Administration (FAA) National Simulator Program [54] is one actor. In cooperation with the aviation industry and independent management consultants, they have developed The Simulation Quality Assurance Program (SQAP 2000) [54]. The aim is to make reductions in FAA resource requirements for recurring evaluations, improved confidence in the day to day reliability of flight simulation devices, and improved efficiencies experienced by the respective flight simulation device sponsor.

*Immersion TouchWare Gaming* is building upon Immersion TouchSense technology [40] and can transform any game into a multi-sensory experience by engaging the sense of touch. The hardware partners of Immersion provides force feedback game controllers which let the user experience an explosion's reverberations or the centrifugal pull of rounding a race track. It's all possible through a combination of Immersion TouchSense technology inside gaming software and hardware peripherals such as mice, trackballs, joysticks, steering wheels and game pads. Immersion claims that their complete force feedback system adds a whole new dimension of realism to games.

## 6. DISCUSSION

The outcome of the literature study and the market survey, and discussions with experts are in the discussion chapter analysed and merged together. The aim is to design guidelines for teaching and training strategies in training of motor skill tasks. I have divided the analyse into three actions; (1) arguments for an individualised training environment, (2) usability requirement to this kind of environment and (3) guidelines to the design of an individualised training environment.

### 6.1 NEEDS FOR AN INDIVIDUALISED TRAINING ENVIRONMENT

Today's training of motor skills for surgeons has potential for improvement (see section 2.1, 2.3 and 2.4). The apprehensive model, where surgical trainees watch an experienced surgeon in the operation theatre and then participate themselves when their experience increase, is an expensive and time consuming way of teaching. This model is not suitable for objective assessments because the procedures are taught on the basis of the mentor's interpretation of current standards. However the model has worked well enough in the past and still is working. But the computer technology is rapidly evolving and this has effects for the medical education and training area. With the introduction of minimally invasive techniques, or laparoscopic surgery, perceptual-motor relationships are unfamiliar, even for experienced surgeons. New instruments are being developed at a rapid pace which affects the techniques that are also changing rapidly, simultaneously, new procedures are becoming popular. The skills necessary to perform these operations can not be acquired in one or two day courses in the animal laboratory, therefore an alternative training environment are necessary. This environment is meant to both teach new procedures and refresh old knowledge.

Motor skills, described in section 2.2, can be classified as implicit knowledge or silent knowledge. A motor skill is an action that requires voluntary body and/or limb movement and out from a constructivistic learning approach - motor skills are sole *learnt-by-doing*. Motivation to the trainee plays an important role in learning motor skills. The fundamental principles of adult education, outlined in section 2.3, emphasize and favour individual development and a learner-centred, constructivist, approach in an environment conducive to learning. The idea of incongruity, tells that a good learning environment should be challenging and supporting at the same time. However the trainers experience of what is too high respective too low complexity can change all the time with as more knowledge the trainee adapt, which is highly individualised. The challenge for the learning environment designer is than how to individualise a system and how to measure if the trainees are at the attractor point at all times. To optimise the learning curve the trainee needs to be followed up *during* performance process with almost continual high-quality feedback on performance and possibility to change the strategy of teaching, the plan of how the user should receive a goal, meanwhile.

Training motor skills can be trained in a haptic training environment where force feedback is provided. There are a number of products at the market today providing haptic feedback and an individual learning environment. However with a closer study on the individual learning environment to these products, outlined in session 5.1, it shows that this is in reality merely a mix of training modules supplied by the product that a human trainer, teacher or author can combine according to the individual needs of the trainees. So the products on the market today are not fulfilling two questioned aspects; (1) individualised feedback and eventually change of used strategy *during* the performance or session. (2) Comprehensive objective assessment. Although the training is computer-supported, still a human trainer is deciding the needs of the individual trainees (and this will be different among the trainers).

### 6.2 USABILITY REQUIREMENTS FOR VIRTUAL TRAINING ENVIRONMENT

Effectiveness and efficiency, described in session 2.6 and 2.3.3, are two overall usability requirements that are important to meet. Effective training ensures that all training objectives are met, efficient training ensures that the training means are cost effective and that the required training time is minimized. Since

safety and patient outcome are the most important criteria in surgery, training effectivity should be of primary importance. At the same time the learning is wanted to be as efficiency as possible, to learn as much as possible in an as short time as possible. The third important usability requirements to meet are satisfaction among the users. Satisfaction is the level of comfort that the users feel when using the training environment and how acceptable the simulator is to users as a means of achieving their goals. The motivation to the trainee to learn motor skills is important, the acceptance or satisfaction of the environment in where this is learned probably affects the motivation.

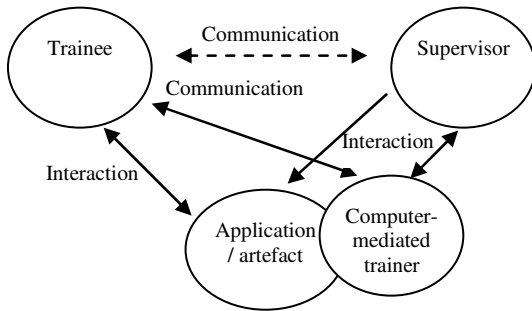
There are also other usability aspects important to fulfil. To get an efficient learning curve there are requirements to the *system*, which is the framework for teaching and is in this thesis represented by the Haptic Workbench (HWB). The system should be separated from the *task performance* which is the actual motor skill training. If a training environment facilitates learning the efficiency will benefit. Learnability in terms of how to learn to use the HWB as fast as possible is important. As faster the user can use the HWB as faster can the user start to perform tasks and train motor skills. The grade of learnability affects the efficiency. Guessability, the cost in terms of effort, to the user in using the HWB to perform a new task for the first time, affect the users mental view of the training environment and with that the satisfaction with and motivation to use it. Both learnability and guessability are important factors to the *system*. The actual motor skill learning, or task performance, will benefit if the simulator which is in this thesis represented of the Haptic Workbench, got as low cost as possible in learn- and guessability.

Consistency, when similar tasks are done in a similar way, is a usability requirement to concern. When the learnt motor skills are aimed to be used in reality, it is important to make sure the tasks learned is presented correct. That the skills learnt in the virtual environment are valid in reality operation theatre. Feedback and visual clarity are, as mentioned earlier, optimally given during the performance. The two types of feedback and visual clarity are relating to haptic interaction respective the tutorial system, i.e. task performance. The haptic interaction is related to consistency while the task performance feedback and visual clarity is related to the individualisation of the training environment.

### **6.3 GUIDELINES TO THE DESIGN OF AN INDIVIDUALISED TRAINING ENVIRONMENT**

Arguments in section 2.1-2.5 show that there is a need for an individualised motor skill training environment where the trainees can learn-by-doing and getting feedback meanwhile performing a task. The role and involvement of a human trainer is important, it is recommended to keep the human trainer to make the final assessment about the performance of a trainee. For example, to decide whether the trainee is competent to start to practice on humans. However the assessment and planning of the curriculum can be done asynchronous from the training, according to the CSCW model. The synchronous follow up to a trainee is likely appropriate to be overtaken by an ITS.

The basic collaboration model is basically involving three parts; the trainee, the human trainer and the application/artefact, see Figure 7 in section 2.3.4. To receive a higher effectiveness in the training the design of the model was discussed with experts at CSIRO. To reduce the involvement of the human trainers, to make the human trainers role time effective as possible in teaching every individual trainee, my idea is to put the trainers function into the application/artefact. To let the synchronous follow up and feedback to a trainee be produced by the use of a computer-mediated trainer, and rather let the human trainer gets a role of a supervisor who is working asynchronous, see Figure 39.



**Figure 39. A modified Collaboration model where the human trainer has got the role of a supervisor and a computer-mediated trainer takes the place of the trainer.**

The profit with this model is that the trainee and the tending supervisor can act asynchronously, according to the CSCW model, which increases the flexibility to the system. A human trainer does not have to be present for training to take place and the trainee can practice both by her-/himself and as much as he/she will (as long as the system is available). The supervisor's role is to follow up the trainee, administrate the application/ artefact and author the computer-mediated trainer. Those roles can be managed by one or several persons, according to the requirement to the different roles and skills to the supervisor/s/.

Outlined in session 2.2.3-2.2.5, there are three types of aids to use teaching motor skills; chose of strategy and goal setting, demonstrations and instructions, and finally feedback. According to literature, well use of those will increase the motivation to the trainee and therewith increase the efficiency of learning.

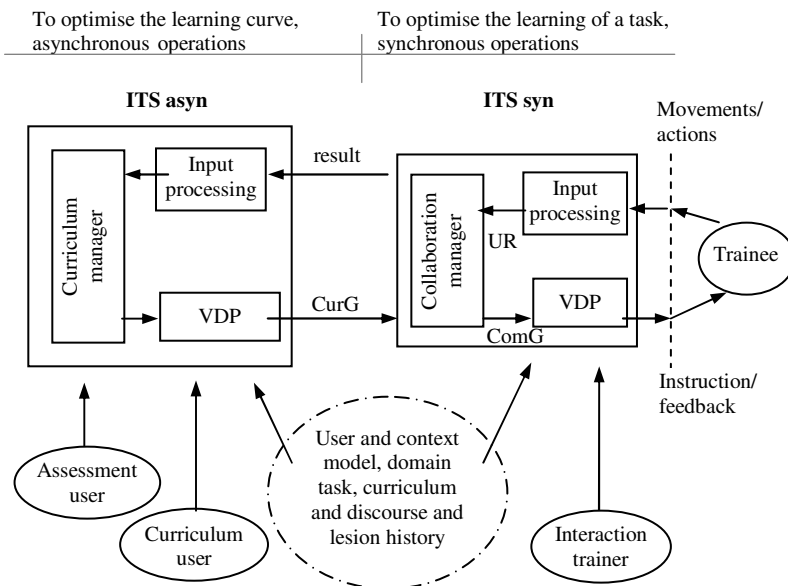
- The goals should be objective, master related, performance goals, i.e. to pass; a specific task should be approved and it should be assessed based on facts. Because of all trainees must master a number of tasks to pass, the overall goals can not be set at individual basis. However there should be different goals for different user groups, from experienced surgeons to novice trainees. If the user strives to achieve to the goal, the system should be highly supportive and provide appropriate instruction or change training strategy.
- As used in laparoscopic surgery, demonstration and instructions when training lower level muscular groups, the thesis view is that there might be a positive effect of instruct explicit *what* to do, but not *how* to implicit do it, i.e. there is little effect in guiding the trainee physically [21]. Explicit knowledge is used to train implicit skills. Attention should be directed towards the external effects of the action, e.g., the gallbladder will stretch if it is grabbed and pulled, rather than the trainee's limbs, and e.g., the wrist should be held in a 45 degrees angel. However, demonstrations and instructions for novice are not necessary the same for experts, often they are dealing with different motor problem according to their respective pre-knowledge.
- If improved skill learning shall occur, it is important that the performer of the skill gets optimized feedback. The two types of feedback in a haptic training environment are (1) sensory feedback or force feedback, given from the haptic part of the artefact and (2) performance feedback which is the assessment of the outcome. Feedback also plays an important role in the motivation to the trainee, which make the presentation of the feedback critical. Feedback related to the movement should be as simple as possible and convey important information about the goal attainment.

## 7. PROPOSALS TO THE DESIGN OF TEACHING STRATEGIES

The outcome of the theory, result and discussion chapter gives a base for me to come up with two design proposals; (1) the general design and requirements to the Intelligent Tutorial System (ITS) and Virtual Document Planner (VDP). (2) A range of basic teaching strategies to use in motor skill training. Those strategies depend upon assessable dimensions and this chapter suggest several parameters to use as dimensions. The feedback provided for the trainee by the VDP depends on which strategy is used. The physical interaction by the trainee takes place in the Haptic Workbench (HWB). Please note that I use theoretical data and is not aiming to be complete but to give a basic insight and idea of how to design an Intelligent Tutorial System (ITS) appropriate for training of motor skills to surgeons with focus on teaching strategies. Teaching is the tutorial task where training is the domain task.

### 7.1 INTELLIGENT TUTORIAL SYSTEM AND VIRTUAL DOCUMENT PLANNER

The thesis suggests a design of the Intelligent Tutorial System (ITS) used for teaching motor skills, where the Virtual Document Planner (VDP) is integrated as one part of the tutorial system. Figure 40 illustrates that the ITS is decomposed in two parts where ITS asyn is on a conceptual level and the ITS syn is on a realistic level. This is to make the system as flexible as possible; both to use and to administrate. The content to both ITS asyn and ITS syn are designed based upon the environment in which the training takes place. This is included concern about the user and context model, the domain task, the curriculum and the discourse history. Please note that this is a draft.



**Figure 40.** ITS in motor skill training with the aim to optimise the learning curve. There are four types of users, the trainee, the assessment of the trainee user (AU), the curriculum for the trainee user (CU) and the interaction trainer (IT). The Virtual Document Planner (VDP) is here a part of the ITS. Between the ITS asyn and the ITS syn a curriculum goal (CurG) is sent and between the collaboration manager and the VDP a commutative goal (ComG) is sent. The user response (UR) is sent between the input processing and the collaboration dialog.

In this model of training environment, used for motor skill training, there are two types of Intelligent Tutorial Systems involved; (1) ITS syn (working synchronous with the trainee), is focusing on the task performance. How to guide the trainee to fulfil a task, e.g., to remove the gallbladder. Which teaching strategy to use and how to give instructions and feedback. (2) ITS asyn (working asynchronous with the

trainee) that is focusing on the long term goal which is to optimise the learning curve for learning motor skills. This is a part of, e.g., the overall medicine studies where the goal is to handle the required motor skills when performing real surgery. This part considers the result of previous tasks to choose which task to present next.

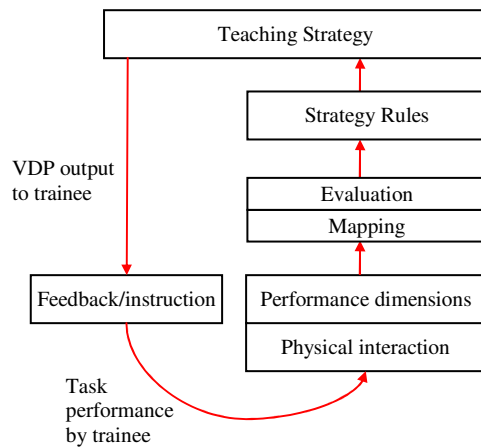
ITS syn gets a curriculum goal (CurG), or a motor skill goal, from ITS asyn. The collaboration manager decides based upon knowledge about the user how to communicate the task and sends a communicative goal (ComG) to the VDP which decides which learning strategy to use and instruction and feedback to give. The ITS syn has except from the trainee another user as well. The interaction trainer (IT) is an expert in a motor skill field and designs the haptic task and feedback.

ITS asyn gets the return from user response (UR), or result of the performed task, from ITS syn. The input processing works on this information, sends it further to the curriculum manager and the VDP formulate next performance curriculum goal and send this to ITS syn. ITS asyn creates lesson history and has two types of users. It is the assessment of the trainee user (AU) that follows if a student performs what is expected, that approve that the student has succeeded the motor skill curriculum. The curriculum for the trainee user (CU) is the one deciding what to be taught. What tasks is needed to manage before being approved in the motor skill skilfulness.

## 7.2 TEACHING STRATEGIES

Teaching strategies used in Intelligent Tutor System synchronic (ITS syn), outlined in session 7.1 focuses on motor skill training for surgical trainees. The teaching strategy is able to change from one trial at a task to the next. This is to provide, so the trainee receives an optimal and appropriate amount of information at all times (so the trainee is at the attractor point at the incongruity curve). This session focuses on teaching strategy for the surgeon trainee and is not concerning other users as authors of the system.

The teaching strategy to use is settled by the user's physical interaction which is divided into several assessable performance dimensions. The physical interaction is assessed by the performance dimensions and the outcome is mapped, evaluated and used as input for a set of strategy rules which adjust the teaching strategy. The dimensions of the physical interaction are both assessed independently of each other and as a whole constitute the assessment of the task performance. When the Virtual Document Planner (VDP) prepares teaching strategy for upcoming task, the VDP should consider strategy both depending upon the overall result from previous task strategy and if there is a need for adjusting strategy, the performance dimensions should be considered to be independent. The instruction and feedback provided for the trainee by the VDP depends on which strategies are used. See Figure 41.



**Figure 41. Architecture of the basic layers which settle which teaching strategy to use.**

An exercise is several repetitions of a task, and a task is illustrated as one loop in Figure 41. The task is repeated according to the theory of learn-by-doing. At each loop the same motor skill task is trained but the explicit goal can vary.

### 7.2.1 Physical interaction

The physical interaction by the trainee takes place in the Haptic Workbench (HWB) and aims to train motor skills. To give following sessions a framework, the domain task is in the chapter presented by a model task in needle insertion, for conceptual purpose. The example is an example of a closed motor skill where the object of the response remains stationary, and there is no change in response requirements from one response to the next. The example was chose because of it's complexity including the elementary tasks and performance dimensions, discussed in session 7.2.2.

The needle insertion procedures range in complexity from superficial needle pricks to the biopsy of deep-seated tumours, and involve the subcutaneous insertion of long, slender surgical tools and needles into soft, inhomogeneous tissue, usually without visual feedback from below the skin's surface [56]. Physicians and surgeons often rely only upon kinaesthetic feedback from the tool, correlated with their own mental 3D visualisation of anatomic structures [56].

The needle insertion can be decomposed into four steps; (1) approach of the surface where the needle should prick. (2) Rotation of the needle to reach the correct angle towards the surface and/or the underlying structure. (3) Point in the correct direction which is the same as a pause when the two criteria above are fulfilled. (4) Push the needle towards the surface and into the target structure.

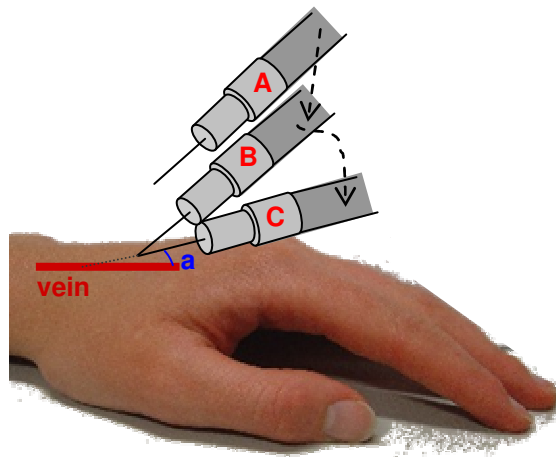


Figure 42. The figure illustrates the procedure of needle insertion in the *vein* with the appropriate angle  $a$ . The steps preceding the insertion is illustrated by the needle *A*, *B* and *C*.

Figure 42 illustrates the procedure that precedes the needle insertion. The needle *A* is approaching the surface, i.e. the skin at the hand. The needle *B* has approached the surface and is rotated to reach the correct angle towards the *vein*. The needle *C* has reached the appropriate angle  $a$  towards the *vein* and the final step is to push the needle through the skin, into the *vein* with the correct amount of force.

### 7.2.2 Performance dimensions

When a trainee performs a task, the physical interaction of the trainee can be decomposed into performance dimensions. The trainees action can be interpret in terms of timing, precision, smoothness, stability and strength, see Table 4. The performance dimensions can be measured in physics terms and assessed objectively.

The exercise the training environment supply to the trainee is a composition of several elementary tasks. The elementary tasks are united by performance dimensions where one task is depending upon several dimensions, see Table 4.

<b>Performance dimensions</b>	<b>Timing</b> time (s)	<b>Precision</b> [x,y,z] length (m) or rotation (rad)	<b>Smoothness</b> acceleration (m/s <sup>2</sup> )	<b>Stability</b> [x,y,z] change of length and/or rotation = 0	<b>Effort</b> force (N)
<b>Elementary tasks</b>					
Linear transformation	x	x length (m)	x		
Angle transformation	x	x rotation (rad)	x		
Pointing				x	
Holding/pressing				x	x
Pulling/pushing	x	x	x		x

**Table 4. Illustration of performance dimensions and their decomposition in elementary tasks.**

Used upon the example outlined in session 7.2.1, the needle insertion exercise, the linear transformation is the trainee's transportation from A to B, i.e. in the example it is to move the needle from current position to the top of the hand, where the skin constitute as surface. To do this, a movement in space (x, y and z), measured in length is required. How long time it takes to fulfil the movement is measured in time. How smooth the movement is made is measured in change of speed, number of accelerations or the wish that the accelerations there is should be smooth.

When reaching the skin there must be an angled transformation, i.e. a rotation of the needle to reach the appropriate angle towards the vein to precede the insertion of the needle in the patient. The rotation is measured in radian change in space (x, y and z). As the linear transformation, how long time it takes to reach the correct angle and how smooth the movement is, is considered.

When the needle finally is in appropriate place and angle, the needle is pushed with appropriate effort into the vein. The used force must then be reduced so the needle is not push through the vein and out on the other side. The task of pushing (and pulling) is considered time it takes to perform the movement, the precision of the movement, how smooth the movement are and how much force is used. Note that effort is not referring to the muscular effort preformed by the trainee; instead effort is referring to the measurable use of force (measured in Newton) in the training environment to perform a task.

The goal of a needle insertion can be to inject a liquid on the vein. The task is then to hold the needle still while this is performed. Holding (and pressing) require use of force and stability. Stability is measured in lack of (or minimal) movement in space, no change in x, y, z. If there had been no pressing or holding required the task had been defined as pointing. A common task where pointing is required is use of camera in laparoscopic surgery. The camera is required to be hold still but no force (in the environment) is required.

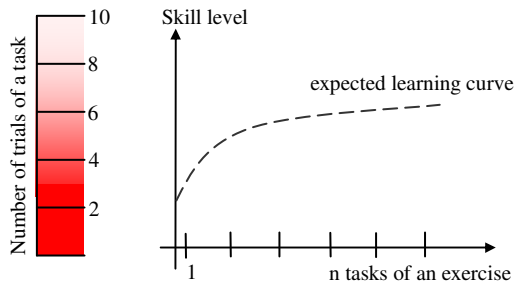
It is one additional event that will take place in the environment but it is not considered as a task because it has no intention and no goal. It is when the trainee "do nothing" or dwelling. This can be seen as a separator in space and time between two tasks but two task must not necessary be separated by dwelling.

The overall completion of the task in terms of time is an aspect or dimension to consider to not letting a task go on "forever". However it is not considered to be a performance dimension, instead the performance dimension there is have included a timing dimension respectively. The overall completion of the task is assessed in both absolute time (seconds) and the ratio between the respective timing dimensions of the performance dimensions.

The exact use of the performance dimensions in terms of what is appropriate in a reality surgery and with that in the simulation (how smooth a movement needs to be or how much force is required to pull an organ) is not discussed in this thesis. This is a question for surgery experts.

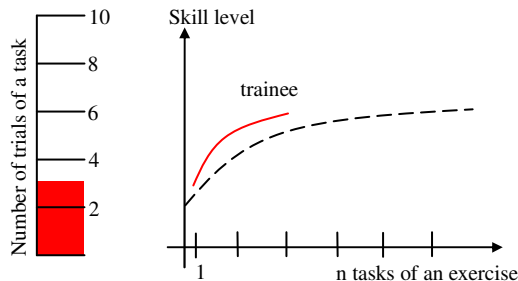
### 7.2.3 Hypothetical performance scenarios

The physical interaction is mapped by the performance dimensions, and can have several outcomes. The performance development of a task follows the general learning curve or the result of a fictive control group [60], see Figure 43. The trainee is expected to rapidly increase the level of performance in the first two to three repetitions and then to slow down at the pace of improvement. One task will be repeated until satisfying results is performed. One trial of the task is assumed to take 30-60 seconds to perform and is suggested to be repeated up to ten times, see Figure 43. Before repeating the task, teaching strategy can be changed (Figure 41). The skill level is in terms of performance and is measured in the performance dimensions. Before entering a task there no explicit expectations to the trainee, but after his/her first trial, the performance are compared to the expected learning curve.



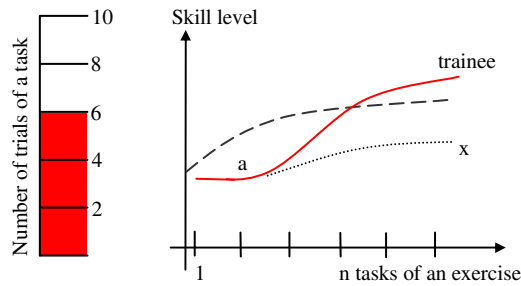
**Figure 43. The general, expected, learning curve and a graphical illustration of number of trails made at task.**

In the first case, illustrated in Figure 44, the trainee performs with better result than the expected learning curve. The trainee is assessed to handle the motor skill task and to not make the trainee bored, the task is ended after three trials and the trainee is presented for next exercise.



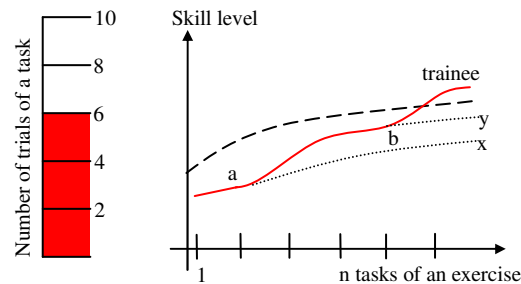
**Figure 44. A case where the trainee perform better than expected, the trainee is assessed to handle the motor skill and the task ends after three trials.**

Figure 45 illustrates a trainee performing poorly than expected; the trainee’s skill level is below the expected learning curve. The curve  $x$  illustrates hypothetical performance, at constant too poor level, if the teaching strategy had not been changed. After one trial, at  $a$  the teaching strategy is considered, by the VDP, to be changed and the trainee starts to perform better again. After six task trials the trainee are considered to perform good enough to end the exercise.



**Figure 45.** The trainee perform poorly than expected and at teaching strategy is changed at *a*. The *x* curve illustrates hypothetical performance if the teaching strategy had not been changed.

It is possible that the teaching strategy have to be changed more the one time as illustrated in Figure 46. First at *a* but also at *b* when it is considered that the learning curve has started to flatten but without that the trainee has reached the expected skill level. The curves *x* and *y* illustrate hypothetical performance if the teaching strategy had not been changed.



**Figure 46.** A case where the teaching strategy is changed twice, at *a* and *b*. The *x* and *y* curve illustrate hypothetical performance if the teaching strategy had not been changed.

The number of possible cases to occur is infinitive. The examples above are examples that aim to give an idea of when a change of teaching strategy is appropriate and what effect it is expected to give.

#### 7.2.4 Strategy Rules

The assessment of the performance dimensions, outlined in session 7.2.2, underlie the rules of which teaching strategy to use. The performance dimensions are mapped and evaluated to measure to quality of the performance comparatively to the optimal result of a trial. There are four basic alternative of the assessment of a trial to a task; (1) the performance is good, (2) the performance is poor in one specific dimension, (3) the performance is poor in one dimension but it change from trial to trial which one it is, and finally (4) the performance is poor in several dimensions.

If the performance is good there is no need to change teaching strategy. An exception is if the task is presented with detailed instructions, in this case it is appropriate to reduce the information given gradually, to keep the challenge up and avoid boredom.

If the performance is poor in one specific dimension the goal must be redefined and concentrate on how to increase the trainees motor skill in this specific dimension. The teaching strategy should focusing on this specific dimension e.g. if the trainee have a problem with holding the instrument still and fulfil the performance dimension of stability, the teaching strategy should focus on train this dimension. It is also possible to provide a task change, to give the trainee a task concentrating on this dimension, together with instructions of how to do.

Poor performance in one or a few performance dimensions, but when which dimension/s/ it is change from trial to trial, the trainee might have a problem coordinating his/her movement or is not focusing on the task well enough. The teaching strategy is then appropriate to train a few dimensions at a time to slowly build up an improved performance with all dimensions included.

Finally if the trainee performs poor in several or all performance dimensions, the case is either that the task is too complicated for the motor skills the trainee has achieved at present, or that the trainee does not understand what to do. The teaching strategy is than appropriate to change into more explicit guiding of the trainee of what to do. If this has not given satisfying result within a few trials, the exercise should be ended and replaced with a less demanding exercise.

### 7.2.5 Teaching Strategies

The trainee’s physical interaction, the assessment of the performance dimensions and use of the strategy rules decides which teaching strategy to use for next task. With starting point in the strategy rules, outlined in session 7.2.4, there are four different teaching strategies identified, see Table 5.

Task performance:	Change to teaching strategy:	Output:
Very good	Increase challenge	Give fever instructions
Good	-	
Poor in specific dimension/s/	Iterate	Focus on poor dimension/s/, repetition of task several times to learn-by-doing
Poor in one/a few dimension/s/ (but which one/s/ change from trial to trail)	Teach	Concentrate on few dimensions at time
Poor in several dimensions	Guide	Give more instructions of what to perform

**Table 5. The alternative teaching strategies. The strategies are depending upon the task performance that needs to be attendant in one or another way.**

It is the assessment of one task performance that might change the teaching strategy, it is not necessary to wait for the overall performance level of the trainee. The change from one training strategy to another is not linear, i.e. the change between strategies in Table 5 is depending upon the trainee’s performance, not which teaching strategy the trainee is using at present.

If the performance is good there is no need for changing teaching strategy. The teaching strategy *Improve challenge* results in that less instruction is given to the trainee. The strategy *Iterate* builds upon the philosophy learn-by-doing where the task is repeated several times to get the poor dimension “in the bones”. *Teach* is used when the trainee’s performance is poor in one or a few dimension/s/ but which dimension/s/ it is change from trial to trail. The *Teach* strategy focus on a few performance dimensions at a time to let the trainee get used to combine several dimensions in a task. The strategy *Guide* is used when the trainee performs poor in several dimensions. The strategy focuses on making it explicit for the user what to perform, to give more instructions of how to receive the goal of the task.

## 7.2.6 Guidelines for feedback and instructions

It is necessary to give instruction and feedback to receive optimal performance. Please note that this section is not aiming to be complete, but to give a basic insight and idea of how feedback and instructions can be design and presented for the user in the framework of haptic training for surgeon, with focus on teaching strategies.

The theory chapter (chapter 2) presents three types of augmented feedback that are used in the examples below. The three types are; (1) Knowledge of Result (KR) which tells about the result in objective terms, e.g., seconds, meters or Newton or in interpreted terms, e.g., percent from reaching optimal outcome. (2) Knowledge of Performance (KP) tells about the result in subjective terms, e.g., the precision was fine or the movement was not smooth enough. (3) Augmented Sensory Feedback (ASF) is when the external device (in this case the Haptic Workbench) enhances sensory feedback, e.g., a sound is given when the performance is good enough/not good enough.

The Knowledge of Result (KR) and Knowledge of Performance (KP) can be translated into terms of demonstration and instructions. Demonstration is when the trainee is showed what to do, e.g., an animation of what to perform. Animations can be used for showing the performance dimensions precision, timing, smoothness and stability but it does not handle to instruct effort in terms of how much force to use. To demonstrate this effort the trainee must be guided physically and the assumption for this thesis is that this is not of benefit for motor skill training. Instructions is telling the trainee of how to perform in terms of what to focus on and care about while performing, e.g., follow the line x and perform the movement gentle. How to perform is not concerning how to adjust and move own limbs. Instruction can be given before the trainee starts to perform and during the performance.

Instructions and feedback are not necessary the same for a novice as an expert surgeon. This thesis focuses on the design of instructions and feedback towards novice users. The novices are meant to work with the environment continuously during their student period and with no or very little pre-knowledge in surgery, the trainee is a good example to use when designing instructions and feedback. However the overall recommendation is that the experts begin the training task using less instructions and the feedback is focusing on the result of the outcome (KR). The reason for this that the experience surgeons are supposed to already possess a fairly high level of motor skills and domain knowledge.

### Instructions and feedback for specific performance dimension

Examples of Instructions, before the task is performed for the first time (Table 6) and after feedback is given (Table 8) and examples of feedback of KP (Table 7), for the respective performance dimensions. Examples of Demonstration and KR are not given since those will vary from task to task, depending upon the exact task to perform.

Performance dimensions	Instructions given at the beginning of the exercise
Timing	Fulfil the task in a time effective way / fulfil the task in 30/60/90 seconds / ...
Precision	Follow the line x / rotate the tool as the marked angle shows / make sure that the distance from start to finish is as short as possible / rotate the tool to reach appropriate angle / ...
Smoothness	Perform the movement gentle / perform the movement firmly / perform the movement stable / ...
Stability	Hold the tool still / ...
Effort	Use a small amount of force / use a medium amount of force / use a large amount of force / ...

**Table 6. Examples of Instructions, at the start of a task for respective Performance dimension.**

<b>Performance dimensions</b>	<b>Feedback of Knowledge of Performance (KP)</b>
Timing	Very good / good / too slow / too fast
Precision	Precise / good / not precise enough
Smoothness	Elegant / good / too rough / too aggressive
Stability	Stable / good / too shivery / too shaky
Effort	Very good / good / too much force / too little force

**Table 7. Examples of Knowledge of Performance (KP) feedback, for respective Performance dimension.**

<b>Performance dimensions</b>	<b>Instructions given during the exercise, with intention to improve/correct the performance</b>	<b>How to improve the performance</b>
Timing	Keep the good work up / try to perform the task faster / try to slow down	
Precision	Try to follow the line x more precise / try to rotate the tool more/less to reach a more precise angle / try to shorten the distance from start to finish / ...	
Smoothness	Try to be more gentle / try to be more firm / try to be more stable / ...	Relax in the shoulder, arm and hand. Make sure you got a good ergonomic posture
Stability	Try to hold the tool more still / ...	Relax in the shoulder, arm and hand. Make sure you got a good ergonomic posture
Effort	Try to use less/more force / ...	

**Table 8. Examples of Instructions, after feedback is given, with intention to improve/correct the performance for the respective Performance dimension.**

### Instructions and feedback for respective teaching strategy

Which, how and when the instructions and feedback given is depending upon which teaching strategy is used. Table 9 suggests, based on session 2.2, motor skills, how to use instructions and feedbacks for the respective teaching strategies.

Teaching strategy	Instructions	Feedback
Improve challenge	Give fewer instructions, instructions given focuses on how to perform.	Give feedback focusing on the KR after each task trial.
Iterate	The instructions, both what to perform and how to perform, should concentrate around the dimension that is not performed satisfactory.	Give feedback both about KR and KP after each task trial. Give ASF during performance.
Teach	The instruction, both what to perform and how to perform, should concentrate around few dimensions at a time, focusing on combining several dimensions.	Give feedback both about KR and KP after each task trial.
Guide	Step-by-step guiding, precise instructions of what to do, both what to perform and how to perform, with main focus on what to perform.	Give feedback after each elementary task completion, focus on KP.

**Table 9. Design of instructions and feedback for respective teaching strategy.**

#### 7.2.7 Scenario

Following case aims to give a scenario of the use of teaching strategies. The examples used, insertion of a needle, is outlined in session 7.2.1. The scenario is focusing on a verbal communication of feedback, this to make easy understandable illustration, feedback can be given through other modalities as well.

Ewan logs in and while he enters the Haptic Workbench, he becomes recognised by the Collaboration Manager as a second year medicine student, still defined as a novice. This is Ewan's second time at the Haptic Workbench. Yesterday he got a lecture in needle insertion and he presumes that this is what he is going to practice today. The training system has after a check at the result of last times performance decided to keep Ewan in the *Teach* strategy mode.

The screen shows an animation of what to do and then Ewan gets an instruction:

*"The goal with the task is to practice needle insertion in the dorsal veins of the hand. The goal is to insert a needle as smoothly as possible in the patient.*

*Move the tool to the surface of the hand, rotate the tool as the marked angle shows. Try to perform the movement firmly."*

Ewan performs the task and gets feedback and new instructions, designed by the Collaboration Manager:

*"Good precision and good smoothness in the movement, you are 10% from optimal performance in these dimensions. But you use too much force in the insertion; please try to use less force."*

Ewan performs the task twice more but the training system is not pleased with the effort dimension. Ewan uses too much force in his attempts. The Manager decides to change teaching strategy from *Teach* mode to *Iterate* mode to focus on the effort used.

*"Try to use less force in the needle insertion. When you hear the 'bip' you know that you use an appropriate amount of force"*

The task is performed three more times and Ewan gets feedback of how much force, in terms of Newton, he use at each trial and what to focus on and care about to improve the performance further. Finally the training system considers the task fulfilled for this time and gives Ewan the feedback:

*“You have passed the exercise for the first round, well done!”*

Ewan is pleased but he considers himself that he needs to practice the needle insertion more and books a new time for training the following day.

## 8. CONCLUSION

In medicine, technological tools are rapidly evolving. The recent year's development of computer-supported tools has had a huge impact on the surgery arena and use of many new techniques has been enabled. This development has impact of training area, to be able to make use of the profit of the new technology the surgeons must be trained to us it. There is a need for an alternative training environment for surgeons, and haptic training in a virtual environment is under developing.

Findings in this thesis show that there is a lack of individualised training and follow up of the trainee during the performance among the products on the market; most systems are not offering a tailored training course with respect to the trainees' individual development. The most common used training model used today, is the apprenticeship model. Trainees learn by watching an experienced surgeon and participating in reality surgery. It is an expensive model because the trainer and trainee must be at same place at the same time and a trainer can not train more than one or a few trainees at a time. However the trainees get direct feedback and follow up, which is necessary for effective and efficient learning, according the view of motor skill training adopted by this thesis. The thesis propose to use the collaboration model but to take the role of the human trainer and apply this role to a combined Virtual Learning Environment (VLE) and Intelligent Tutorial System (ITS) training environment. On one hand the VLE offers non-threatening and risk free learning, the ITS on the other hand guarantees that the trainee receive the appropriate instruction and feedback that are important for learning. The result will be a training environment where the trainee gets direct instruction and feedback from the system and herewith can train motor skills. The human trainer gets a role of a supervisor.

The thesis proposes the design of an individualised training system where the change of the applied teaching strategy during the performance is central. This approach enables training focused on to optimise the learning curve. The training systems proposed in the thesis bases on two parts; the first part manages the planning of the explicit representation of the domain task and the curriculum. The second part manages the planning of the tutorial task, with focus on the task performance. This part considers which teaching strategy to use and instructions and feedback to give upon the trainees' physical interaction assessed by a set of performance dimensions and a set of strategy rules. The performance dimensions are decomposition of the trainees' physical interaction in the training environment and can be measured in physics terms and assessed objectively. The performance dimensions underlie the strategy rules of which training strategy to use.

## **9. FURTHER WORK**

This thesis is only based on literature search, discussions with experts and product survey. Further development of the design should be to involve users in the process and consider the usability of the environment. The thesis shows that there is a need for individualised training in the virtual motor skills training environment. To establish the dimensions and parameters in the proposed design of teaching strategies, it is necessary to involve experts from the teaching and surgery subject area. The work constitute as a part of CSIRO's engagement to design alternative training methods for surgeon trainees.

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## GLOSSARY

### Technical terms:

Apprenticeship model	System of learning which is characterized by a mentor-student relationship.
Collaboration model	A software component that mediates the interaction between a software interface, agent and a user.
CSCW	Computer Supported Cooperative Work
CSIRO ICT	Australia's Commonwealth Scientific and Industrial Research Organisation, science area of Information and Communication Technology.
Explicit knowledge	Knowledge that can be easily expressed in words or numbers.
Haptic	Sense of touch or tactile sensations; having a greater dependence on sensations of touch than on sight.
HWB	Haptic Workbench, stereoscopic workspace which combines stereo images, co-located force feedback and 3D audio to produce a small-scale hand immersive virtual environment system.
Implicit knowledge	Knowledge or know-how that people carry in their heads, silent knowledge.
Incongruity	The relationship between internal complexity of a learning system and external complexity of the context.
ITS	Intelligent Tutorial Systems
Motor skill	Skill that requires body and/or limb movement to accomplish the goal of an action or task.
PLZT shutter glasses	Used in the HWB to create stereo images.
Skill	Capability of accomplishing something with precision and certainty; practical knowledge in combination with ability; cleverness, expertness
VDP	Virtual Document Planner, technology used at CSIRO to handle representation of large amount of data.
VE	Virtual Environment
VLE	Virtual Learning Environment
VRML	Virtual Reality Makeup Language

### Medical terms:

Bronchoscopy	Procedure that permits the surgeon to see the breathing passages through a lighted tube.
Cardiovascular system	The circulatory system which comprises the heart and blood vessels.
Cholecystectomy	Surgical removal of the gallbladder.
Endometriosis	Cells that normally grow inside the uterus (womb) instead grow outside the uterus.
Endoscopy	A broad term used to described examining the inside of the body using a lighted, flexible instrument called an endoscope. In general, an endoscope is introduced into the body through a natural opening like the mouth or anus.
Endourology	Endoscopic procedure used in urology to examine, e.g., kidney, ureter and bladder.

Endovascular	Endoscopic procedure used in the vascular system, e.g., blood vessels.
Fluoroscopy	X-ray procedure that makes it possible to see internal organs in motion.
Fundoplication	A surgical technique that strengthens the barrier to acid reflux when the lower esophageal sphincter does not work normally.
Gastrointestinal	Adjective referring collectively to the stomach and small and large intestines.
Laparoscopy	A type of minimally invasive surgery in which a small incision (cut) is made in the abdominal wall through which an instrument called a laparoscope is inserted to permit structures within the abdomen and pelvis to be seen.
Oophorectomy	The removal of one or both ovaries by surgery.
Phlebotomy	Obtaining blood from a vein.
Tubal ligation	Sterilization technique for women.