MASTER THESIS

REQUIREMENTS FOR EFFICIENT ROBOTIC SURGERY TRAINING

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1 Abstract

Robot assisted surgery is the next step in the evolution of the surgical domain. To support this development well-structured training programs are needed. Schreuder, Wolswijk, Zweemer, Schijven, and Verheijen (2012) give a structured overview of the robot assisted surgery training literature. Fisher et al. (2015) summarize the status of emerging training programs. Those two literature reviews are extended with a newly performed literature review. The extension includes the road to expertise, a broader use of expertise literature and lessons learned from aviation and sports. The purpose of the review is to find requirements for robot assisted surgery training. Further, gaps in the provided literature reviews are discussed. According to the core requirements for a robot surgery training the curriculum should be: (a) cognitive science and expert literature based, (b) proficiency based, (c) simulation based, (d) standardized, (e) validated, and (f) adaptive to experience level of the trainee. Those core requirements can be extended by the following recommendations. A robot assisted surgery training should consist of: (a) technical and non-technical skill modules, (b) emergency training, and (c) recursive proficiency based assessments and credentialing of surgeons. Last but not least a prototypical curriculum creation process is provided.

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3 Requirements for efficient robotic surgery training

Robot assisted surgery has created a solid momentum in the last two decades, supported by surgeons as well as by researchers. An exponential growth in literature releases about the topic promotes this development, as shown by Schreuder and Verheijen (2009). They further show an exponential growth of performed procedures with the da Vinci robotic system. In 1998, 127 procedures were performed. In 2008, there were 132 454 procedures. The da Vinci robotic system (Intuitive Surgical, Inc) is the only commercially available system for general robotic assisted surgery, after the discontinuation of the ZEUS robotic surgical system in 2003. Schreuder and Verheijen (2009) summarize their results of a literature review they performed, with a list of advantages and disadvantages of robotic surgery. Among others, the main advantages they found are: (a) “better ergonomics for the surgeon”; higher degrees of freedom of the instruments compared to a human hand, (b) “elimination of physical hand tremor”, (c) “improved dexterity” (fine motor skills), (d) better vision, and (e) the “elimination of fulcrum effect” (p. 207). In laparoscopic surgery the fulcrum effect is the reversal of the movements of the instruments to the movements of the surgeon’s hand. Better performance and less physical and cognitive stress for the surgeon compared to laparoscopic methods are for example reported by van der Schatte Olivier, Van’t Hullenaar, Ruurda, & Broeders (2009). Nevertheless, there are some disadvantages too: (a) “high costs [for the] robotic system [and the] maintenance [of it]”; (b) “bulky size of the robotic system”; (c) “sometimes difficult access to the patient”; (d) “no tactile feedback [for the surgeon]”; (e) “chance of breakdown”; and (f) they criticize the monopoly of the da Vinci system, as the only commercially available option for robot-assisted surgery (Schreuder & Verheijen, 2009, p. 207).

As of 2015 more advantages can be added, as some were missing in their summary. Blute and Prestipino (2014) describe that data in the literature suggest less blood loss and shorter stays in the hospital compared to traditional procedures. However, they point out that these advantages have to be considered with care, because the overall postoperative complication rate could only differ minimally between the methods. The experience of the surgeon and the number of performed procedures with either of the methods at the hospital are better predictors for the outcome of the procedure than only the used method (Blute & Prestipino, 2014). Another disadvantage of robot assisted surgery is that it has led to severe complications in the past. These were attributed to inexperienced surgeons regarding the new technology and to the use of the technology for not well documented cases. All in all, Blute and Prestipino (2014) point out that the key to success for the introduction and use of the new technology is a well-designed and carefully integrated training program. Scientifically grounded guidelines and literature reviews are needed to support the development of such a training program. The most important reviews are shown in the following section.

3.1 Training of robot assisted surgeons

After a literature review about surgical robot assisted training programs Guzzo and Gonzalgo (2009) concluded that there is no current standardized training program and that the programs vary significantly in form and duration. A training can be as short as two days or as long as a full two years long trainee program. According to them, the most effective training is a “structured mentored training program” (p. 217). Subsequent to a systematic literature review about training and learning aspects of robotic surgery Schreuder, Wolswijk, Zweemer, Schijven, & Verheijen (2012) stated that “designing a competence-based training curriculum for robotic surgery remains a challenge …” (p. 146). Competency or proficiency based training is defined as setting a benchmark, validated by expert performance that has to be reached to gain credentialing. This is in contrast to a training model that is based on the time the trainee has spent acquiring the needed skills for surgery, i.e. volume-based training. The authors further describe the following points: assessment of skills training, learning curve and other aspects of robot assisted surgery training and they point out possible components of a structured competence based training in their guidelines. According to them most training models are divided into two categories, system training and procedural training, and their guidelines contains means to train knowledge and skills for the specific category. System training refers to knowledge and skills that are specific for the robotic system used, procedural training refers to the knowledge and skills needed to perform specific procedures with the robotic system. Last but not least they stress that with a stepwise and systematic training a safe and efficient use of the new method is possible. There are gaps in the review which can only be answered with further analysis of the literature and a broader scope, further discussed in the next section.

Schreuder et al. (2012) summarized training modalities, learning curve, training future surgeons, curriculum design and implementation. They did not embed those findings into the frameworks and literature about expertise, problem solving and decision making. Further, they did not provide findings about similarities and differences in comparison to classical minimal invasive surgery and open surgery. They did also not provide lessons learned in other disciplines like aviation or top-level sport about finding the road to expertise. Some of those lessons might be useful for the save introduction and maintenance of a robot assisted surgery program at a hospital. Last but not least they did not provide an overview of how to model surgical workflow and how to elicit expert knowledge. These areas are important if a program designer has to choose and create the content of the training program. Another important aspect for robot surgery training, which is missing in the review, is the transfer of skill from one operation modality to the other, for example from classical minimally invasive surgery to robot assisted surgery. To fill in the mentioned gaps a literature review was performed. Also issues that arose while trying to close the gaps will be discussed.

3.2 Frameworks and the development of robot assisted surgery training

One guiding theme for designing a medical training program is breaking down the experts' knowledge and procedures into smaller parts. After that the training program designer has to decide which parts should be learned with which method. Suturing, for example, could be learned on a simulator with the help of virtual reality, in a dry lab, in a wet lab, or a combination of those methods. Guidelines and research for designing such a training need to be embedded into frameworks as mentioned in the previous sections. Without such frameworks research in a systematic way would be difficult.

Experts are not born, they become an expert by deliberate practice (Ericsson, Krampe, & Tesch-Römer, 1993). Ericsson et al. (1993) provide a framework on how to become an expert trough deliberate practice. This framework from expertise literature can be useful for creating guidelines for training development. Anderson (2004) provides another line of research on how to develop specific skills with his three stage model for skill acquisition.

Not only frameworks about how to become an expert are relevant for guidelines. Frameworks and research regarding cognitive processes on expert level are also relevant. For example, a surgeon performing on expert level has to make informed decisions in complex real world scenarios. One approach to describe decision making in complex real world scenarios is naturalistic decision making initially developed by Klein (2008). Understanding those cognitive processes can help training designers to focus on key elements that a trainee has to learn to perform on an expert level later on. For future daVinci training programs it is interesting how the mentioned frameworks about expertise can shape future training programs and also what the status quo in literature is. These frameworks and lines of research among others will be used and further discussed in the following sections.

3.3 Research questions

The main research question for this literature review is: what are the requirements for efficient, effective and save robotic surgery training? To answer this question, it is approached with sub questions. These sub questions are: How can a training program designer define the road to expertise for the efficient, effective and save use of the daVinci robot? What are the relevant tasks a surgeon has to perform? What are the relevant frameworks for cognitive and sensorimotor processes in being and becoming an expert in robotic assisted surgery? What are the similarities and differences between laparoscopy and robot assisted surgery? How do these differences influence the transfer of laparoscopic skills to robotic surgery ones? Are there lessons learned in other domains, which could be useful in the context of robotic surgery? To answer these questions a literature review was performed to give an overview of the relevant topics and to line out the issues that arise. After that the literature was analyzed to give recommendations for promising future research topics.

4 Method

The process of the literature review is as follows. A similar method was used for the systematic literature review as was used by Schreuder et al. (2012). In contrast to the review of Schreuder et al. (2012) different search engines were used. Also, the date of publishing was not limited. An overview of the process can be found in figure 1. Further, the stepwise guidelines provided by the library of the University of Twente were followed (Boxem, n.d.). The used databases for the search are: (a) PsycINFO, (b) Web of Science, and (c) Scopus with integrated PubMed.

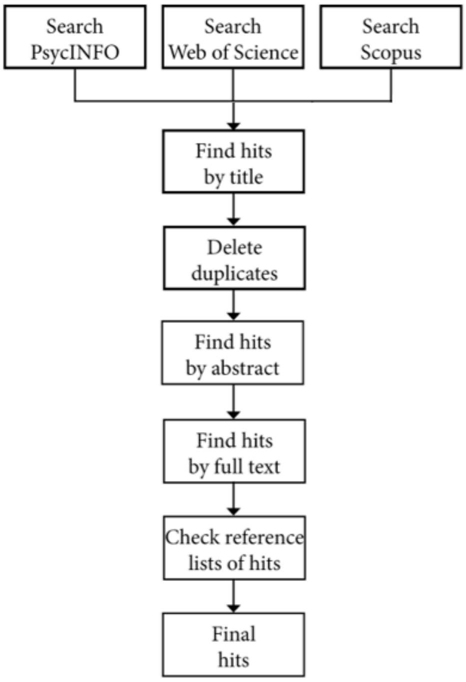

Figure 1. Stepwise search process until final selection of relevant articles.

The following initial search terms were used as a starting point:

- Transfer of skill
  - → (laparoscop* AND robot* surg*) AND (skill OR task) AND transfer)
- Surgical task decomposition and acquisition
  - → (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND (skill OR task) AND (decomposition OR deconstruction OR training OR aqui* OR proficiency)
- Task analysis
  - → (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND task AND analysis
  - → (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surge*) AND cognitive AND task AND analysis
  - → (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND hierarchical AND task AND analysis
- Cognitive, sensor, motor demands and skills
  - → (cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*)
- Critical incidents
  - → (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND (critical incident*)
- Aviation
  - → aviat* AND skill AND surg* AND training
- Sport
  - → sport AND skill AND surg* AND training

The initial search terms were refined if too many non-relevant entries or entries which were not specific enough were found. Further, the search terms were separated or changed if the search engine did not accept the search operators. Articles are eligible for use in the final review, when aspects of cognitive, sensor or motor demands of surgeons are addressed in the field of traditional, laparoscopic or robot assisted surgery. Articles covering requirements for robot training, critical incidents and task decomposition in the context of surgery are eligible, too. Articles regarding training, decision making and expertise in the field of Surgery and other domains, for example aviation and top-level sport are also considered as hits. For a fully systematic literature review the category transfer and comparison was processed until the step hits by full abstract. In the other categories an emphasis was placed on selecting literature reviews and literature that fill the gaps in those reviews as mentioned in the introduction. Finally, the articles were categorized and a short description of the most relevant aspects of each article for this study was summarized (see Appendix A). Until the step of finding hits by abstract and categorizing them, the literature review was performed systematically. To keep the work within the boundaries of a master thesis the literature review was further performed partly systematic. A detailed literature review protocol was created (see Appendix B).

5 Results

In the following sections the outcome of the search process is presented. This is followed by a general overview of the working field. After that the results of the literature review are shown in more detail for the different working field areas.

5.1 Search results

A literature review was performed to answer the aforementioned research questions. An overview of the search process is given in Figure 2. A total of 2696 hits without duplicates were gathered from the search engines Scopus, Web of Science, and PsychInfo. These were then further filtered via finding hits by abstract and categorizing them. Reference checks of the chosen literature resulted in six new hits. A total of seven hits are from other sources. The search and filter process resulted in 70 hits that were used for the literature review.

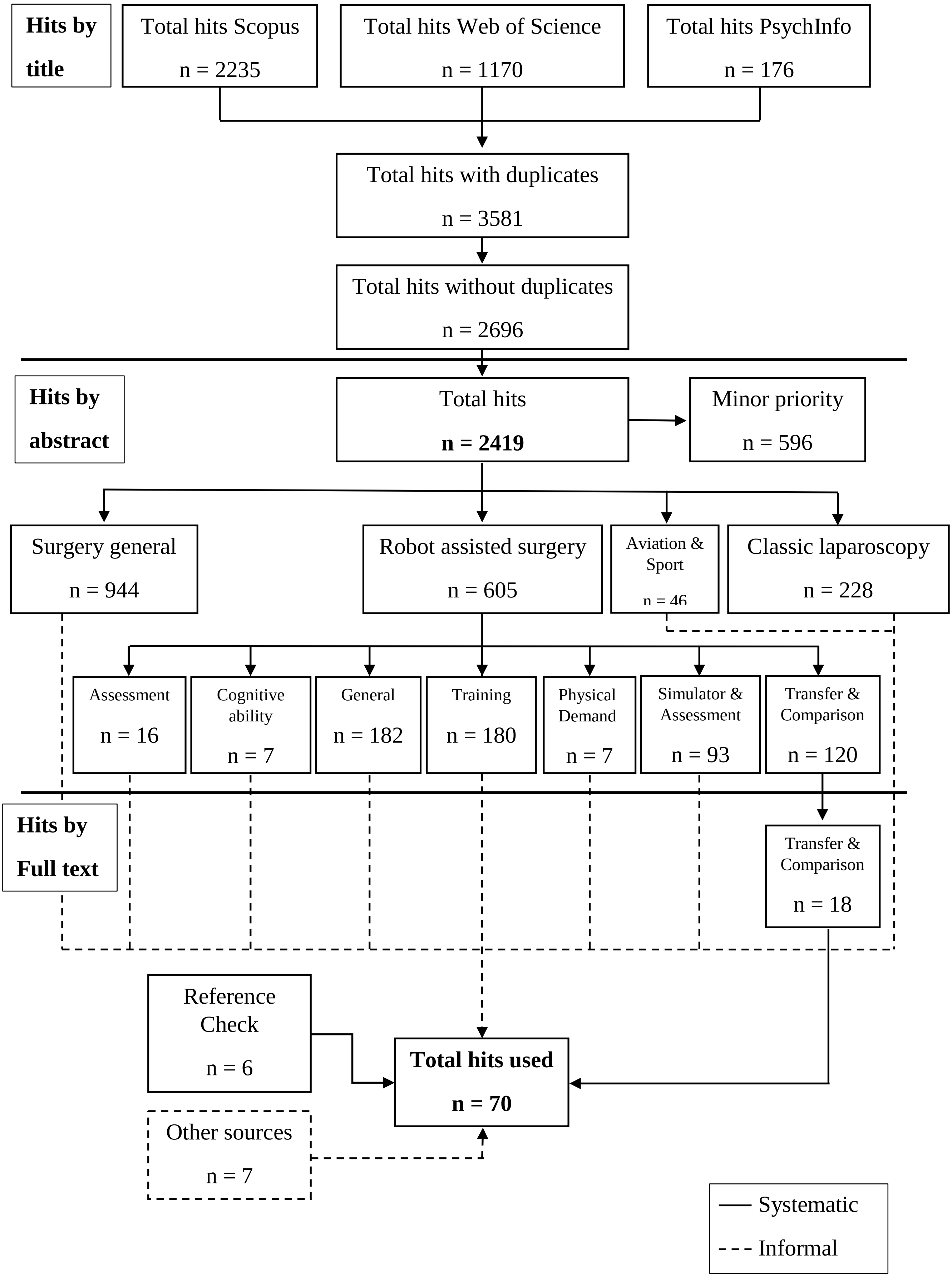

Figure 2. Overview and results of literature search.

5.2 General overview of the field

Setting up and maintaining a training program for robotic surgery is a demanding and complex task. Applicants need to be chosen, needed knowledge and procedures for becoming an expert has to be gathered. Means and modalities to train the knowledge and procedures have to be considered. Underlying cognitive, sensor and motor processes of a robotic assisted surgeon have to be broken down for structuring and content creation of the training program. Figure 3 gives a general overview of the field. The different parts of the work field and the found literature will be summarized and analyzed in the following, with the main focus on the transfer of skill, not covered by the literature review by Schreuder et al., (2012).

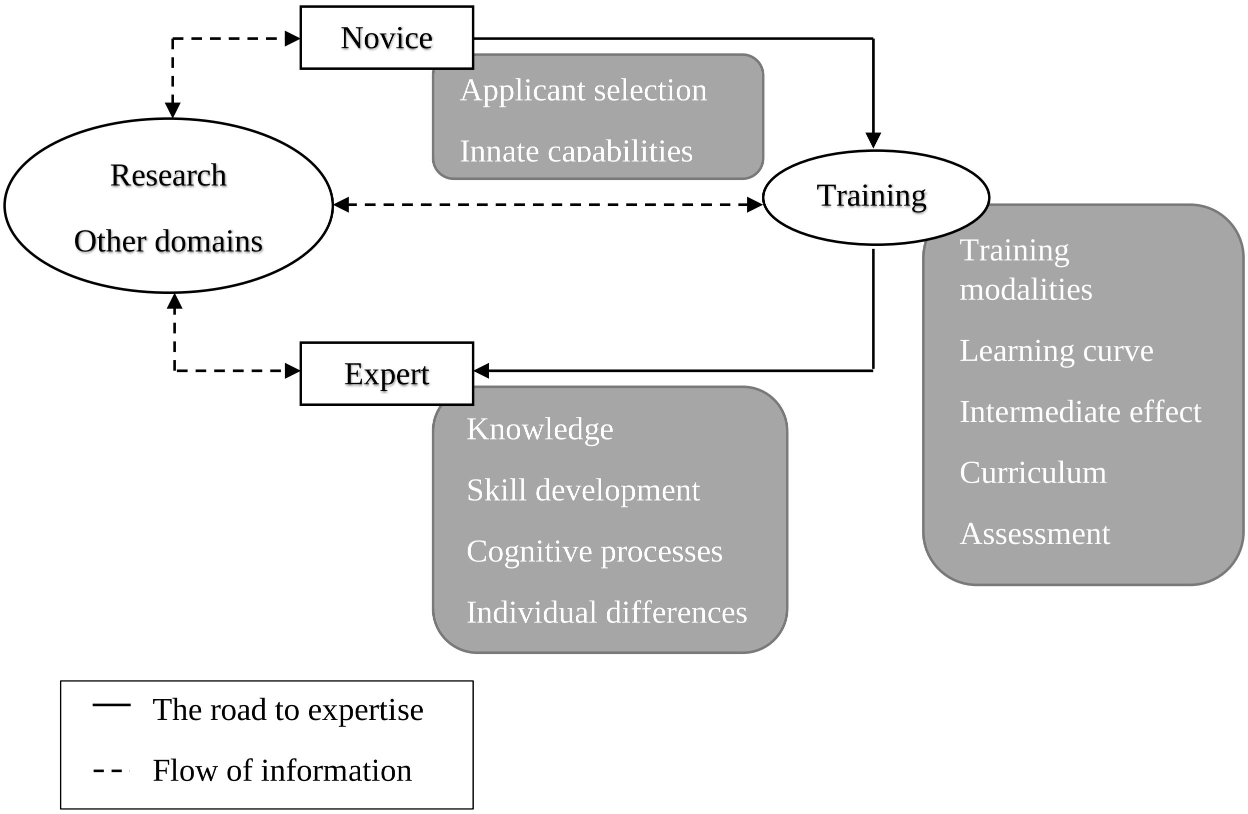

Figure 3. General overview of the field. Based on Robertson (2001).

5.3 Road to expertise

Expertise has to be broken down into smaller pieces for a detailed discussion, because of its complexity. Robertson (2001) suggests the following dimensions to research and discuss expertise: (a) “knowledge”, (b) “skill development”, (c) “cognitive processes”, and (d) “innate capabilities and individual differences” (p.168). Those aspects are summarized in the context of robot assisted surgery in the following part.

5.3.1 Surgery in terms of problem solving. A problem can be described by its initial state, the goal state, operators and restrictions (Robertson, 2001). For a better understanding of the problem it is important to categorize the problem. Surgery is an ill-defined, real world problem. Cao and Rogers, (2004) describe the main goal structure of a surgeon as follows:

> "As most of the global decisions for surgery have been made before entering the operation room, the surgeon's cognitive task during surgery consists of two parallel goals: 1) to execute a planned sequence of actions based on knowledge of the surgical procedure, and 2) to detect and correct deviations from the pre-planned course of action, as the operation proceeds, based on new information from the environment, as well as declarative knowledge of anatomy and case-specific details." (p.77)

The description of the problem already has all the key elements a training has to provide to help a novice to become an expert in surgery. It has to provide enough declarative knowledge, so the surgeon can make informed decisions for the next step. Surgeons need enough *experience*, so that they can execute the needed sequence of actions. Experience is building up over time resulting in *declarative* and especially *procedural knowledge*. Most prominent is anatomical knowledge as an example for declarative knowledge. *Cognitive* and *sensorimotor processes* are also listed implicitly in the description, so procedural knowledge is a key to success for becoming a surgeon. Detecting deviations from the pre-planned sequence involves attention to important aspects for each step, sensing those information and processing them, so *situational awareness* is important. The recall of the different steps for a procedure also involves cognitive processes.

The description of a surgical operation as a problem, and the surgeon as the information processing system (IPS) who navigates with the operators, for example informed decisions and actions, through the problem space inherits the information processing approach described by Newell and Simon (1972). This notion is important because it can help formalize the process of becoming an expert. It also helps navigating through the problem space of a surgical operation by using known cognitive architectures. Robertson (2001) summarizes that a human information-processing system has several limitations. They are summarized in Table 1. Those limitations have to be accounted for in a training program. Otherwise the efficiency of the program can suffer.

Table 1
Limitations of a human information processing system

Limitations
Limited working-memory capacity (Miller, 1956)
Limited throughput of information from the senses
Interference of new memories with old ones
Limited ability to retrieve stored information
Limited “ability to maintain optimum levels of motivation and arousal” (p. 19)

The state action space of a problem is the description of every possible step, or problem state the problem can have. Because of the limitations and the experience of a human IPS an instantiation of the state action space, called problem space, is individually created. In concrete terms, this means that a surgeon cannot and must not consider every possible step and its consequences to reach the goal of a successful surgical operation. He pre-plans and executes the plan within his own narrowed down problem space. The notion that a surgeon pre-planned the necessary steps and made most general decisions before the surgical operation implicates that the surgeon generates an internal representation of the problem, the specific surgical operation with the case history in mind. He also chooses a method to reach the goal. Newell and Simon (1972) are defining a method as “a process that bears some rational relation to attaining a problem solution” (p88), (Robertson, 2001). The process of getting experience and developing needed skills and knowledge to become a surgeon is further described in the following sections.

5.3.2 Knowledge. Knowledge can be categorized into declarative knowledge and implicit knowledge (Anderson, 2004). Declarative knowledge is fact or episodic based and can be expressed verbally. An example is anatomical knowledge of the human body. Implicit knowledge like for example procedural knowledge is often highly automatized and expressed by performance. Procedural knowledge holds knowledge for cognitive and motor skills. The consensus groups of the fundamentals of robotic surgery, further discussed in later sections, line out the basic elements they consider to be taught in lecture format, those are: (a) “Introduction to the principles and functionality of robotic surgical devices”, (b) “pre-operative set up” with all elements that are needed before the surgeon is using the robotic console, (c) “intra-operative use of the robot, description of the critical psychomotor skills, surgeon ergonomics, visual field control, operative control of the robot, necessary instruments and supplies […] ” and “ […] communication skills from the console to the operating room team” and (d) “Post-operative steps for shutting down the robot, removing a robot from the operative field and transitioning the patient to a gurney.” (Smith, Patel, & Satava, 2014, p. 382). The elements taught in lecture form are most likely to become declarative knowledge.

The content for lectures, for example described above, needs to be linked to the tasks a surgeon has to perform. So to create the content, knowledge representations are required to describe the knowledge that is needed to perform surgeries. This field is called surgical process modelling (Lalys & Jannin, 2014). The knowledge representations have to be based on data and information acquired from surgeries and experts. Lalys and Jannin, (2014) conducted a literature review and give an overview of the working field. They concluded, that the data acquisition for surgical process modelling can be distinguished by four main elements: “(1) the level of granularity of the surgical information that is extracted, (2) the operator(s) on which the information is extracted, (3) the time when the acquisition is performed and (4) the recording method” (p. 499). They created two axes, one for granularity and one for formalization level. The axis for granularity ranges from low – level information, over motions, activities, steps, phases, up to procedure. It can be seen in Figure 4. It ranges from very fine grained to broad descriptions of a surgery

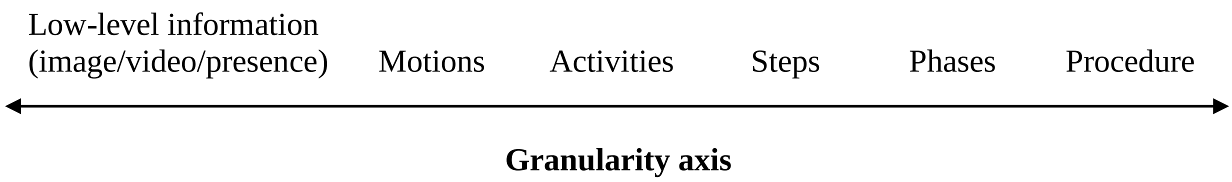

Figure 4. Levels of granularity of a surgical procedure, reproduced (Lalys & Jannin, 2014)

The formalization axis ranges from non-sequential lists up to heavyweight ontology. The axis can be seen in Figure 5. They further pointed out that the recording method depends on where the focus of the study lies in terms of the two axes. A description of a surgery process and building up declarative knowledge with lectures is not enough to become an expert for surgery. Skills and procedural knowledge are required to actually perform surgeries on an expert level. How part of the declarative knowledge that needs to become procedural knowledge can be transformed is described in the next section.

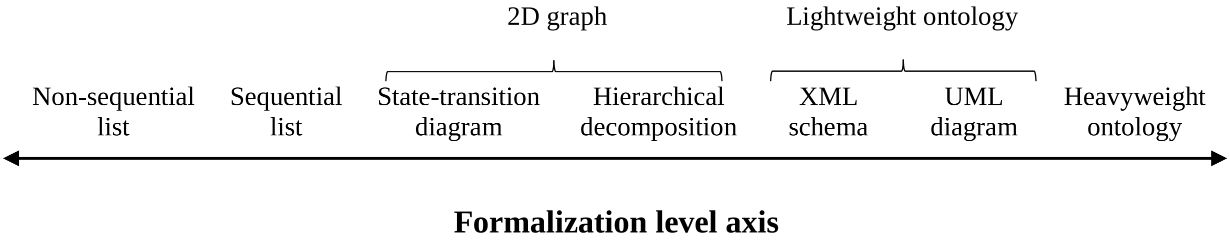

Figure 5. Levels of formalization of the surgery, reproduced (Lalys & Jannin, 2014)

5.3.3 Skill Development Anderson (2004) is proposing a three stage model of skill acquisition. Those three stages are (a) the cognitive stage, (b) the associative stage, and (c) the autonomous stage. In the cognitive stage, the learned declarative knowledge is used to perform the tasks and skills, for example docking the robot to a patient. In this stage the tasks will have the highest cognitive workload compared to a task in another stage. At the associative stage, “errors are gradually detected and eliminated […] ” and “ […] the connections among the various elements required for successful performance are strengthened” (Anderson, 2004, p. 282). At this stage, the procedural knowledge builds up. For example, at this stage it is no longer required to rehearse the docking procedure before performing the task, because the declarative knowledge gradually converts to procedural knowledge. In the autonomous stage “the procedure becomes more and more automated and rapid” (Anderson, 2004, p. 282). From stage to stage the cognitive workload of the task degrades freeing up resources for other tasks, for example for team communication while docking the robot to the patient. However, even if all relevant skills for robotic surgery are developed until stage three it still needs deliberate practice to become an expert instead of only a very experienced professional (Ericsson et al., 1993).

5.3.4 Cognitive processes Frameworks could be helpful to describe cognitive and sensorimotor processes and to model learning. The combination of surgical process modelling, skill development theories and cognitive frameworks can help to make decisions in the training design process. Cao and Rogers, (2004) are proposing to use a modified version of Wicken’s information processing and manual control model as a cognitive and sensorimotor framework to “describe the cognitive processes that underlie the decisions for motor responses in MIS” (p. 77). They further line out the usefulness of Rasmussen’s model for describing the different levels of human behavior (Rasmussen, 1983). The usefulness of this model in the domain of surgery is further mapped out by Wentink, Stassen, Alwayn, Hosman, and Stassen (2003).

The decision making of a surgeon needs special attention. During a surgery the surgeon makes many decisions fast, automatically on a subconscious level (Crebbin, Beasley, & Watters, 2013). However, with the help of situational awareness, the surgeon’s decision process can switch to slower more conscious analytical decision making. According to Crebbin et al. (2013) the surgeon varies between those extremes based upon situational cues. They provide a model for the monitoring and intraoperative decision making. This is in line with the overall goal structure mentioned above. Flin, Youngson, & Yule (2007) further map out the usefulness of integrating decision making strategies into surgical training in the tradition of naturalistic decision making. The switching between slower and faster more automated decision making could have the following consequence. For a surgeon coming from classical minimally invasive surgery the removal of the fulcrum effect and the loss of haptic feedback could lead to a high initial error rate or a longer time for completion compared to their classical minimally invasive task scores. Cues coming from haptic feedback and different visual cues could interfere with the automated processes. This example shows that a closer look at the transfer of laparoscopic skills to robotic surgery could be fruitful, so training programs can address these issues.

These examples show that models for cognitive processing can be useful for hypothesis formation in the domain of surgical training and can support decision making in designing a training program. For example, the notion that situational awareness is a key to success for the procedure, therefore other skills should be as much automated as possible so enough resources can be used and attention can be shifted to the situational awareness skill. However, the notion that skills once automated are difficult to alternate and the alternation of an automated skill is a slow learning process should also lead to careful considerations which skill should be automated to which level. This leads to the conclusion that skills automation and the resource freeing effects of it should be in balance with the risk of over automatization of skills, which can lead to devastating errors. One possible solution could be that a trainee could train skills with variation in tasks. For example, a trainee could train suturing with and without the fulcrum effect, and with and without haptic feedback on a simulator in alternating order. This could lead to longer training times, but could prevent costly errors and thus could be a cost effective training nonetheless. Spruit, Band, Hamming, and Ridderinkhof, 2013 are also suggesting task variation for motor task learning. They summarize that task variation has led to better learning outcomes than without variation. This effect “is called the contextual interference effect” (Spruit et al., 2013, p. 883)

5.4 Applicant selection

Before a training starts candidates with a high potential for completion of the program should be filtered out. The costs of a daVinci robot goes into the millions of dollars and even simulator have sometimes costs of hundred thousand dollar or more. Instruments of the daVinci robot cost upwards of a thousand euro. They can only be used a couple of times. With such high costs admitting only high potential candidates can make a training program as cost effective as possible. Despite the need of candidate screening like in other high risk domains, it is only rarely used in the domain of surgery (Mann, Gillinder, & Szold, 2014). It is an ongoing line of research to find the underlying factors and innate differences that differentiates high potentials from other candidates.

A study compared two groups of second year students (Gupta, Lantz, Alzharani, Foell, & Lee, 2014). Participants of one group had a preference in pursuing a career in surgery the other group was interested in other medical disciplines. Baseline scores for “self- reported scores of dexterity and surgical technical skill […]” and “[…] prior surgical exposure and experience [..]” had no statistical significant differences. Also, “[…] gender, handedness, video game use, sport participation, prior open suturing exposure, prior cystoscopic exposure, prior laparoscopic exposure, prior robotic surgery exposure, mean self reported dexterity score and mean self-reported surgical skill score” showed no statistical significant differences (Gupta et al., 2014, p. 243). After a urologic skill assessment, the researcher of the study report that there were statistical significant differences between those groups. For certain skills in laparoscopy and all robotic skills tested the surgical group outperformed the non-surgical group. The authors conclude that there are innate differences between the participants of the two groups. They speculate that visual spatial perception or psychomotor learning curve could cause those differences.

In laparoscopy, the influence of cognitive aptitude on the learning curve and performance of a surgeon is a focus of ongoing research. More specifically visuo – spatial ability, spatial memory, perceptual speed, and general reasoning are considered as valuable variables (Groenier, Schraagen, Miedema, & Broeders, 2014). Groenier et al., (2014) summarize that based on their study, cognitive aptitude cannot be used for resident selection, but could be promising for creating individualized training programs.

Despite the fact that more research is needed to find the underlying factors that cause the differences of candidates, there are attempts for candidate screening. Mann et al. (2014) showed for example, that scores of participants from a simulator could predict “individual candidate’s chances of succeeding in” fundamentals of laparoscopic surgery tasks. These are tasks that American trainees have to perform to become a surgeon (Mann et al., 2014 p. 196).

All in all, it can be concluded that a lot of future research is needed to create a standardized, validated screening method for laparoscopy and robot assisted surgery training.

5.5 Training

After the results of the literature review regarding the theoretical background were presented it is also interesting what the status quo in robot assisted training is. To give an overview a short history of surgical education is given. This is followed by a description and discussion of the training provided by Intuitive Surgical, the manufacturer of the DaVinci robot. After that the two main initiatives who develop a robot assisted training that is independent of intuitive surgical are shown.

5.5.1 A short history of surgical education. Traditionally open surgery was taught in the operating theatre (Spruit, Band, Hamming, & Ridderinkhof, 2014). An experienced surgeon taught residents stepwise in an apprenticeship model. However, there were several shortcomings for this model. First, with the appearance of minimally invasive surgery, this model was more and more inefficient. The loss of degree of freedom, the fulcrum effect and the loss of 3D perception makes the procedures more complex compared to open surgery. The procedures are also less visible. Second, surgery is a high risk domain, so an ongoing development is overcoming as much as possible of the learning curve of a surgeon outside of the operating theatre, so patient safety is as high as possible. One of the founders of the fundamentals of laparoscopy (FLS) training is describing the situation as follows:

"(1) a huge group of surgeons required training, as did residents, in an environment where not a lot of teachers were available; and (2) surgeons were being trained through industry-funded courses that were highly variable in terms of their format. People would attend courses and then go back to the hospital and get credentials" (Brunt, 2014, p. 11)

A fast expansion of the procedures performed with minimally invasive surgery and the lack of standardized and validated training curricula lead to severe complications, which put the method of minimally invasive surgery as a whole in question. To overcome this issues, the FLS was created. It is meant to teach the basic knowledge, procedural and motor skills specific to minimally invasive surgery. This content was validated by multiple institutions. A surgeon attending this training should have a guaranteed level of proficiency for the basic tasks involved in MIS. The program was so successful, that it became the gold standard in the United States for teaching basic laparoscopy skills and is a requirement for the final exams for United States based surgeons. It is also used in 20 other countries (Brunt, 2014). Now with the rise of robotic surgery a similar situation appears and is further laid out in the following sections.

5.5.2 Robot assisted surgery training Intuitive Surgical, Inc., at this moment in time the only company producing a robot for general surgery, sustains an online community for training, marketing and peer to peer communication. The training pathways for the different team members, surgeon, multi-port first assist and operation room staff, are laid out. Further, they provide online training modules, detailed step by step procedure descriptions for specific surgical operations like prostatectomy and full length narrated procedure videos free of charge for now. Those step by step procedure descriptions “are developed with, reviewed and approved by independent surgeons” (Intuitive Surgical Inc., 2015, p 3). The company also has training centres all around the globe. As helpful that material may be, there are severe limitations:

> ” da Vinci® Surgical System training programs are not replacements for hospital policy regarding surgical credentialing. Certification, OR access and hospital privileges are the responsibility of the trainees and their institutions, not that of Intuitive Surgical. Any demonstration during Intuitive Surgical-sponsored training or instructional material on how to use the system to perform a particular technique or procedure is not the recommendation or ‘certification’ of Intuitive Surgical as to such technique or procedure, but rather is merely a sharing of information on how other surgeons may have used the system to perform a given technique or procedure“ (Intuitive Surgical Inc., 2015, p 3)

In short that means that “Intuitive Surgical does not teach surgery, nor does it provide or evaluate surgical credentialing” (Intuitive Surgical Inc., 2015, p 3). Dulan et al. (2012) point out, that in several surgical disciplines well-structured curricula are available and some of them, as US based surgeons have to go through for credentialing, for example “the Fundamentals of Laparoscopic Surgery (FLS) program, is required by the American Board of Surgery for certification” (p. 477). They further state, that there are no established standardized training programs for robotic surgery. On one side, this leads to the conclusion, that a surgeon who wants to gain proficiency in robot surgery can use the provided material and training from Intuitive Surgical but also needs approval of the hospital to be privileged to use the robot. On the other side, the hospital has the problem that without standardized, evaluated and widely accepted training programs for credentialing, it has to create its own policy based on educated guesses. Kodera (2014) describes the consequences of this dilemma for Japan. According to him, Japan has the most daVinci robots available in Asia but compared to other countries in Asia, has only small case numbers where the robot is used. The insurance companies are not covering the risk a surgeon has to face performing the robot assisted surgery, because of the lack of certification and the patient has to cover all costs of the procedure. Because of that, only surgeons with high proficiency scores in laparoscopic surgery are performing those procedures and surgeons with lower scores who could profit from the robot in complex tasks do not even think about using the robot because of the risks involved. This suggests that laparoscopic experience and expert level transfers to robot assisted surgery. This will be further investigated in a later section.

Another reason for the need of system producer independent certified robot training programs is the upcoming competition within the market. Important patents for robot surgery are expired and companies like Titan Medical and Kymerax are expected to enter the market in the upcoming years (O'Reilly, 2014). With more systems on the market than only the daVinci system, a template with the basic requirements for robotic surgery is needed. All in all, the leading opinion in the literature is that a widely accepted, evaluated, validated, and well-structured training program for the certification of robot ready surgeons and their team is desperately needed (Schreuder et al., 2012).

5.5.3 Striving for the gold standard The monopoly of Intuitive Surgical Inc. and their tremendous experience with the daVinci robot makes their provided pathway to become a robot assisted surgeon especially interesting. Their road to expertise is described in a total of four phases: (a) introduction to daVinci Technology, (b) daVinci technology training, (c) initial case series plan, (d) continuing development (Intuitive Surgical Inc., 2015). Ben-Or, Nifong, and Chitwood (2013) describe the pathway in more detail. The first two phases are about daVinci product training. In the first phase the surgeon watches and reviews at least one narrated full procedure video, and then test drives the system to familiarize with the daVinci robot. A "system overview provides initial instructions for safe use of the system" (Ben-Or et al., 2013, p. 120). After that the surgeon observes live surgeries. In the second phase, the surgeon forms the team for the robot surgery program at their hospital, which consists of "first assist, circulating nurse, scrub nurse, and other necessary individuals" (Ben-Or et al., 2013, p. 121). For those team members, Intuitive Surgical Inc. provides further pathway descriptions for each role individually. "After this selection, online system training is done to include the system technical overview, safety features, docking, advanced surgeon console controls, and an online assessment." (Ben-Or et al., 2013, p. 121). After gaining a certification of completion of the online module, an in-depth technology skills drills training is performed on site with a kit for dry lab training or on a simulator. After that again, at least two full length narrated procedure videos should be watched and reviewed. The last step in the second phase is off-site training for the team at an approved training center. This training can be “performed on a cadaver and/or animal model” (Ben-Or et al., 2013, p. 121). The training can last “one to two days, depending on clinical specialty” (Intuitive Surgical Inc., 2015, p. 1). The surgeon has to complete a protocol within the scheduled time and all members of the team may not leave the training early, otherwise the certificate for the off-site training completion will not be granted. Intuitive Surgical recommends that a minimum of two cases should be scheduled for the third phase, initial case series plan, as fast as possible, because “increased retention, improvement of system skill and confidence are connected to the immediate application of the skills learned in da Vinci Technology Training” (Intuitive Surgical Inc., 2015, p. 1).

Phase three and four are about post system training. In Phase three, initial case series plan, the team rehearses the procedure needed for the first case with a dry run, followed by the initial case series. It is recommended to start with level one cases, which means choosing a patient, with a good overall health, no reoperation, and a low procedural complexity. This initial case plan should be guided by an experienced proctor. “The surgeon should be proctored until s/he determines, in his/her surgical judgment, that s/he is sufficiently competent to operate independently” (Intuitive Surgical Inc., 2015, p.2). Further they recommend to perform two da Vinci technology skill development activities per week. These activities involve completion of the skills drills sessions, skills simulator sessions and the review of relevant surgery procedure videos for the cases at hand. After the initial case series, in phase four, the surgeon and the team should continue to develop the competencies so that the team gets competent enough for more complex procedures. Intuitive surgical recommends to attend to at least two courses led by a surgeon from their course catalogue, those are: (a) “surgeon lecture program”, (b) “complex da Vinci procedure observation”, (c) “complex da Vinci procedure video review”, (d) “da Vinci surgery webinar”, and (e) “Peer-to-Peer consultation via Surgical Congress” (Intuitive Surgical Inc., 2015, p.3). The lack of standardized validated proficiency levels of the team members after completion of the training and the system producer dependence of the training program disqualifies this candidate to become the gold standard for robot surgery training in general.

5.5.4 The major contenders to become the gold standard. The most potent initiatives who strive to become the gold standard for robot surgery were filtered out of 462 initial search hits and summarized by Fisher et al., (2015) in a literature review. According to them there are four main robotic curricula in various stages of development at this moment in time: (a) “Fundamentals of Robotic Surgery (FRS)”, (b) “Fundamental skills of Robotic Surgery (FSRS)”, (c) “Proficiency-based robotic curriculum”, and (d) “ERUS robotic surgery training curriculum" (Fisher et al., 2015, p. 120). Further they suggest to use the Fundamentals of Laparoscopic Surgery (FLS) training program as a benchmark to compare the main curricula of robotic surgery training to. After reviewing the main curricula they conclude that FRS and the ERUS initiative have the strongest offerings to become the gold standard for robot surgery, because they "[…] use a variety of models in a fellowship-style course […]" and their " […] methods are transferable from one robot specification to another." (Fisher et al., 2015, p. 121). An overview of the two potential candidates for the gold standard will be given and the content and development of the curricula will be used for analysis in the following sections.

5.5.4.1 Fundamentals of robotic Surgery (FRS). The initiative of FRS is based on subject matter experts of 14 international societies working on a consensus to create a validated basic skill training for the save use of robotic assisted surgery (Smith et al., 2014). These were joined by members of the certifying specialty boards and surgical education societies. The society of American Gastrointestinal and endoscopic surgeons (SAGES), who is responsible for the creation and wide acceptance of FLS, participates in the initiative and is joined by the US department of defense, just to name a few. The curriculum was gathered by multiple work groups, developing the four different modules of the program, and discussed in multiple consensus conferences. The FLS is used as the prototype for the development of the FRS. Further, a template was created with which several work groups are creating training curricula for their specific specialty. The skills training can be performed with a box trainer using the daVinci robot or virtual reality simulators. The training is supposed to train the basic knowledge and skills involved in robotic surgery.

5.5.4.2 ERUS robotic surgery training curriculum. The Robotic urology section (ERUS) of the European association of urology (EAU) developed a curriculum in multiple meetings based on focus groups interviews (Ahmed et al., 2015). Four modules are proposed for the curriculum: (a) "e-learning", (b) "simulation training", with dry lab, virtual reality and wet lab as training modalities, (c) "operation room training under supervision", and (d) "videoed full procedure and trainer's report", which will be used for certification. (Ahmed et al., 2015, p. 98). The wider range of training modalities compared to the FRS is used to "allow skills to be more transferable to the operating room" (Ahmed et al., 2015, p. 99). This road to expertise has a lot in common with the training of Intuitive Surgical, however the most important difference is that before the trainee enters the operating theatre to perform non proctored procedures the trainee needs certification. This certification should be provided by accredited, regional training centers. The authors further point out that the potential training aspirant may have different levels of proficiency in advance, for example experience in open surgery or laparoscopy, or begins without experience, so that the training program should be tailored to the trainee's needs.

5.5.4.3 Evaluation of emerging standards. The above described standards are just at their dawn. Parts of them are still not published. Validation studies are in development or in progress. It seems that there are several years ahead until a golden standard is established. However, it is still interesting to evaluate the two above mentioned candidates that could become the gold standard. A detailed comparison with the commonalities and differences of the two curricula is provided by Fisher et al. (2015), a short summary is given in the following.

First of all, both curricula are based on simulation training. Both have modules where the trainee gains declarative knowledge. These are followed by modules where procedural knowledge is gathered via simulator skill drills. The biggest difference between the two curricula is that the FRS is a short comprehensive training. It should be seen as a starting point for "initial accreditation upon which further training is built" (Fisher et al., 2015, p. 117). The ERUS curriculum not only has simulator based training. The curriculum supports the trainee with a combination of dry lab, wet lab and structured mentorship until the trainees can perform full surgical procedures. The advantage of the FRS is that it can be integrated more easily into existing training programs. However, the ERUS training program can interconnect the modules of the program more easily once the curriculum is fully developed.

The previously described skill development stage model can be used to further clarify the difference of the two programs (Anderson, 2004). Both programs start with the cognitive stage. They provide declarative knowledge about robot assisted surgery. That is followed by the associative stage. Here the trainees train procedural skills. So part of the declarative knowledge starts to become procedural knowledge. The last stage, the autonomous stage is where the two programs differ the most. With the FRS the trainee will reach the autonomous stage barely for basic skills. The ERUS program however supports the trainee until the autonomous state for full surgical procedures. In both cases deliberate practice will still be needed to gain expert level performance.

Another advantage of the FRS over the ERUS program could be that it has the potential to adapt to new technologies and robots more quickly. Right now it is too early to judge which one will become the future gold standard. Further evaluation will be needed when more details of the training modules are published.

5.6 Task analysis

After the results of the literature review for the theoretical background and surgery training it is important to know what the actual tasks of a robot assisted surgeon are. In a study, the cognitive and procedural skills needed for robotic surgery were identified with the help of interviews of six subject matter experts for the purpose of curriculum creation (Dulan et al., 2012). The deconstruction of the tasks was further validated via 10 observational task analysis sessions. The result is a task deconstruction list of a total of 23 tasks and their descriptions. This list was used together with a further literature review, presentations and a discussion of subject matter experts at a consensus meeting to find the tasks involved in robotic surgery for the creation of the FRS (Smith et al., 2014). A list of 25 tasks ranked by importance, with the task name, description, errors, outcomes and metrics is provided in the report of the consensus meeting and an excerpt can be seen in Table 2 (Satava, Smith, & Patel, 2011). The tasks are categorized into pre-operative, intra-operative, and post-operative tasks. This is one example for how the knowledge basis for the content creation and training design can be gathered.

Table 2

Relevant tasks for robotic surgery training and their rank order gathered by subject matter experts, adapted from Satava et al., (2011).

Occurrence	Task name	Rank order
Pre-op		
	Situation awareness	1
	Closed loop communication	9
	Docking	10
	Robotic trocars	16
	Ergonomic positioning	19
	System settings	20
	Operating room set-up	22
	Respond to robot system error	23
Intra-OR		
	Eye-hand instrument coordination	2
	Needle driving	3
	Atraumatic handling	4
	Safety of operative field	5

Occurrence	Task name	Rank order
	Camera	6
	Clutching	7
	Dissection fine & blunt	8
	Knot tying	11
	Instrument exchange	12
	Cutting	13
	Energy sources	14
	Foreign body management	15
	Suture handling	17
	Wrist articulation	18
	Multi-arm control	21
Post-op		
	Undocking	24
	Transition to bedside assist	25

5.7 Robot assisted surgery in the context of open and laparoscopic surgery

Robot assisted surgery does not stand alone as a surgical technique. It evolved from laparoscopy. As the method evolves the surgeons have to evolve as well. Because of that it is important for training programs to know what the differences and similarities of the new surgical method are in comparison to the already established ones. Further, the impact of the differences and similarities on learning and performance of surgeons familiar with laparoscopy and open surgery is important. These issues will be addressed in the following sections.

5.7.1 Robot assisted surgery in comparison to laparoscopy It is often considered, that results of laparoscopy can be extrapolated to robot assisted surgery, (Balkin, 2013, Cao & Rogers, 2004). After participating in surgical training activities and 400 hours of observation of robot assisted surgeries in an ethnological study, Balkin (2013) argues that the extrapolation needs to be handled with care. The detachment of the surgeon from the patient narrows the senses from the surgeon to a three-dimensional in vitro video stream.

In summary the found differences of robot assisted surgery to laparoscopy are different learning curves, where laparoscopy students have more problems “moving beyond basic tasks to more complex manoeuvres” (Balkin, 2013, p. 695). Also quicker learning of basic tasks for laparoscopic surgeons but a more gradual learning experience for robot surgery. The authors also found differences in skill acquisition mainly due to lack of haptic feedback of the daVinci robot. An “increase in both quality and quantity of communication between surgeon […] and the First Assistant as compared to teams using laparoscopic technology”, (Balkin, 2013, p. 695). Difficulties were found to navigate in robot assisted surgery, because anatomy is often taught when the patient is in supine position, but different positions are sometimes needed in robot assisted surgery. Surgeons also reported that they are feeling like “working in a tunnel”, because of in vitro three dimensional view for the robot assisted surgeon, (Balkin, 2013, p. 695). Last but not least differences were found in camera use because of more extreme angles of view in robot assisted surgery. This amplifies “the difficulties with perceptual judgement” compared to laparoscopy so that beginners get “lost in the anatomy” more easily, (Balkin, 2013, p. 695). More details of the changes in skill acquisition and cognitive work are promised by the author, but not yet published.

For a validation of the finding the rank numbers of table 2, representing importance of task, can be used. The high rank number of atraumatic handling with an emphasis on understanding the deployed forces on tissue confirms the importance to compensate the lack of haptic feedback through training. Atraumatic handling is defined as causing as little damage of tissue trough the surgery as possible. The high rank numbers of safety of operative field, which is about the correct and save positioning of instruments, and camera control also confirms the notion that special attention is needed for navigational and anatomic knowledge specific for robotic assisted surgery. Communication also ranks in the first half of the tasks and thereby confirms the above notion that an effective communication within the team is a crucial part for the success of a robot assisted surgery. Last but not least situational awareness ranking on place one and eye-hand instrument coordination ranking on place two, with the notion that efficient movement of instruments is one outcome measure for that task, supports the overall goal structure of a surgeon mentioned above. The differences in learning curve are validated for example by Sumi et al., (2012) and an overview of learning curve regarding robotic surgery is given by Kaul, Shah, and Menon, (2006). The authors of the literature review come to the conclusion that “the use of robotic assistance decreases the learning curve for both standardized tasks and actual operation”, (p. 127). However, the data supporting this conclusion was “scant and much of the data citing the benefit of robotic surgery lies in anecdotal testimony” (P. 127). The differences in the observation of learning from Balkin (2013) and the conclusion of Kaul, Shah, and Menon, (2006) could be due to that fact. More validation research is needed to clarify the similarities and differences in learning curve for the surgery methods.

5.7.2 Prior surgical experience and skill transfer to robotic assisted surgery The differences and similarities between classical laparoscopic surgery and robot assisted surgery mentioned above raise the question how those skills transfer to the new method of robotic assisted surgery and vice versa. Surgeons that want to become robot assisted surgeons have open or laparoscopic experience or a combination of it. This state of the training market for robot surgery at the moment requires a closer look at implications of prior experience for robot surgery training. In general, the comparison of skill enhancement and transfer of skill for a trainee can take place on a continuum from no prior surgical experience to a fully trained experienced surgeon with thousands of performed procedures. The found literature will be discussed in the following to map out the transfer of skills.

As mentioned earlier, positive or negative transfer could be possible, but most likely a combination of it will occur. The influence of prior knowledge and skill will be discussed further on three levels, (a) strategy, (b) communication, and (c) sensorimotor skills. The strategic level is about making the plan for the surgery and making pre - and intraoperative decisions as described earlier. The communication level is about team communication. One example is here a closed loop communication protocol also mentioned earlier. The sensorimotor skill level is about sensing cues for decision making and motor control. It is also about the actual actions and motor skills a surgeon performs. First the strategic level, with decision making and planning at its center, will be looked at. This topic gets only little attention in the literature in the context of transfer. One conclusion could be that the knowledge and skills involved are readily transferable from existing trainings for surgeons. If studies confirmed this thesis, experienced and fully trained surgeons would not need further training on that level for the conversion to robotic surgery. Second, the communication level will be addressed. The teams performing open, classical laparoscopic or robot assisted surgery are composed of different team members with different roles. In classical laparoscopy a camera assistant is needed who controls and guides the provided in vitro view for the surgeon. In robotic surgery this is done by the surgeon at the console of the robot. Further, in robotic surgery a first assistant exists with a different role compared to classical laparoscopic surgery. The first assistant works directly on the patient and inserts new instruments for example (Yuh, 2013). The first assistant is also the one first reacting to emergencies, because the console surgeon does not work directly at the bedside. The separation of the surgeon from the patient’s bedside and the different roles of team members compared to other surgery methods changes the team’s communication (Balkin, 2013). The FRS described earlier therefore introduced a training module for communication specific for robotic surgery. They further propose the requirement of closed loop communication for surgical teams. To conclude, trained surgeons who want to become robot surgeons can profit from further training in communication skills specific to robot surgery, because transfer from other surgery methods does not seem to be enough for a safe, efficient and effective robot surgery performance. Third, the sensorimotor skill level will be issued. This aspect has gotten the most attention in the literature for transfer of skill. It is discussed in the following sections.

5.7.3 Transfer of motor skills from laparoscopy to robotic assisted surgery. Three main aspects differentiate classical laparoscopy from robotic assisted surgery. The fulcrum effect is eliminated, the degrees of freedom for the instruments regained and a three dimensional view is provided by the robotic system. The most benefit for the enhancement of surgical performance of novice trainees or trainees with minor surgical experience by the daVinci robot compared to laparoscopic surgery seems to be the combination of the vision improvement and the instrument improvements of the daVinci robot (Blavier, Gaudissart, Cadière, & Nyssen, 2007). Both factors on their own had no statistical significant effect on performance scores in the study of Blavier et al. (2007). The participants had also higher confidence and satisfaction rating for the robot assisted modality compared to classical laparoscopy. The study lays out the situation for novice trainees and trainees with a very short familiarization period of just a few trials.

In another study Blavier & Nyssen (2014) summarize and further map out that novice trainees are the most dependent on the surgery method they train with. After a switch of the surgery method low performance scores were measured “suggesting that there is no transfer of skills in novice performance” (Blavier & Nyssen, 2014, p. 516). Further they describe that experts in laparoscopic surgery can readily transfer their motor skills to robotic surgery. They showed similar performance scores laparoscopically, and with the daVinci robot in 2d and 3d view mode. However, surgeons trained with both modalities show better performance robotically. The authors conclude that even with the showed transfer of skill there is a method dependence expertise that needs to be trained to reach best results with each modality.

Transfer of skill can be already obtained after a very short training time. In a study participants were either trained laparoscopically or robotic assisted up to two hours in knot tying (Öbek et al., 2005). Then the participant had to perform the knot tying task with the untrained method. Both groups showed transfer of skill. The transfer seems to be better from laparoscopic modality to robotic assisted than vice versa. The authors argue, that participants trained laparoscopically could train with haptic feedback so “subjects learned to rely on visual cues to correlate suture resistance with knot tension during conventional laparoscopic training and conveyed this skills to their robotic performance" (Öbek et al., 2005, p. 1103). This observation can be important for robot surgery training to facilitate the training by using a variation in motor skill training with and without haptic feedback as mentioned earlier.

The study of Angell, Gomez, Baig, and Abaza (2013) supports the observation of enhanced performance for laparoscopically relatively inexperienced trainees. They also show that the performance after one month of laparoscopic training does not seem to negatively interfere with the switch to robotic surgery. However, those results need to be considered with care. They only showed the performance after the switch of one month of training for specific motor skills, not the switch of method after hundreds or even thousands of full surgical procedures that has to take place for some future robot surgeons. They also did not have a control group where the trainees trained the task with the daVinci robot, so the effect size of the transfer compared to only robotically trained participants cannot be estimated. The results combined with the one of Öbek et al. (2005) support the observation that with increasing laparoscopic experience for specific motor skills the switch of modalities becomes easier and is in contrast to the earlier mentioned possible outcome that negative transfer leads to significantly higher time to completion or errors. The observations are further validated in the literature. A study compared laparoscopic novices, with laparoscopic advanced participants, performing three motor tasks with and without the daVinci robot (Panait, Shetty, Shewokis, & Sanchez, 2014). All participants had no prior experience with the robot. They measured the initial scores for the tasks after familiarizing one minute with every modality. They conclude that the performance of participants with less laparoscopic experience was enhanced by the daVinci robot when the task's difficulty was high. The more experienced subjects showed slightly lower performance scores robotically compared to the laparoscopic method for easy tasks. In the more difficult tasks they showed equal performance. These results also support the observation, that inexperienced surgeons' performance is enhanced by the robot compared to laparoscopy. The more experienced laparoscopic surgeons' performance seems not to be enhanced but for more difficult tasks the laparoscopic skills seem to be transferable. Kaul et al. (2006) is arguing that this could mean that for simple tasks the benefits of the robot are not needed and are more useful for complex tasks. All in all, the study shows that the level of proficiency of laparoscopic skills corresponds to different needs of the trainee for the robotic surgery training.

To conclude the observations from the literature, robot surgery enhances the minimal invasive surgery performance of novices. With more and more experience in laparoscopy this enhancement effect diminishes. So a novice shows overall better performance with the robot compared to laparoscopy. An experienced laparoscopic surgeon shows similar performance scores with or without the robot. These observations are also supported by several studies, (Heemskerk, van Gemert, de Vries, Greve, & Bouvy, 2007; Kim, Choi, Park, & Park, 2014; Landman et al., 2004; Nguan, Girvan, & Luke, 2008). This is in line with the observations of Balkin (2013) mentioned above for the learning curve. However, when an experienced surgeon trains with the daVinci robot further performance improvements can be gained. An overview of the studies discussed in this section can be found in Table *3*.

In summary, the findings have multiple implications for robot surgery training. Surgeons should train not only one modality. Motor skills transfer partly from one surgery method to the other. Specific robotic training should be complementary to already established trainings for open and classical laparoscopic surgery to prevent the risks of conversion of surgeries. Surgeons should also not train solely with the robot. Learned haptic feedback in other surgery methods can transfer to the robot training and facilitate it. The novice trainees' enhanced sensorimotor skill performance through the robot has also training implications. The fast progress towards expert level scores and higher confidence and satisfaction levels compared to laparoscopy requires special attention to the credentialing process of robot surgeons. Non sensorimotor skills as for example intraoperative decision making and team communication develops at a non-robotically enhanced pace. The fast progress in sensorimotor skills could lead to overestimation of overall surgical skill performance. Therefore, mainly robotically trained surgeons should be evaluated with special attention to that aspect.

Table 3

Overview of studies regarding transfer of skills from classical laparoscopy to robotic assisted surgery

Study	Participants	Tasks	Time of transfer	Results and conclusions
Angell et al. (2013)	14 medical students without any surgical experience	Rope transfer; bean drop; freehand suturing; knot tying; anastomosis	After one month of laparoscopic training	• Scores of robotic exercises were statistically significant higher after one month of laparoscopic training. • Scores of the robotic exercise were higher after a month of laparoscopic training compared to laparoscopic scores

Study	Participants	Tasks	Time of transfer	Results and conclusions
Blavier et al. (2007)	60 medical students without surgical experience	Pick and place; checkerboard; rings route; circular pattern cutting; suture and knot	After short familiarization phase of ten repetitions	• Higher self-confidence and satisfaction in the robotic surgery group compared to classical laparoscopic group • Best scores obtained robotically compared to classical laparoscopy scores • Poor performance after switch from robot assisted to classical laparoscopic method without familiarization period.
Blavier & Nyssen (2014)	12 medical student; 12 classical laparoscopically surgeons; 4 robotically and classically trained surgeons	Pick up and place; checkerboard; Rings route; Circular pattern cutting; suture and knot	12 surgically inexperienced students; 12 surgeons with more than 100 classical laparoscopic surgeries; 4 surgeons with more than 100 surgeries laparoscopically and robotic assisted	• Novice participants benefited most from the daVinci robot for training skill enhancement • “The results showed a variable sensitivity to perspective (2D - 3D) and instrumental (robot-classical laparoscopy) aspects according to the level of expertise but also according to the type of task.” (Blavier & Nyssen, 2014, p. 515)
Guru et al. (2007)	6 faculty members; 6 fellows; 10 residents	Beads; loops; knots	After various degrees of laparoscopic training, 6 participants had robotic experience	• Different skills for the two surgery methods requires a specific training in robotic surgery

Study	Participants	Tasks	Time of transfer	Results and conclusions
Heemskerk et al. (2007)	8 medical students without experience in surgery	Pick up and drop; Give over the bead; cap the needle; suturing and knot tying	Learning curve of cross trained participants without earlier experience.	• Tasks were performed more accurately and faster with the daVinci robot Tendency of initially faster learning for robotic assisted surgery
Kaul et al. (2006)	One open surgeon; one laparoscopic surgeon; one robotic assisted surgery trainee	Full procedure of radical prostatectomy	After various degrees of laparoscopic training	• DaVinci robot shrinks the learning curve • Open or laparoscopic experience not required for robotic training
Kim et al. (2014)	10 medical students; 10 surgical trainees and fellows	Pick up and give over a bead; ring insertion onto a cone; suturing and tying of knots	10 laparoscopic novices; 10 laparoscopic experienced residents and fellows with formal laparoscopic training and at least 12 cases a month	• Laparoscopically novices have more benefits of robotic system than laparoscopic experienced participants • Laparoscopic experienced participants have the same or slightly better performance robotically compared to classical laparoscopically
Landman et al. (2004)	21 Surgeons	Pipe cleaner; Ring drill; Bead drill; Knot drill	Novice; intermediate; expert surgeon	• Surgical robot enhances performance of novice surgeons compared to experienced surgeon. • Shorter learning curve for robot assisted surgery is suggested by the authors
Nguan et al. (2008)	4 staff surgeons; 4 postgraduate trainees; 4 medical students	Suturing; Knot tying	4 novices; 4 intermediate; 4 laparoscopic experts	• Surgical experience can compensate method advantages

Study	Participants	Tasks	Time of transfer	Results and conclusions
Öbek et al. (2005)	20 medical students	Knot tying	After training of maximal 2 hours	• Knot tying skill was partly transferred from classical laparoscopy to robotic assisted surgery and vice versa • Classical laparoscopically trained participants had higher scores robotically than robot assisted trained participants classical laparoscopically
Panait et al., (2014)	14 medical student; 14 surgery residents all without robotic experience	Three FLS skills: (a) peg transfer, (b) circle cutting, and (c) intracorporeal suturing	After various degrees of laparoscopic training, with one minute of familiarization time for method and task	• Less laparoscopy experienced trainees' learning enhanced by robot • More experienced trainees have initially robotically assisted lower scores compared to laparoscopy skills for low difficulty tasks but equal scores for more complex ones.
Trabulsi, Zola, Gomella, & Lallas (2010)	One surgeon	Full procedures	Continuous transition from classical laparoscopy to robot assisted surgery	• The surgeon had better results with robot surgery compared to his classical laparoscopic performance scores

5.7.4 Transfer of motor skills from open surgery to robotic assisted surgery. The results found in the literature are mixed regarding transfer of motor skills from open to robotic surgery. An overview of the found articles is given in Table 4. A lot of the studies lack in design to make generalizations. For example, one surgeon reports after 8 to 12 robotic assisted procedures that he had operative times that are comparable of procedure times of classical laparoscopic surgeons after 100 procedures (Ahlering, Skarecky, Lee, & Clayman, 2003). This was also reported in the literature by comparing the learning curve of three surgeons of various prior experience levels (Kaul et al., 2006). Another study suggests to discriminate the learning curve by performance and outcome measures. The authors reported for example, that the three hour procedure benchmark for radical prostatectomy was reached after 110 to 120 procedures in their institution. Equal early continence outcomes were reached after 200 procedures compared to open surgery outcomes (Johnson & Wood, 2010). The very small participant numbers make a generalization of the conclusions difficult. The outcomes could be due to individual differences of the participants and therefore will be difficult to reproduce. This is also observed for literature regarding transfer of motor skill from microsurgery.

Microsurgeries are surgeries where the surgeon needs a microscope to perform the procedure. The surgeon's posture and the binocular view are considered to be similar to that of robot surgery. The surgeon has also no haptic feedback. If the surgeon uses forces that could give back haptic feedback trough the instruments the suturing fails because of the destruction of the suture (Perez et al., 2013). The close resemblance of work environment and viewing conditions suggests an overlap of sensorimotor skills. However no transfer of sensorimotor skill is reported (Karamanoukian, Bui, McConnell, Evans, & Karamanoukian, 2006). The authors used only 8 participants to come to the conclusion. A study with 49 surgeons as participants showed that surgeons with microsurgery experience have better performance in a dry lab compared to surgeons without that experience. The authors suggest to use cheap microsurgery training drills for robotic surgery training (Perez et al., 2013). In summary, there are the following implications for robotic surgery training. The single surgeon reports can be seen as a proof of concept. Open surgeons can become robot surgeons without the need of prior laparoscopic experience. Microsurgery training could be a cheap training module to familiarize the trainees with the work environment and to acquire sensorimotor skills. Both implications need further research for more precise recommendations for robot surgery training.

Table 4

Overview of studies regarding transfer of skills from open surgery to robotic assisted surgery

Study	Participants	Tasks	Time of transfer	Results and conclusions
Ahlering et al. (2003)	1 Surgeon	Full procedure	Experienced open surgeon after one day training	• Transfer of skill from open to robot assisted surgery in 8 to 12 cases for radical prostatectomy • Performance outcome comparable to outcome of laparoscopic surgeons after 100 laparoscopic radical prostatectomy

Study	Participants	Tasks	Time of transfer	Results and conclusions
Doumerc et al. (2010)	1 Surgeon	Full procedure	Continuous comparison of learning curve with and without robot aid	• Different aspects of surgery outcome and transferring skill takes different learning times to achieve comparable outcomes to open surgery outcomes
Johnson & Wood (2010)	Institution report	Full procedure	Continuous comparison of learning curve with and without robot aid	• After 100 procedures operative times are similar • No difference in complication rate • “The surgeons who are beginning to incorporate robotic surgery into their repertoire should expect outcomes to mirror their open results” (p. 78) • Learning of robot surgery is easy for an open surgeon that has no or minor prior laparoscopic experience
Karamanoukian et al. (2006)	3 surgeon; 5 residents	Anastomosis on bovine arteries	Comparison of fully trained microvascular surgeon and intermediate residents	• Results indicate “that no transfer of training exists” (p. 664)
O’Brien & Shukla (2012)	Institution report	Full procedure	Continuous comparison of learning curve with and without robot aid	• Robotic surgery learning curve is shorter from transition of an open surgeon to robotic surgery compared to a transition to classical laparoscopy • Transition from open to robotic surgery is possible without first learning classical laparoscopy

Study	Participants	Tasks	Time of transfer	Results and conclusions
Perez et al. (2013)	49 Surgeons	Pick and place; peg board; ring and rail; camera targeting; match board	After experience in microsurgery and without microsurgery experience	• Surgeons with microsurgery experience have better overall scores in robot surgery tasks than surgeons without that experience. • “Sitting position”, “workspace”, “forearm position”, “wrist working” and “binocular vision system” from microsurgery are strongly considered to be similar to the robotic surgery environment (p. 355). • Basic microsurgery training could result in cost effective robot surgery training

5.8 Lessons learned from other domains

Learning precise sensorimotor procedures, acting and deciding under high psychological and physical stress, handling of high cost equipment and fatal errors counted in the loss of human lives is not unique to the domain of surgery. Pilots, and especially fighter pilots, have to act under similar circumstances (Buchholz, 2014). In top level sport, athletes also have to perform under high psychological and physical stress and have to perform highly trained sensorimotor procedures where mistakes can lead to severe injuries or even death of the athlete. Therefore, it can be fruitful to look at other domains and how the lessons learned can be used for the domain of surgery.

5.8.1 Aviation At the beginning of pilot training the situation was similar to the beginning of surgeon training, mentioned above. A senior pilot was teaching a trainee in a master to trainee fashion in the cockpit (Buchholz, 2014). However, from thereon the situation has changed dramatically between those domains. Pilot training has legally binding international regulations, based on constantly developed and re-evaluated standardized syllabi, infused by detailed critical incident report evaluations. Every airplane producer has to provide detailed manuals for their products that meet the demands of those regulations. The training of a pilot is two parted, where the pilot first gains the basic flight license and then performs a training tailored specifically to the aircraft the pilot will operate. Every crucial skill, cognitive or procedural, is described in the syllabi in detail and outcome measures are mentioned according to tasks performed. Examples are given by Buchholz, (2014). Further “all pilots must demonstrate their proficiency situations every 6 month in a check-flight (at present, mostly in a simulator) to renew their license” (Buchholz, 2014, p. 34). If the proficiency level is not sufficient to renew the license the pilot undergoes additional training. If the pilot still does not meet the requirements for the license the employment contract will be terminated. Comparing this situation to the situation the training of surgeons shows the problems and risks the healthcare system takes by not providing legally binding certification of surgeons. An analogy can be drawn. A pilot could not work on a line where two types of aircrafts are used and has only training for one of the types. Even if almost always the type of aircraft is used that was trained and the other aircraft is used for backup purposes. The chance that the pilot may have to operate the other aircraft requires the pilot to be trained for both types of aircrafts. Brunt (2014) is describing that there are procedures in surgery that are almost always performed with the minimally invasive surgery method these days but that rare complications may occur that requires a transition to open surgery. However, there are surgeons who never performed those procedures with open surgery and even state that they feel uncomfortable if such a transition is required (Brunt, 2014). These untrained scenarios, where the surgeon needs to transition from laparoscopy to open surgery, can lead to severe complications and death. A similar conclusion was drawn from critical incident analysis of the Air France flight 447 (Bhangu, Bhangu, Stevenson, & Bowley, 2013). A loss of speed indication made the autopilot useless. The pilot was not prepared to manually fly the plane at a high altitude, usually done by autopilot. Further the team was caught by surprise of a sudden problem resulting in the death of 228 passengers and crewmembers. For the context of surgery, the authors recommend that a surgeon and the surgical team should have gone through a comprehensive emergency and non-technical skill training. Further they should be trained in performing the procedures without the help of technology. In rare emergency occasions where technology fails or critical incidents requires a transition to traditional open surgery the team must be prepared.

In conclusion, a requirement by international law and regulatory for surgery training should be that a surgeon must be sufficiently trained, based upon a proficiency level, for every method the surgeon could encounter for a specific procedure the surgeon performs. This should be followed by a standardized emergency training. This could lead to higher initial costs and longer training times but, compared to the costs of death of patients for a society these higher costs could be compensated and thereby makes the resulting training of surgeons more cost effective and safer. Hereby not even considering the prevention of the tragically loss and traumatic experience for the relatives of the patient and the surgeon itself.

Quest (2007) a former fighter pilot with wartime experience and experienced neurosurgeon, is also pointing out key differences and similarities between the training of those two professions. The lack of emergency training, the lack of proficiency based training and not time based training like in surgery training, and the missing re-evaluation of the state of proficiency of surgeons are his main critique points and lessons that could be useful for the training of surgeons. He also points out that the simulator training of surgeons are "primitive and rudimentary" compared to flight simulators (Quest, 2007, p. 1072). The last notion is especially important for robotic surgery, because the console with the 3d view and the lack of haptic feedback is predesignated to be simulated with high fidelity to overcome parts of the learning curve outside of the operating theatre. However, with sophisticated simulators in development and in validation research, simulation training with mechanical, hybrid and virtual reality simulators are on their way to be a crucial part of save and efficient surgery training in general and for robotic surgery training especially (Cosman, Cregan, Martin, & Cartmill, 2002), (Halvorsen, Elle, & Fosse, 2005), (Patel et al., 2014).

The notion that all four main curricula in development for robotic surgery, mentioned above, are using simulation based training shows that simulator based training in surgery is catching up to pilot training standards. The effectiveness of simulation based robotic surgery training on a readily available simulator is shown for example by Patel et al., (2014). The FRS curriculum shows that some of the lessons from pilot training are already in place. The (a) systematic deconstruction and description of the tasks involved specific to robotic surgery, (b) the resulting outcome measures, mentioned in an earlier section, and (c) the notion that the certification process is proficiency based, resembles the basic properties of pilot training. However, training and credentialing of surgeons is scattered across countries, (Buchholz, 2014), knowledge and curricula are highly variable in content and duration even between hospitals in the same country and there are no international regulatory in place. These differences can be seen as reasons why Intuitive Surgery has developed the companies own training without credentialing and the notion that it does not teach surgery. The company acts within the boundaries of the market to be profitable and does not act as a regulatory instance in the best interest of countries and their inhabitants. However, this should not be the task of a company in the first place, so regulatory instances like the European Union should act to overcome these risky parameters of the healthcare market.

First attempts for aviation style surgical training are reported in the literature. A training based upon crew resource management training, resulted in the “improvement in attitude to safety, team non-technical performance and technical error rates both in the operative field and outside it” (McCulloch et al., 2009, p 111). The key concepts of the training were to “increase in knowledge, change attitudes and improve behavior in relation to: (a) safety, situation awareness, and error management; (b) self-awareness, communication and assertiveness; and (c) decision-making, briefing and debriefing” (McCulloch et al., 2009, p. 111). A comparison to the key tasks found by the FRS team emphasizes the usefulness of such a training for robot surgery training. Another attempt to implement and research such a training for surgical teams shows the complexity of such an endeavor (Catchpole, Dale, Hirst, Smith, & Giddings, 2010). The authors of the study put the emphasis on the notion that the operation theatre should be seen as a socio - technological system. In that context, two aviation trainers performed a human factors skills training in three hospitals. The surgical teams were observed before and after the training by experienced human factor practitioners. They report that the training “was clearly effective in encouraging more briefing, time-out, and debriefing practices, with site specific improvements in all aspects of performance” (Catchpole, Dale, Hirst, Smith, & Giddings, 2010, p. 184). A key to success of the training was the commitment of the surgery team and the hospital at all management levels. They found more or less resistance against the training in all of the three hospitals. Here major differences between aviation and surgery become apparent. In aviation airlines and airports are acting internationally and high standardization of procedures and safety is required to operate efficiently. Hospitals and its surgical teams are acting locally and are much less dependent on each other or the standardization of procedures. So an intra hospital climate occurs that has a major influence on commitment to patient safety and surgical efficiency. This again supports the call for more standardization and patient safety measures by regulatory authority. Another approach would be to standardize trainings and their curricula for medical students and integrate key to success aspects like human factors based non-technical skill training. However, the hierarchical structure of hospitals might prevent an adoption of new concepts coming from universities and other domains like for example briefing and de-briefing or checklists.

5.8.2 Top-level sport. There are several similarities in the performance of top-level athletes and surgeons. In both domains a highly trained skills set conglomerates to be used at a specific point in time. At that time the best possible performance is expected under high psychological and time pressure. In his editorial Gibney, (2012) summarizes that in sports psychology the following psychological skills are relevant for performance optimization: “(1) concentration, the ability to focus and control attention; (2) self-confidence or self-efficacy; (3) arousal control, the ideal balance between anxiety and relaxation; and (4) coping skills, which relate especially to the ability to perform well under pressure” (p. 543-544). He further points out that these skills can be learned and used trough “(1) imagery, (2) self-talk, (3) relaxation, and (4) goal setting” (p. 544). Those factors are sometimes summarized under the term mental toughness in sports psychology (Colbert, Scott, Dale, & Brennan, 2012). In surgery mental imagery has gotten the most attention of those factors to be used for training. Mental imagery means that a specific motor task is imagined and performed in the mind. The training is very cheap and done outside of the operating theatre. It has already shown positive effects for laparoscopy in randomized controlled trials (Arora et al., 2011), (Immenroth et al., 2007). Another concept often researched for sport, but also for music, is warm-up. According to a systematic literature review the concept has shown positive effects on surgical performance in five out of six studies (Abdalla et al., 2015). However, the authors describe that a lot of research questions still need more attention. For example, how should the warm-up period be scheduled, and what tasks should be used for warm up? A warm up with integrated mental imagery could proof to be useful to rise patient safety and the surgeon’s performance. It could also be used for performance enhancement of trainees first performing new procedures in the operating theatre. With further research the best practice for that procedure should be investigated.

6 Discussion

Assisting robots for surgery like the daVinci robot are not just some new tools in the operating theatre. It is an evolutionary step that has new challenges for the surgeon, for example the detachment of the surgeon from the patient. Those challenges need to be overcome with well-structured training programs. To support the development of such training programs this literature review was performed. There are literature reviews which in summary give an overview of the field. Schreuder et al., (2012) give a general overview and Fisher et al., (2015) give an overview of the main training curricula. Those reviews had gaps. The transfer of skills from one surgery method to the other was missing for example. Those gaps were discussed and tried to close. Last but not least a broader overview of the field was given in the literature review above.

6.1.1 Requirements for efficient, effective and safe surgery training After the performance of the literature review requirements for efficient, effective and safe robotic surgery training can be formulated. It should be grounded on cognitive science (Papa & Harasym, 1999). More specifically it should be based upon expertise literature. Multiple theoretical frameworks have shown usefulness for hypothesis creation and training curricula formulation. At its forefront seems to be deliberate practice.

Further, in surgery there is always the possibility of conversion of surgery method. Therefore, robotic assisted surgery training should be only one part of the surgeons training. Laparoscopy and open surgery techniques should not be neglected. Skills gained from laparoscopic or open surgery have also shown that training with haptic feedback transfers partly to robotic surgery. A variation in task training therefore should be required so that a surgeon is prepared for performing a surgical procedure with or without the robot.

Another requirement is that the training needs to be adaptive to the surgeon’s experience level (Ahmed et al., 2015). Different levels of experience correspond to different training needs of the trainee. Also, the training should be adaptive to the factor if the trainee has laparoscopic or open surgery experience or a combination of it.

Intuitive Surgical has already multiple generations of the daVinci robot on the market and competitors are expected to enter the market in the coming years. Therefore, the content of the curriculum of a robotic assisted training should be producer independent, recursively updated to new robot generations. It should also be easily transferable from one robot generation and specification to another (Fisher et al., 2015).

For the sake of patient safety as much of the learning curve of a surgeon should be overcome outside of the operating theatre. Simulation based training from low to high fidelity simulators are required for that intention. Surgery simulators are catching up to aviation training standards but still a lot of research is needed for the optimal use of simulators in surgery curricula. The simulators for example could easily be used to adapt the training to the trainee’s experience level.

The training should also be credentialing so that the surgeon, hospitals and insurance companies get confident in incorporating the robot surgery technique into the day to day business. The credentialing process is required to be standardized. The standardization process should be based upon proficiency levels gained from robot surgery experts. These proficiency levels should be re-evaluated at least from robot generation to robot generation. Those standards and re-evaluations should ideally be triggered in the training marked by a legally binding certification processes.

In summery the core requirements for a robot surgery training according to the literature review are: (a) cognitive science and expert literature based, (b) proficiency based, (c) simulation based, (d) standardized, (e) validated, and (f) adaptive to experience level of the trainee. Gallagher et al., (2005) describe such a program a paradigm shift for surgery training. Especially the proficiency based training and use of simulation that keep the learning curve as much out of the operating theatre as possible could have the most impact on training quality.

Apart from the core requirements more recommendations can be given. The content requirements should come from a task analysis. However, the emphasis on technical skill and system knowledge often found in the literature needs to be considered with care. As seen in earlier sections communication and other non-technical skills, sometimes called human factor skills, are crucial for the success of a robotic surgery program. Therefore, a robot assisted surgery training should have a dedicated non-technical skills module. Also coming from aviation, emergency training should be an inherent part of the curriculum. The last recommendation is that the proficiency level of a robot surgeon should be re-evaluated regularly. If the surgeon does not reach the benchmark levels for proficiency the surgeon should be supported by additional training until the benchmarks are reached again. So supplementary to the core requirements are the following recommendations. The training should have: (a) technical and non-technical skill modules, (b) emergency training, and (c) recursive proficiency based assessments and credentialing of surgeons.

6.1.2 A prototypical training approach. The following describes one prototypical approach in how to set up such a robot assisted surgery training based upon the literature review. This approach for curriculum creation incorporates lessons learned from aviation and sport. An overview can be seen in Figure 7. The content of the training should be split specifically into declarative and procedural knowledge. Based upon the road to expertise by Anderson (2004) first declarative knowledge should be taught that then transforms with practice partly into procedural knowledge. The knowledge, tasks, and skills specific to robot surgery should be described in a comprehensive syllabus for basic robot surgery tasks and in detail specific to the specialty it is used for. That syllabus should also be infused by the investigation of critical incident reports. After that, tasks and skill drills should be developed and validated to be relevant for the tasks of a surgeon. Then the simulation details must be set. A fidelity – transfer of skill analysis must be done. This is a cost – benefit analysis. The higher the fidelity the higher the expected transfer of skill to the operating room, but the higher the costs. Further the use of cheap training drills like microsurgical training and mental imagery should be considered. In the next step the curriculum creator needs to determine the training process, duration, sequence of skill drills and variation of tasks. Various factors have to be considered, for example experience level, training modalities, order and variation of skill drills and trainee's individual differences.

For motor skills training in laparoscopy Spruit et al., (2014) give guidelines, however as mentioned above other aspects than motor skills are also relevant for the surgeons performance and training. Guidelines for communication, emergency training, simulator training and adoption of content to experience level are rare or non-existent for robot assisted surgery training. Spruit et al., (2014) performed a literature review to find guiding principles for the creation of a procedural motor skill training for laparoscopy. Guidelines like that are needed for the last step of curriculum creation. The reccomendations are based upon the framework of deliberate practice. They also come to the conclusion that a minimally invasive surgery training should be proviciency based. It should be adaptive to the trainee's training pace and the tasks trained should be segmented but not to a point where interactive elements between tasks are neglegted. For the transfer of skills the skill drills should have key elements of the criterion task. They also reccomend task variation "to enhance skill acquisition and long-term retention and to optimize flexibility of trained skills." (p. 884). The training should be spaced and they also recommend mental imagery as a cheap training method. Last but not least they recommend dual task assessment to test the learned automaticity of the skills. Here the trainee performs the automated trained task simultaneously with another not automated task. The performance scores for the not trained tasks then indicates how much resources the trainee needs for the trained task. As the automation progresses more and more resources of the trainee can be used for the untrained task. In the final step of content creation, skills assessment and credentialing methods must be evaluated. Credentialing on basis of benchmark proficiency levels and not on a time based basis is recommended for the last step.

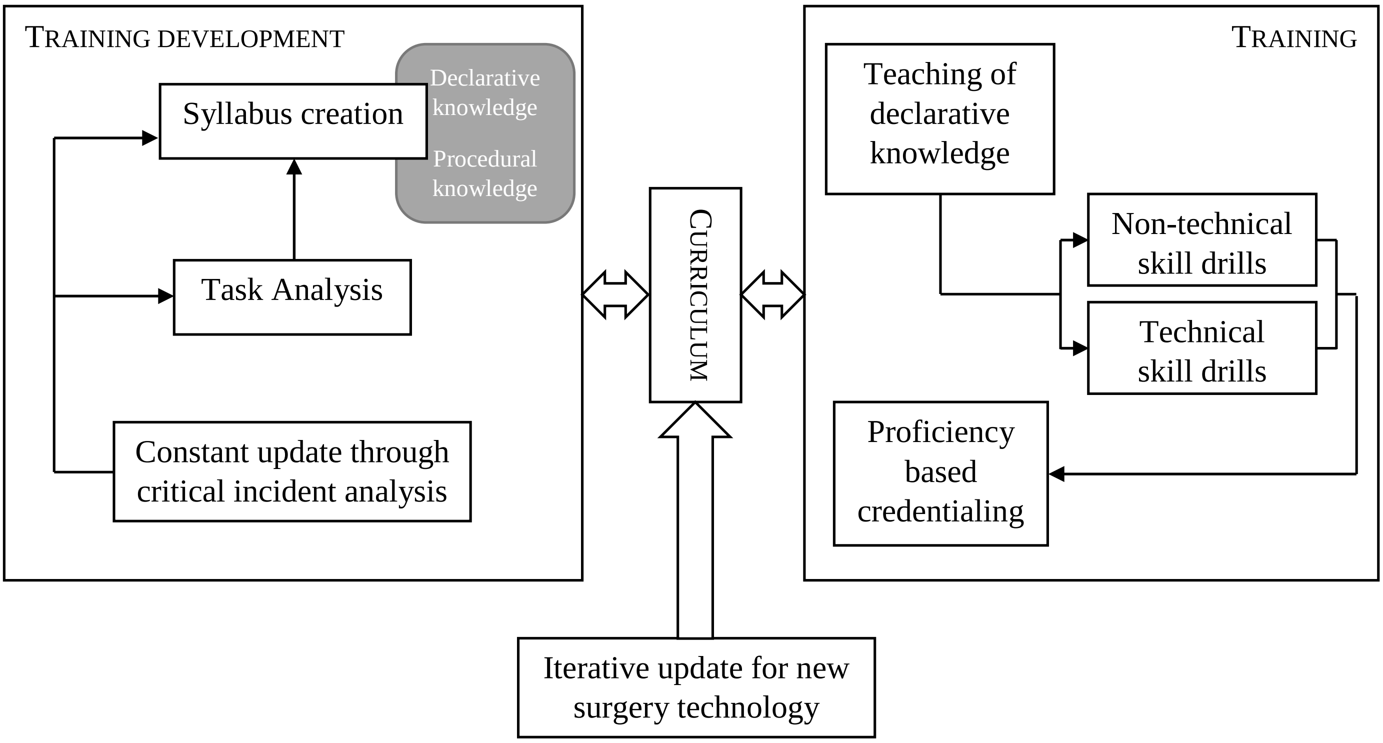

Figure 6. Prototypical surgery training curriculum creation process.

6.1.3 The status quo in robot assisted surgery training. Intuitive Surgical seems to have the most experience in providing robot assisted surgery training. The robot manufacturer dependence and the missing credentialing of the trainees makes new training programs necessary. The FRS and the ERUS initiative are the two main contenders to become the gold standard in robot assisted surgery training. The FRS tries to solve the puzzle of curriculum creation by training the basic skills needed for robotic assisted surgery and tries to be the lowest common denominator to gain basic proficiency levels for robotic assisted surgery. The FRS therefore is meant as one part that can be integrated into existing trainings. The creation of the curriculum resembles most of the prototypical approach described above. The ERUS initiative, the second main contender to become the gold standard for robot assisted surgery training, tries to solve it by a more individualized, broader approach. Even with these major projects in development further research is needed to optimize curriculum creation. This is further sketched out in the next section.

6.2 Future research recommendations

There are multiple areas that need further research for the optimization of training design in surgery. A standardized procedure should be developed that iteratively analyses new developments and technologies in surgery. The progress from open to classical minimally invasive surgery had major difficulties and drawbacks that cost human lives. Similar difficulties are found for the introduction of robot assisted surgery. Future developments like augmented reality, partly automated robots and evolutionary progress in the robot development seem right around the corner. Now is the time to prepare the introduction of those new technologies and learn from the difficult introduction of classical minimal invasive surgery and robot assisted surgery. That systematic standardized procedure should result in ready to use guidelines and recommendations that can be easily incorporated into existing training curricula. With such a procedure patient safety can be better assured. Such a project needs major resources and combined multi institutional support and focus of the research community.

Areas for research are: (a) systematic investigation of skill transfer, (b) systematic investigation in optimizing skill acquisition, (c) systematic international critical incident reports and analysis, (d) systematic research in learning curve variations in the context of new technology, (e) systematic research for technical but also non-technical skill in context of new technology, and (f) investigations for authoritative regulatory creation and recommendations for introducing new technologies. Right now research is mostly done intra institutional, with low subject numbers, or with students and residents with higher subject numbers for the study, but in dry lab scenarios. This results in difficulties for interpretation and generalization of the outcomes. The scattered health market with hierarchical microclimate structures will make such an undertaking a challenge. A meta-research for the main factors for the introduction of a standardized iterative research process for new technology in the health system could help quick start such a project.

6.3 Limitations

The literature review of this thesis was performed within the boundaries of a master thesis. Not every area of the working field is discussed evenly deep. This could lead to a selection bias. However, the focus was lead by reviews. That should minimize the selection bias. The main focus of the thesis then was to fill in gaps in existing literature reviews. There is no conflict of interest.

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8 Appendix A
Literature description

For all used articles of the project a short description can be found in the Table 1 to 5. They are sorted by the main category the articles are eligible for. The categories are: (a) theoretical background and framework, (b) robotic surgery general (c) surgery training, (d) Aviation, and (e) Sport. * is added to mark texts from other sources than the literature search.

Table 1
Short descriptions of literature under the main category theoretical background and framework

Article aspect	Description
Title	Cognitive psychology and its implications*
Reference	Anderson, J. R. (2004). *Cognitive psychology and its implications*. New York, NY, US: Worth Publishers.
Statement	In this book the author describes his stage model for expertise, which can be used as a theoretical background for training models.
Quotes	“The development of a skills typically comprises three stages” (p. 281)
Methodology	-
Article aspect	**Description**
Title	How to do a systematic search for information*
Reference	Boxem, B. (n.d.). *How to do a systematic search for information*. Retrieved from http://www.utwente.nl/ub/en/documents/sys_search_en.pdf
Statement	This guideline was used for the systematic literature search.
Quotes	-
Methodology	-
Article aspect	**Description**
Title	Robot-assisted minimally invasive surgery: the importance of human factors analysis and design.
Reference	Cao, C. G. L., & Rogers, G. S. (2004). Robot-assisted minimally invasive surgery: the importance of human factors analysis and design. *Surgical Technology International*, *12*(9), 73–82. doi:10.1177/0278364909104276
Statement	This article provides a human factors framework for MIS and robot assisted MIS. An information processing model after Wiecken is described as well as Rasmussen’s model to describe different levels of the surgeon’s behavior. It also provides a surgeon’s goal structure for a procedure.
Quotes	“As most of the global decisions for surgery have been made before entering the operation room, the surgeon’s cognitive task during surgery consists of two parallel goals: 1) to execute a planned sequence of actions based on knowledge of the surgical procedure, and 2) to detect and correct deviations from the pre-planned course of action, as the operation proceeds, based on new information from the environment, as well as declarative knowledge of anatomy and case-specific details.” (p.77) “In information-processing terms, therefore, MIS “telemanipulation” involves recognition, encoding, transformation, decoding, and comparison – integrated with anticipation, past experience, and feedback – for response selection and execution.” (p.77)
Methodology	CTA with nine SME’s

Article aspect	Description
Title	Clinical decision making: How surgeons do it
Reference	Crebbin, W., Beasley, S. W., & Watters, D. a K. (2013). Clinical decision making: How surgeons do it. *ANZ Journal of Surgery, 83*(6), 422–428. doi:10.1111/ans.12180
Statement	This paper provides a model of surgical decision making. Situational awareness and a preplanned procedure are the center pieces of the model. This is in line with the goal structure of a surgeon described in another review.
Quotes	“This paper describes some of the complexities around CDM within the contexts of (i) making the decision to operate; (ii) preparing for the surgical procedure; and (iii) monitoring operative progress.” (p.421) “Clinical judgement, clinical decision making and metacognitive skills, as represented in each of the three models, are interlinked and overlapping.” (p.427)
Methodology	-

Article aspect	Description
Title	The role of deliberate practice in the acquisition of expert performance.*
Reference	Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363–406. doi:10.1037/0033-295X.100.3.363
Statement	Deliberate practice is one line of research about the road to expertise. This line of research can be used as a theoretical background to design a robot assisted surgery program.
Quotes	“People believe that because expert performance is qualitatively different from normal performance the expert performer must be endowed with characteristics qualitatively different from those of normal adults. This view has discouraged scientists from systematically examining expert performers and accounting for their performance in terms of the laws and principles of general psychology. We agree that expert performance is qualitatively different from normal performance and even that expert performers have characteristics and abilities that are qualitatively different from or at least outside the range of those of normal adults. However, we deny that these differences are immutable, that is, due to innate talent. Only a few exceptions, most notably height, are genetically prescribed. Instead, we argue that the differences between expert performers and normal adults reflect a life-long period of deliberate effort to improve performance in a specific domain.” (p.400)
Methodology	Experiment with 30 participants and interview of 10 professionals

Article aspect	Description
Title	How do surgeons make intraoperative decisions?
Reference	Flin, R., Youngson, G., & Yule, S. (2007). How do surgeons make intraoperative decisions? *Quality & Safety in Health Care*, *16*(3), 235–239. doi:10.1136/qshc.2006.020743
Statement	Here, a more simplified decision model of surgeons is provided. It is developed in the context of naturalistic decision making. A model of the surgeon's decision making process can lead to needed skills an expert must have to reach an experts performance level. Those skills could be then analyzed so that a training supports the trainee in gaining the skills.
Quotes	"From the available evidence in surgery, and drawing from research in other safetycritical occupations, four decision-making strategies that surgeons may use are discussed: intuitive (recognition-primed), rule based, option comparison and creative." (p.235) "The consequent reduction in attendance in the operating theatre produces a concomitant reduction in exposure to clinical situations and in the requisite number of operative procedures." (p.235) "Decision making during surgery, particularly during emergency surgery, is a key element in clinical practice that merits better preparation than is currently delivered." (p.238)
Methodology	-

Article aspect	Description
Title	Naturalistic decision making.*
Reference	Klein, G. (2008). Naturalistic decision making. *Human Factors*, *50*(3), 456–460. doi:10.1518/001872008X288385
Statement	Naturalistic decision making tries to explain decision making in complex real world scenarios where the decision maker has limited time and uncertainty. This framework is used for specific models of the surgeons decision making process.
Quotes	"The NDM framework emphasizes the role of experience in enabling people to rapidly categorize situations to make effective decisions" (p.456) "The recognition-primed decision (RPD) model describes how people use their experience in the form of a repertoire of patterns" (p.457) "Because cognitive field research methods have proven so effective for generating insights about decision making, they are being used to study other "macrocognitive" functions, such as situation awareness, sensemaking, planning and replanning, and the ways they are linked." (p.458)
Methodology	-

Article aspect	Description
Title	Surgical process modelling: a review
Reference	Lalys, F., & Jannin, P. (2014). Surgical process modelling: a review. *International Journal of Computer Assisted Radiology and Surgery*, *9*(3), 495–511. doi:10.1007/s11548-013-0940-5
Statement	For the content creation of a training program the knowledge has to be organized and represented. In this review an overview is given on how the surgical process can be represented and modeled.
Quotes	"Research studies have been performed towards the development of sophisticated techniques for optimising, understanding and better managing surgeries and the OR environment based on SPMs." (p.509) "To organise the review, we have introduced a classification based on 5 major aspects of the SPM methodology: acquisition, modelling, analysis, application and validation/evaluation." (p.509)
Methodology	Literature review

Article aspect	Description
Title	The magical number seven, plus or minus two: some limits on our capacity for processing information.*
Reference	Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97. doi:10.1037/h0043158
Statement	This article discusses that working memory has limitations in how much information it can hold. Those limitations have to be considered by designing a training program.
Quotes	"First, the span of absolute judgment and the span of immediate memory impose severe limitations on the amount of information that we are able to receive, process, and remember. By organizing the stimulus input simultaneously into several dimensions and successively into a sequence of chunks, we manage to break (or at least stretch) this informational bottleneck." (p. 95)
Methodology	-

Article aspect	Description
Title	Human problem solving*
Reference	Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.
Statement	This book discusses human problem solving and describes the human as an information processing system. This can also be used as a framework and put surgery into terms of problem solving. However newer approaches like naturalistic decision making should get priority in the discussion.
Quotes	-
Methodology	-

Article aspect	Description
Title	Medical curriculum reform in North America, 1765 to the present
Reference	Papa, F. J., & Harasym, P. H. (1999). Medical curriculum reform in North America, 1765 to the present. *Academic Medicine*, *74*(2), 154–164. doi:10.1097/00001888-199902000-00015
Statement	This article gives a historical view of the surgical domain.
Quotes	“Improvements in medical education occurred as each new curriculum model built on the strengths of past innovations and at the same time overcame identified weaknesses of past approaches. “ (p.162)
Methodology	-

Article aspect	Description
Title	Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models*
Reference	Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-13*(3), 257–266. doi:10.1109/TSMC.1983.6313160
Statement	This model is sometimes used to describe the surgical process.
Quotes	“In our work, concern is with the timely development of models of human performance which can be useful for the design and evaluation of new interface systems. For this purpose, we do not need a single integrated quantitative model of human performance but rather an overall qualitative model which allows us to match categories of performance to types of situations. In addition, we need a number of more detailed and preferably quantitative models which represent selected human functions and limiting properties within the categories. The role of the qualitative model will generally be to guide overall design of the structure of the system including, for example, a set of display formats, while selective, quantitative models can be used to optimize the detailed designs.” (p.264)
Methodology	-

Article aspect	Description
Title	Problem solving*
Reference	Robertson, S. I. (2001). *Problem solving*. New York, NY, USA: Psychology Press. doi:10.4324/9780203457955
Statement	The author discusses the various aspects of problem solving. He lines out the most common concepts and theoretical frameworks for becoming an expert. Learning, building mental models and problem solving strategies are discussed. This book is an ideal starting point to get an overview of the research field and to build up the theoretical framework for this literature study.
Quotes	“As PI is a model designed to show how we learn from experience of instances, and as it includes algorithms for both generalisation an specialisation, it is a general model that explains the development of expertise” (p.154) “As a rule of thumb, an expert is someone who has had 10 years’ experience in that domain” (p.167)
Methodology	-

Article aspect	Description
Title	Rasmussen's model of human behavior in laparoscopy training
Reference	Stassen, L. P. S., Alwayn, I., Hosman, R. J. a W., Stassen, H. G., & Wentink, M. (2003). Rasmussen's model of human behavior in laparoscopy training. *Surgical Endoscopy*, *17*(8), 1241–1246. doi:10.1007/s00464-002-9140-z
Statement	This is an example of Rasmussen's model used for training development.
Quotes	"Much as in conventional surgery, the laparoscopic surgeon must effectively combine the three levels of behavior. Instrument handling and dissection techniques require skill-based behavior, whereas the recognition of surgical anatomy requires a great deal of rule-based behavior. Complications such as uncontrollable bleeding or unsuspected situations such as the encountering of aberrant anatomy require problem solving on a knowledge-based level." (p.1243)
Methodology	-

Table 2

Short descriptions of literature under the main category robotic surgery general

Article aspect	Description
Title	How Surgical Robotics Transform the Development of Expertise in Modern Operating Rooms: An Ethnographic Study
Reference	Balkin, E. A. (2013). How Surgical Robotics Transform the Development of Expertise in Modern Operating Rooms: An Ethnographic Study. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *57*(1), 693–697. doi:10.1177/1541931213571150
Statement	The author argues that robotic assisted surgery differs significantly from traditional methods. These differences should be addressed in robot assisted trainings. The view is in contrast to the opinion, that results for laparoscopy can safely be extrapolated onto robot assisted surgery.
Quotes	"This paper provides results that indicate a RAS has produced a qualitative shift in cognitive and collaborative work within the robot equipped operating room." (p.693)
Methodology	Ethnographic study

Article aspect	Description
Title	"Factors associated with adoption of robotic surgical technology in US hospitals and relationship to radical prostatectomy procedure volume." (p. 7)
Reference	Blute, M. L., & Prestipino, A. L. (2014). Factors associated with adoption of robotic surgical technology in US hospitals and relationship to radical prostatectomy procedure volume. *Annals of Surgery*, *259*(1), 7–9. doi:10.1097/SLA.0000000000000390
Statement	The authors summarize key factors that should be considered using robot assisted surgery. They emphasize careful privileging surgeon access to the daVinci robot.
Quotes	"Inappropriately allowing privileging of use of the robot has led in several instances to significant complications related to the use of the technology" (p.9)
Methodology	-

Article aspect	Description
Title	The role of cognitive abilities in laparoscopic simulator training.
Reference	Groenier, M., Schraagen, J. M. C., Miedema, H. A. T., & Broeders, I. A. J. M. (2014). The role of cognitive abilities in laparoscopic simulator training. *Advances in Health Sciences Education : Theory and Practice*, *19*(2), 203–17. doi:10.1007/s10459-013-9455-7
Statement	Here, the influence of cognitive aptitude on laparoscopic performance and learning is investigated. Too little is known about the influence and mediating effects of cognitive aptitude to use those factors for assessment or selection. More research is needed.
Quotes	"Before cognitive aptitude testing can be used as an assessment or selection tool, more research is necessary to examine how cognitive abilities influence MIS performance at different stages of learning as well as the relationship between cognitive aptitude and operating room performance." (p.216)
Methodology	Experiment with 53 participants

Article aspect	Description
Title	Baseline urologic surgical skills among medical students: Differentiating trainees
Reference	Gupta, V., Lantz, A. G., Alzharani, T., Foell, K., & Lee, J. Y. (2014). Baseline urologic surgical skills among medical students: Differentiating trainees. *Cuaj-Canadian Urological Association Journal*, *8*, 242–246. http://doi.org/10.5489/cuaj.1807
Statement	This experiment demonstrates that there are differences between medical students that want to become surgeons and those that want to pursue another career in the medical domain. However, the authors could not determine what the discriminating factors are.
Quotes	"Our study demonstrates that there is a significant difference in objective innate technical ability between the surgical and non-surgical groups, particularly for laparoscopic and robotic skills." (p.245)
Methodology	Experiment with 29 medical students, with control group.

Article aspect	Description
Title	Surgeons strive hard to break the Da Vinci code.
Reference	Kodera, Y. (2014). Surgeons strive hard to break the Da Vinci code. *Gastric Cancer : Official Journal of the International Gastric Cancer Association and the Japanese Gastric Cancer Association, 17*(3), 399–401. http://doi.org/10.1007/s10120-013-0304-4
Statement	This article describes the dilemma that the training marked for robot assisted surgery has. It is sketched out for Japan. This demonstrates the need for certifying training programs.
Quotes	"Somewhat paradoxically, only proficient laparoscopic surgeons who can perform gastrectomy laparoscopically without any help from either an instructor or a robot are considered appropriate to seek assistance from this device in Japan, which is essentially because Da Vinci has not been approved by their social insurance system." (p.399)
Methodology	-

Article aspect	Description
Title	The role of stereopsis in virtual anatomical learning.
Reference	Luursema, J. M., Verwey, W. B., Kommers, P. A. M., & Annema, J.-H. (2008). The role of stereopsis in virtual anatomical learning. *Interacting with Computers*, *20*(4-5), 455–460. doi:10.1016/j.intcom.2008.04.003
Statement	In this article it is shown that stereopsis is beneficial to anatomical learning. Stereopsis is one of the advantages of robot assisted surgery. Further Luursema et al., 2008 point out that visuo-spatial ability is an important predictor for anatomical learning.
Quotes	“We now report an experiment that investigated the contribution of computer-implemented stereopsis on anatomical learning for participants of differing visuo-spatial ability.” (p. 459) “The results confirm earlier research that shows higher visuo-spatial ability significantly indicates better anatomical learning” (p. 459) “Additionally, having been exposed to a study phase with computer implemented stereopsis implied significantly higher accuracy on an anatomical localization task.” (p. 459)
Methodology	Quantitative experiment with control group and 46 participants.

Article aspect	Description
Title	The use of virtual reality simulation to determine potential for endoscopic surgery skill acquisition
Reference	Mann, T., Gillinder, L., & Szold, A. (2014). The use of virtual reality simulation to determine potential for endoscopic surgery skill acquisition. *Minimally Invasive Therapy & Allied Technologies*, *23*, 190–197. http://doi.org/10.3109/13645706.2014.894529
Statement	This is another approach in trying to find a screening tool for surgery training aspirant selection. It is based on taking simulator scores. With those scores the authors try to predict the performance of the trainees for the FLS.
Quotes	„The purpose of this study was to assess whether the Simbionix Lapmentor could be used as a screening tool for surgeons who will have superior OR success.“ (p.194)
Methodology	Experiment with control group, 17 participants.

Article aspect	Description
Title	Patents running out: time to take stock of robotic surgery
Reference	O’Reilly, B. A. (2014). Patents running out: time to take stock of robotic surgery. *International Urogynecology Journal*, *25*(6), 711–713. doi:10.1007/s00192-014-2353-6
Statement	The upcoming competition and the possible diversification of the robot marked has implications for a robot surgery training. It needs to be designed in order to adapt quickly to new robots and technologies.
Quotes	“However, over the last 10 years, patents have expired, and many companies around the world are at various stages of robotic surgical technology development. Intuitive Surgical have been able to command such enormous costs because of its monopoly position as sole supplier of the da Vinci. As with any economic model, competition will bring down costs, and there will certainly be a number of new robotic manufacturersentering the market over the next couple of years (e.g., Titan Medical and Kymerax).” (p.712)
Methodology	-

Article aspect	Description
Title	Robotic surgery.
Reference	Schreuder, H. W. R., & Verheijen, R. H. M. (2009). Robotic surgery. *BJOG : An International Journal of Obstetrics and Gynaecology*, *116*(2), 198–213. doi:10.1111/j.1471-0528.2008.02038.x
Statement	This review lists the advantages and disadvantages of the daVinci robot.
Quotes	"The use of robots is rapidly increasing with a market growth worldwide from less than 5 billion in 2000 to an expected 25 billion in 2010." (p.198)
Methodology	Literature review

Article aspect	Description
Title	Ergonomics, user comfort, and performance in standard and robot-assisted laparoscopic surgery
Reference	Olivier, R. H. V, van't Hullenaar, C. D. P., Ruurda, J. P., Broeders, I. A. M. J., & van der Schatte Olivier, R. H. (2009). Ergonomics, user comfort, and performance in standard and robot-assisted laparoscopic surgery. *Surgical Endoscopy and Other Interventional Techniques*, *23*(6), 1365–1371. doi:10.1007/s00464-008-0184-6
Statement	This article summarizes more advantages of robot assisted surgery.
Quotes	"Robot-assisted surgical systems are designed to facilitate manipulation of surgical instruments by increasing freedom of movement and introducing stereoscopic vision. Additionally, physical workload is reduced as the surgeon operates from a comfortable console instead of standing next to the operating table." (p. 1368) "Our study confirmed that robotic assistance can reduce physical stress significantly." (p.1368)
Methodology	Experiment with 16 participants

Article aspect	Description
Title	The Bedside Assistant in Robotic Surgery - Keys to Success.
Reference	Yuh, B. (2013). The Bedside Assistant in Robotic Surgery - Keys to Success. *Urologic Nursing*, *33*(1), 29–32. doi:10.7257/1053-816X.2013.33.1.29
Statement	The bedside assistant changes the communication that takes place during a surgery compared to laparoscopy. The assistant is also the one first reacting to a crisis. The dependence of the surgeon on the assistant and the communication can be integrated into robot assisted surgical training.
Quotes	"The bedside assistant is a fundamental member of the robotic team and assumes numerous roles during surgerys." (p.29) "A skilled bedside assistant is an essential part of an effective robotic surgery team. Roles and responsibilities for assistants will change in the future, but they remain a vital bridge between the console surgeon and the patient." (p. 32)
Methodology	-

Table 3
Short descriptions of literature under the main category surgery training

Article aspect	Description
Title	"Development Of A Standardised Training Curriculum For Robotic Surgery: A Consensus Statement From An International Multidisciplinary Group Of Experts" (p. 93)
Reference	Ahmed, K., Khan, R., Mottrie, A., Lovegrove, C., Abaza, R., Ahlawat, R., … Dasgupta, P. (2015). Development Of A Standardised Training Curriculum For Robotic Surgery: A Consensus Statement From An International Multidisciplinary Group Of Experts. *BJU International*, *116*(1), 93–101. doi:10.1111/bju.12974
Statement	This is the description of the creation process and contend of the curriculum of the ERUS initiative. The initiative is one of the main contenders to become the gold standard in robot surgery.
Quotes	"Potential training paths following the robotic surgery curriculum have been proposed and experts in robotic surgery are in agreement with this proposal." (p.99)
Methodology	Consensus report
Article aspect	Description
Title	Robotic surgical training.
Reference	Ben-Or, S., Nifong, L. W., & Chitwood, W. R. (2013). Robotic surgical training. *Cancer Journal (Sudbury, Mass.)*, *19*(2), 120–123. doi:10.1097/PPO.0b013e3182894887
Statement	The authors describe their approach to gaining expertise in robotic assisted surgery and stress, that trainees with different experience levels need different training approaches.
Quotes	"More experienced surgeon learners process these algorithms differently than younger surgeons." (p.123)
Methodology	Literature review
Article aspect	Description
Title	"Celebrating a decade of innovation in surgical education" (p. 10)
Reference	Brunt, M. (2014). Celebrating a decade of innovation in surgical education. *American College Of Surgeons*, *99*(11), 10–15.
Statement	The beginning of minimally invasive surgery is outlined. The creation of the FLS is described. Similarities can be seen in the introduction of robotic assisted surgery. Lessons learned from the introduction of laparoscopy can be drawn for robot assisted surgery.
Quotes	"As crazy as that sounds, what we're finding is that [with] many surgeons now coming straight out of training, there are some operations they've only done laparoscopically." (p.15)
Methodology	-

Article aspect	Description
Title	Virtual reality simulators: Current status in acquisition and assessment of surgical skills
Reference	Cosman, P. H., Cregan, P. C., Martin, C. J., & Cartmill, J. A. (2002). Virtual reality simulators: Current status in acquisition and assessment of surgical skills. *ANZ Journal of Surgery*, *72*(1), 30–34. doi:10.1046/j.1445-2197.2002.02293.x
Statement	This article gives an overview of the state of simulators for surgical skills. The future of surgical education seems to be simulators but as the review shows there is still a lot of work to do until the domain reaches aviation simulator standards.
Quotes	"There is no doubt that simulators will play a role in the training of future generations of surgeons. It is our duty to investigate thoroughly all the issues associated with this exciting new field to ensure that the education of surgeons does not fall below the current high standard, and that the many pitfalls associated with new technologies and educational interventions are avoided." (p. 33)
Methodology	-

Article aspect	Description
Title	Developing a comprehensive, proficiency-based training program for robotic surgery.
Reference	Dulan, G., Rege, R. V, Hogg, D. C., Gilberg-Fisher, K. M., Arain, N. A., Tesfay, S. T., & Scott, D. J. (2012). Developing a comprehensive, proficiency-based training program for robotic surgery. *Surgery*, *152*(3), 477–488. doi:10.1016/j.surg.2012.07.028
Statement	This study is the basis for the FRS curriculum. The found tasks were further developed by multiple consensus meetings.
Quotes	"The expert interviews and case observations resulted in a task deconstruction list that contained 23 unique and necessary skills, including 7 cognitive and 16 technical skills." (p.485)
Methodology	interviews of six subject matter experts, validated via 10 observational task analysis sessions

Article aspect	Description
Title	"An over-view of robot assisted surgery curricula and the status of their validation." (p.115)
Reference	Fisher, R. a., Dasgupta, P., Mottrie, A., Volpe, A., Khan, M. S., Challacombe, B., & Ahmed, K. (2015). An over-view of robot assisted surgery curricula and the status of their validation. *International Journal of Surgery*, *13*(JANUARY), 115–123. doi:10.1016/j.ijsu.2014.11.033
Statement	This is a systematic overview of the major contenders for creating a validated robot surgery training for credentialing. They found in total six projects that are developing training programs for credentialing robot surgeons. It is one of the most important papers for this master thesis.
Quotes	"This review outlines the historical perspectives of curriculum development, available curricula, their process of development, validation status and current utilization." (p. 116) "The main curricula are the FRS, the FSRS, the BSTC and the ERUS initiative." (p. 121)
Methodology	Partly systematic literature review

Article aspect	Description
Title	Virtual Reality Simulation for the Operating Room
Reference	Gallagher, A. G., Ritter, E. M., Champion, H., Higgins, G., Fried, M. P., Moses, G., … Satava, R. M. (2005). Virtual Reality Simulation for the Operating Room. *Annals of Surgery*, *241*(2), 364–372. doi:10.1097/01.sla.0000151982.85062.80
Statement	The authors discuss in detail what aspects have to be taught in order to integrate virtual reality simulation into a training program. According to them a successful integration of simulation into surgery is very likely to happen.
Quotes	“Simulation when integrated into a well-structured curriculum has the potential to be a very powerful training and assessment tool when properly applied.” (p. 371)
Methodology	Literature review

Article aspect	Description
Title	Robotic surgical training of the urologic oncologist.
Reference	Guzzo, T. J., & Gonzalgo, M. L. (2009). Robotic surgical training of the urologic oncologist. *Urologic Oncology*, *27*(2), 214–217. doi:10.1016/j.urolonc.2008.09.019
Statement	This article provides a review about robot assisted training. The main topics are surgical simulation and learning curves.
Quotes	“Robotic training exists in many current forms and is currently without standardization. The most effective robotic training approach appears to be a structured mentored training program.” (p.217)
Methodology	Literature review

Article aspects	Description
Title	Simulators in surgery
Reference	Halvorsen, F. H., Elle, O. J., & Fosse, E. (2005). Simulators in surgery. *Minimally Invasive Therapy & Allied Technologies*, *14*(4-5), 214–223. doi:10.1080/13645700500243869
Statement	This article provides a review about simulators in surgery. The simulators are discussed sorted into the categories mechanical, hybrid, and virtual reality. This review can be used to show the status quo of surgery simulators.
Quotes	-
Methodology	-

Article aspects	Description
Title	da Vinci® Training Passport Technology Training Pathway: Surgeon
Reference	Intuitive Surgical Inc. (2015). *da Vinci® Training Passport Technology Training Pathway: Surgeon*.
Statement	This pathway shows the different phases of the training from Intuitive Surgical. The authors also clearly state that training of Intuitive Surgical is only sharing of information not a certifying or privileging process to use the robot for surgery.
Quotes	"Any demonstration during Intuitive Surgical-sponsored training or instructional material on how to use the system to perform a particular technique or procedure is not the recommendation or "certification" of *Intuitive Surgical* as to such technique or procedure, but rather is merely a sharing of information on how other surgeons may have used the system to perform a given technique or procedure.“ (p. 3)
Methodology	-

Article aspects	Description
Title	Can we become better robot surgeons through simulator practice?
Reference	Patel, A., Patel, M., Lytle, N., Toro, J. P., Medbery, R. L., Bluestein, S., … Lin, E. (2014). Can we become better robot surgeons through simulator practice? *Surgical Endoscopy*, *28*(3), 847–853. doi:10.1007/s00464-013-3231-x
Statement	This study proves that a simulator can be used for training purposes in the domain of surgery. They also suggest to use recorded metrics of the training sessions for individual training recommendations. This study shows the usefulness of simulation training and the advantages such a training can have comparted to non-simulation based training.
Quotes	"Despite growth of the robotic surgery platform, no standardized approach to training for a surgeon has been developed.“ (p. 830)
Methodology	Retrospective data analyze of 26000 minutes of simulator exercises recorded in log files.

Article aspects	Description
Title	Fundamentals of Robotic Surgery: Consensus Conference on Outcomes Measures
Reference	Satava, R. M., Smith, R. D., & Patel, V. R. (2011). *Fundamentals of Robotic Surgery: Consensus Conference on Outcomes Measures*.
Statement	This document describes the process of how the founder of the FRS filtered out and ranked the 25 tasks most relevant in robot assisted surgery.
Quotes	„*Objectives*: To develop a list of skills, tasks and errors critical to the performance of robotic surgery, and identify quantitative outcome metrics that accurately measure performance.“ (p. 3)
Methodology	Consensus conference based on Delphi methodology.

Article aspect	Description
Title	Training and learning robotic surgery, time for a more structured approach: a systematic review
Reference	Schreuder, H. W. R., Wolswijk, R., Zweemer, R. P., Schijven, M. P., & Verheijen, R. H. M. (2012). Training and learning robotic surgery, time for a more structured approach: a systematic review. *BJOG : An International Journal of Obstetrics and Gynaecology*, *119*(2), 137–49. doi:10.1111/j.1471-0528.2011.03139.x
Statement	This literature review gives an overview of the different training programs reported, of possible means to train robot assisted surgery and of the authors opinion about the missing golden standard in the trainings. This article provides the starting point for an in depth literature review regarding the search for the road to the golden standard in robot assisted surgery training. It falls short in providing a theoretical framework for expertise.
Quotes	“Designing a competence-based training curriculum for robotic surgery remains a challenge, but with the exponential increase of robotic surgery the need for such certified curricula is increasing rapidly” (p.146) “With the increasing quality of virtual reality simulators for robotic surgery it is expected, that this training modality will play an important role in training future robotic surgeons.” (p.146) “Robotic surgical training consists of two equal parts: system training and procedural training.” (p. 145)
Methodology	Systematic literature review

Article aspect	Description
Title	Fundamentals of robotic surgery: a course of basic robotic surgery skills based upon a 14-society consensus template of outcomes measures and curriculum development
Reference	Smith, R., Patel, V., & Satava, R. (2014). Fundamentals of robotic surgery: a course of basic robotic surgery skills based upon a 14-society consensus template of outcomes measures and curriculum development. *The International Journal of Medical Robotics and Computer Assisted Surgery*, *10*(3), 379–384. doi:10.1002/rcs.1559
Statement	The FRS is one of the two main emerging standards for robot assisted surgery. In this document the training and development of it is described. However, the program is still in development and validation phase. Not all details are published yet.
Quotes	“A consensus conference process, involving members from major stakeholder organizations in surgical training, governance and certification across multiple specialties, was implemented, with the result of a curriculum for the most important outcome measures for the safe conduct of robotic surgery.“ (p. 383)
Methodology	Multiple consensus conferences

Article aspect	Description
Title	Optimal training design for procedural motor skills: a review and application to laparoscopic surgery
Reference	Spruit, E. N., Band, G. P. H., Hamming, J. F., & Ridderinkhof, K. R. (2014). Optimal training design for procedural motor skills: a review and application to laparoscopic surgery. *Psychological Research*, *78*(6), 878–891. doi:10.1007/s00426-013-0525-5
Statement	This literature review shows the usability of the deliberate practice framework for the surgical domain. It gives clear guidelines for training development. Guidelines like these are rare or non-existent for robot assisted surgery. Parts of the guidelines of the article seem to be relevant for robot assisted surgery.
Quotes	“Some of the elements of DP are already described in this paper (such as well-defined proficiency goals, matching task difficulty level to the current skill of the trainee and reliable assessment), others include informative feedback from simulators and trainers, monitoring performance, error correction and high trainee motivation and concentration“ (p. 886)
Methodology	Literature review

Article aspect	Description
Title	Learning curves in expert and non-expert laparoscopic surgeons for robotic suturing with the da Vinci® Surgical System
Reference	Sumi, Y., Dhumane, P. W., Komeda, K., Dallemagne, B., Kuroda, D., & Marescaux, J. (2012). Learning curves in expert and non-expert laparoscopic surgeons for robotic suturing with the da Vinci® Surgical System. *Journal of Robotic Surgery*, *7*(1), 29–34. doi:10.1007/s11701-012-0336-5
Statement	This article compares two learning curves of a laparoscopic experienced and an inexperienced surgeon. They come to the conclusion that the robot can have advantages to learn complex laparoscopic skills especially for unexperienced trainees. However, because of the small participant number this needs further validation.
Quotes	„This suggests possible advantages of the introduction of the da Vinci Surgical System for acquisition of complex surgical skills for junior surgeons and its utility in surgical training“ (p. 33)
Methodology	Experiment with two participants.

Table 4
Short descriptions of literature under the main category aviation.

Article aspect	Description
Title	"Lessons for Surgeons in the Final Moments of Air France Flight 447" (p. 1185)
Reference	Bhangu, A., Bhangu, S., Stevenson, J., & Bowley, D. M. (2013). Lessons for Surgeons in the Final Moments of Air France Flight 447. *World Journal of Surgery*, *37*, 1185–1192. doi:10.1007/s00268-013-1971-3
Statement	This is an example of how critical incident analysis can be useful for the creation of training curricula. A critical incident analysis from aviation is mapped onto the surgical domain.
Quotes	"Likewise, in the face of increasing reliance on modern technology, surgeons should ensure that they would be able to perform procedures in the absence of such technologies." (p.1185)
Methodology	Critical incident analysis
Article aspect	**Description**
Title	Pilot training: What can surgeons learn from it?
Reference	Buchholz, N. (2014). Pilot training: What can surgeons learn from it? *Arab Journal of Urology*, *12*(1), 35–36. doi:10.1016/j.aju.2013.08.005
Statement	The author describes similarities and differences between surgery and aviation. Further he argues how aviation style training can improve surgery training.
Quotes	"Transferring these well-tried aviation methods into healthcare will make surgical training more efficient, more effective and ultimately safer." (p.35)
Methodology	-
Article aspect	**Description**
Title	A multicenter trial of aviation-style training for surgical teams
Reference	Catchpole, K. R. ., Dale, T. J. ., Hirst, D. G. ., Smith, J. P. ., & Giddings, T. A. E. B. . (2010). A multicenter trial of aviation-style training for surgical teams. *Journal of Patient Safety*, *6*(3), 180–186. doi:10.1097/PTS.0b013e3181f100ea
Statement	This study shows benefits of an aviation style non-technical skill module. However, it shows also how difficult it is in the health market to establish such a training. Such a training can be very useful for robot surgery teams and should be further researched.
Quotes	"Aviation-style teamwork training can increase compliance and team performance, but this was influenced by the attitude and collaboration of key individuals, and the effect was reduced by significant latent failures." (p.180)
Methodology	Multicenter trial in three hospitals.

Article aspect	Description
Title	The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre.
Reference	McCulloch, P., Mishra, a, Handa, a, Dale, T., Hirst, G., & Catchpole, K. (2009). The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre. *Quality & Safety in Health Care*, *18*(2), 109–115. doi:10.1136/qshc.2008.032045
Statement	The authors of the articles report their experience with the introduction of an aviation-style non-technical skills training. This exemplifies how difficult it is to introduce new standards in the medical domain. It also shows that lessons learned from aviation can have an impact on the performance quality of surgical teams.
Quotes	„NOTECHS classifies non-technical skills into four dimensions: (1) leadership and management (L&M), (2) teamwork and cooperation (T&C), (3) problem-solving and decision-making (P&D) and (4) situation awareness (SA).“ (p. 110) „The aims of the training programme were to increase knowledge, change attitudes and improve behaviour in relation to: (a) safety, situation awareness, and error management; (b) self-awareness, communication and assertiveness; and (c) decision-making, briefing and debriefing.“ (p.111) „Anecdotal evidence from aviation experience suggests that management action to ensure compliance via policies and procedures may be necessary to ensure“ (p. 114)
Methodology	

Article aspect	Description
Title	Naval aviation and neurosurgery: traditions, commonalities, and lessons learned
Reference	Quest, D. O. (2007). Naval aviation and neurosurgery: traditions, commonalities, and lessons learned. *Journal of Neurosurgery*, *107*(6), 1067–1073. doi:10.3171/jns.2007.107.6.1067
Statement	In this article a former fighter pilot compares neurosurgery to aviation and describes commonalities and differences. The author points out that simulators from the surgery are only rudimental compared to simulators from aviation training.
Quotes	“Maintenance of certification is in the embryonic stage in neurosurgery but is well planned and exemplary among the member boards of the American Board of Medical Specialties.“ (p. 1072)
Methodology	-

Table 5
Short descriptions of literature under the main category sport.

Article aspect	Description
Title	The effect of warm-up on surgical performance: a systematic review
Reference	Abdalla, G., Moran-Atkin, E., Chen, G., Schweitzer, M. A., Magnuson, T. H., & Steele, K. E. (2015). The effect of warm-up on surgical performance: a systematic review. *Surgical Endoscopy*, *29*(6), 1259–1269. doi:10.1007/s00464-014-3811-4
Statement	Warm up is well known from sports. It should be considered for surgery training as a method for performance enhancement.
Quotes	“Data gathered in our systematic review seems to favor warming-up of residents, and fellows prior to going to the operating room. “ (p. 1267)
Methodology	Literature review
Article aspect	Description
Title	Mental Practice Enhances Surgical Technical Skills
Reference	Arora, S., Aggarwal, R., Sirimanna, P., Moran, A., Grantcharov, T., Kneebone, R., … Darzi, A. (2011). Mental Practice Enhances Surgical Technical Skills. *Annals of Surgery*, *253*(2), 265–270. doi:10.1097/SLA.0b013e318207a789
Statement	Mental practice training is cheap. This study shows the effectiveness of mental training for inexperienced surgeons. Such a training can help rise patient safety.
Quotes	“This study clearly demonstrates that mental practice also enhances the quality of laparoscopic performance in novice surgeons.” (p. 268)
Methodology	Randomized controlled study with 20 participants.
Article aspect	Description
Title	Performing to a world class standard under pressure—Can we learn lessons from the Olympians?
Reference	Colbert, S. D., Scott, J., Dale, T., & Brennan, P. A. (2012). Performing to a world class standard under pressure—Can we learn lessons from the Olympians? *British Journal of Oral and Maxillofacial Surgery*, *50*(4), 291–297. doi:10.1016/j.bjoms.2012.04.263
Statement	This article describes mental toughness. A concept that could be useful for surgeons. Further research is needed to clarify the implications for training.
Quotes	“Motivation is the foundation of all athletic effort and accomplishment. Without the determination to improve performance, all of the other mental factors mentioned such as confidence, intensity, focus, and emotions, are meaningless.” (p. 294)
Methodology	Literature review; Questionnaire

Article aspect	Description
Title	Performance skills for surgeons: Lessons from sport
Reference	Gibney, E. J. (2012). Performance skills for surgeons: Lessons from sport. *American Journal of Surgery*, *204*(4), 543–544. doi:10.1016/j.amjsurg.2010.12.004
Statement	This article describes concepts of sport psychology. These training methods should be considered as tools for the surgical domain. However, these methods first need more research in the context of surgery to give precise recommendations for training.
Quotes	“Sports psychology recognizes several primary psychological skills considered important to optimize performance. These are as follows: (1) concentration, the ability to focus and control attention; (2) self-confidence or self-efficacy; (3) arousal control, the ideal balance between anxiety and relaxation; and (4) coping skills, which relate especially to the ability to perform well under pressure.“ (p. 543-544)
Methodology	-

Article aspect	Description
Title	Mental training in surgical education: a randomized controlled trial.
Reference	Immenroth, M., Bürger, T., Brenner, J., Nagelschmidt, M., Eberspächer, H., Troidl, H., … Troidl, H. (2007). Mental training in surgical education: a randomized controlled trial. *Annals of Surgery*, *245*(3), 385–391. doi:10.1097/SLA.0b013e31805d0893
Statement	This experiment is an example that shows that an investigation in training methods from other domains can be fruitful. Mental imagery is a cheap method that is promising for surgery training.
Quotes	“Mental training was effective in optimizing the performance of surgeons undergoing training in laparoscopic cholecystectomy.“ (p. 389)
Methodology	Randomized controlled trial.

9 Appendix B

Search protocol

The literature review is intended as a systematically gathered article pool for the purpose of the master thesis and for the ongoing research project about robotic assisted surgery in general. In table 1 the process and results of the Literature review are documented.

Search term (1)	(cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*)
Initial results Scopus	4473
Initial results PsycINFO	823
Hits by title PsycINFO	**90**
Initial results Web of Science	2206
Search term (1.1)	(cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND robot* surg*
Initial results Scopus	317
Hits by title Scopus	**150**
Reviews Scopus	24
Initial results Web of Science	193
Hits by title Web of Science	**49**
Search term (1.2) Scopus	(cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND (LIMIT-TO (DOCTYPE , "re")
Search term (1.2) Web of Science	((cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*)) Refined by: DOCUMENT TYPES: (REVIEW)
Initial results Scopus	554
Hits by title Scopus	**93**
Initial results Web of Science	175
Hits by title Web of Science	**33**
Search term (1.3) Scopus	(cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND NOT child* AND NOT glove AND NOT patient*
Search term (1.3) Web of Science	((cognit* OR senso* OR motor) AND (dexterity OR skill OR requirement OR demand) AND (surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) NOT child* NOT glove NOT patient*)
Initial results Scopus	1872
Hits by title Scopus	**508**
Initial results Web of Science	925
Hits by title Web of Science	**346**

Search term (2)	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND (skill OR task) AND (decomposition OR deconstruction OR training OR aqui* OR proficiency)
Initial results Scopus	8921
Initial results PsycINFO	859
Hits by title PsycINFO	**109**
Refined search term (2.1)	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND (skill OR task) AND (decomposition OR deconstruction OR aqui* OR proficiency)
Initial results Scopus	700
Hits by title Scopus	**453**
Reviews Scopus	56
Initial results Web of Science	603
Hits by title Web of Science	**332**
Refined search term (2.2 (3))	(robot* surg* AND training)
Initial results Scopus	1545
Hits by title Scopus	**705**
Initial results Web of Science	866
Hits by title Web of Science	**408**

Search term (3)	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND task AND analysis
Initial results Scopus	5612
Initial results PsycINFO	486
Hits by title PsycINFO	**34**
Refined search term (3.1) Scopus	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND task W/5 analysis
Refined search term (3.1) Web of Science	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND task NEAR/5 analysis
Initial results Scopus	1997
Hits by title Scopus	**686**
Reviews Scopus	50
Initial results Web of Science	418
Hits by title Web of Science	**142**

Search term (4)	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surge*) AND cognitive AND task AND analysis
Initial results Scopus	365
Hits by title Scopus	**114**
Reviews Scopus	5
Initial results PsycINFO	167
Hits by title PsycINFO	**17**
Initial results Web of Science	239
Hits by title Web of Science	**70**

Search term (5)	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND hierarchical AND task AND analysis
Initial results Scopus	55
Hits by title Scopus	**27**
Reviews Scopus	1
Initial results PsycINFO	10
Hits by title PsycINFO	**3**
Initial results Web of Science	43
Hits by title Web of Science	**21**

Search term (6)	(surg* OR laparoscop* OR robot* surg* OR traditional surg* OR open surg*) AND (critical incident*)
Initial results Scopus	611
Hits by title Scopus	**37**
Reviews Scopus	10
Initial results PsycINFO	26
Hits by title PsycINFO	**3**
Initial results Web of Science	332
Hits by title Web of Science	**27**

Search term (6)	(laparoscop* AND robot* surg*) AND (skill OR task) AND transfer)
Initial results Scopus	45
Hits by title Scopus	**11**
Reviews Scopus	0
Initial results PsycINFO	2
Hits by title PsycINFO	**1**
Initial results Web of Science	39
Hits by title Web of Science	**10**

Other Domains

Search term	(sport AND skill AND surg* AND training)
Initial results Scopus	71
Hits by title Scopus	**17**
Reviews Scopus	1
Initial results PsycINFO	8
Hits by title PsycINFO	**1**
Initial results Web of Science	44
Hits by title Web of Science	**15**

Search term	(aviat* AND skill AND surg* AND training)
Initial results Scopus	69
Hits by title Scopus	**18**
Reviews Scopus	8
Initial results PsycINFO	7
Hits by title PsycINFO	**1**
Initial results Web of Science	72
Hits by title Web of Science	**17**

Total Hits by title Web Ob science: 1170
Total Hits by title Scopus: 2235
Total Hits by title PsychInfo: 176
Total Hits by title with duplicates: 3581
Total hits by title without duplicates: 2650
Total Hits by Abstract: 2386
Minor priority & assessment (for Future research topics of the Project): 119 + 483 = 602
New total hits by Abstract: 1781
Hits transfer laparoscopy to robotic assisted surgery: 18