

Understanding decision making in robotic surgery: a knowledge gap survey and cognitive task analysis of robotic prostatectomy

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Abstract

Robotic surgery is at the forefront of surgical innovation and presents novel challenges for both postgraduate learners and seasoned specialists. Robotic teaching is underway, often without formalized robotic curricula. Research into robotic surgical steps and surgical decision-making that should be imparted to learners has been neglected. As such, I aimed to determine the knowledge gap of urology residents for a robotic prostatectomy. Further, I also aimed to determine the patterns and cognitive rules used by experienced surgeons to complete a robotic prostatectomy. This master's thesis included a knowledge gap survey, completed by urology residents, and compared to urologic oncologists, of a robotic prostatectomy and contained both open-ended and rating scale questions. A cognitive task analysis (CTA) was then performed as a series of semi-structured interviews in which incident-probing questions were used to make urologic oncologists explain visual cues and decision-making processes. 42 surveys were administered to urology residents and urologists at The Ottawa Hospital over 10 weeks. There was disagreement between urology resident and urologist responses from the rating scale responses, from the following procedural steps: vesicourethral anastomosis, apical dissection, and seminal vesicle dissection. The open-ended responses found discrepancies between the residents' and urologists'; understanding of anatomy and surgical decision-making, and of cause-and-consequence cognitive awareness. Subsequently, 16 CTA interviews of four urologic oncologists were completed. After data coding and thematic analysis was performed, CTA grids for each surgeon described a map of a robotic prostatectomy including the steps and goals of the procedure, procedural landmarks, key visual cues for each step, complications and/or error prevention, and management. Specific content not yet described in the literature also includes

how the lack of haptic feedback is compensated by robotic surgeons. Additional findings included a gap in urology resident knowledge and understanding of a robotic prostatectomy. The CTA of a robotic prostatectomy documented the surgical decision-making rules, patterns and visual cues urologic oncologists use to avoid errors, and to manage intraoperative surgical complications. This information is key to expanding the understanding of robotic prostatectomy surgical decision-making and training and can be used to produce robust robotic educational curricula.

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Chapter 1. Introduction.

Statement of problem.

Imagine the inside of an operating room, the patient in the centre with a tall robot beside the table, the arms docked to the patient's bare abdomen, and the surgeon sitting at the back of the room, no sterile gloves, no gown, their hands resting on joysticks puppeteering the robot's fingers. This is not the future—this is the present. Robotic surgery is at the forefront of surgical innovation and the current generation of surgeons have the task of passing on their robotic knowledge to both their colleagues who have performed non-robotic surgery for their entire careers, and to the new generation of surgeons and residents, operating for the first time. To impart this knowledge, robotic surgical curricula need to be constructed to address this educational gap.

The last time in the recent memory of medicine that a single form of technology changed the practice of surgery to this extent, including a new way of performing an operation with new tools, equipment and technology, was the introduction of laparoscopy (Rutledge et al., 1996). This new laparoscopic way of operating led to documented increases in patient complications. One well documented source of poor patient outcomes with laparoscopic surgery was the difficulty surgeons had using available cues to read the surgical situation appropriately (Way et al., 2003). This difficulty was highlighted when laparoscopic surgery was introduced for gallbladder removal surgery, which was previously performed with a large, open incision. After the introduction of laparoscopic technology, there was an increase in bile duct injuries ($R=0.80$, $p=0.0001$) as well as an increase in time for surgeons to master their learning curve (Rutledge et al., 1996). Further, it was recognized that the most common source of complications during the introduction of laparoscopic surgery was an error in decision-making, not in motor skills (Way et

al., 2003). Like laparoscopic surgery, the technology of robotic surgery requires extensive training to not only have comparable outcomes as the previous, or gold standard, technique but to also be safe for patients.

Undertaking these medical education challenges around robotic surgical curricula are no different than other educational challenges. These curricular challenges are addressed by an algorithm consisting of identifying a problem, defining it, and determining what is required to solve it. This algorithm is applied regardless of whether it is for the development of a brand new curriculum or to improve an already existing curriculum (Thomas et al., 2015). The first step in producing some form of solution for an educational need is to identify the problem (Thomas et al., 2015). The better the educational innovators and leaders define the problem in terms of what are the shortcomings of the current curriculum, who the problem affects, who has the knowledge to rectify the problem and what the resources are, the higher the chance of successfully bridging the educational need. A needs assessment should then be completed if the educational program is either new or succeeding an existing curriculum, as per the tenets of curriculum development (Thomas et al., 2015). The needs assessment is critical as a first step to producing an accurate assessment of the educational problem, what is currently being done to address it and how it could ideally be addressed. Comparing how a problem is currently managed and how it could be managed is one of the pillars of solving educational needs in a methodical way.

Currently, robotic surgery is at the front line of surgical education in Europe and North America because of its use of novel technology. Academic centres, and teaching hospitals associated with universities, are expected to teach this new surgical technology to their learners and robotic training curricula are now in the production phase (Ahmed et al., 2015; Fisher et al., 2015; Goldenberg et al., 2018; Rashid et al., 2006). This is true for many surgical specialties

using the robot today, from general surgery to gynecology and urology. It is unclear from the literature, however, the degree to which surgical educational committees and associations have followed these educational curriculum development steps described above, including problem identification, needs assessment and implementation (Thomas et al., 2015).

Surgical education associations and committees, like *Fundamentals of Laparoscopic Surgery* and *Fundamentals of Robotic Surgery*, are meeting and gathering to agree upon what should be included in these robotic teaching curricula (Fisher et al., 2015). These organizations aim to remove the archetypal surgical teaching method of “see one, do one, teach one” and provide thorough teaching programs. Good publishing practices and dissemination of academic work however dictates acknowledging the educational stakeholders needed to produce robotic teaching curricula, not simply content experts, but also program directors, and residents and fellows newly trained on robotic technology (Thomas et al., 2015). For example, Ahmed et al. compiled an expert consensus committee document, which described the procedural components of a robotic prostatectomy to serve as the gold standard for the steps of this surgery, as well as core curricular components that should be included (Ahmed et al., 2015). These steps however have been used to inform the culminating component of a robotic surgery curriculum -- the assessment -- rather than explicitly informing the sequence of robotic teaching or feedback and modification of the robotic curriculum (Goldenberg et al., 2018; Lovegrove et al., 2016). Further, this previously described consensus statement suggested online learning, simulation, and intraoperative training was sufficient for learning. The learning assessment also failed to engage a significant stakeholder, the residents and fellows who are learning the surgical technique, which leaves potential gaps in this suggested standardized curriculum (Ahmed et al., 2015). To date, a more thorough needs assessment has yet to be performed to sufficiently address the

development of robotic curricula. The acceptance of robotic technology into healthcare may have overtaken certain educational and training components and made consulting educational stakeholders secondary as a result of the pace of technological advancement and the eagerness to use this technology. This needs assessment is a critical first step to the safe adoption of this technology.

Robots are findings homes in operating rooms and are being used despite the lack of formalized training curricula encompassing the specific cognitive skills necessary to safely perform robotic surgery. Given the events that occurred with the introduction of laparoscopic surgery, it is possible that a lack of rigorous curriculum development processes could lead to poor patient outcomes. Furthermore, research into how to complete robotic surgical steps and, importantly, what are the surgical decision-making skills that should be imparted to learners has been neglected. Capturing how to complete robotic surgical steps and eliciting the components of surgical decision-making for robotic surgery are essential to designing a robotic training curriculum while incorporating cognitive skills teaching.

Theoretical framework.

Currently there is an escalation in technological change that requires comprehensive, complete, and accurate expert knowledge. One example of this is robotic surgical curricula. This information is best acquired from experts in the field of robotic surgery. The following section presents a brief description of the theoretical framework of expertise and expert surgical decision-making used in this master's thesis. Further, the theories that frame these two foundational concepts will be described, as well as the methods used to obtain expert knowledge and how this will be applied to the under-studied field of robotic surgery.

In order to have a conversation about expertise, what it means to be an “expert” must first be defined. The definition of expert that is used for this thesis is, as described by Ericsson, someone who “has a mastery of specific skills that allows for performance that is beyond one’s peers”. This definition includes both knowledge and skills in the description, as well as a comparison to a larger group of peers and colleagues (Ericsson, 2014).

One of the first steps in understanding what an expert is involves defining the difference between a novice and an expert. These different traits have been described by one theory of expertise, Naturalistic Decision Making (NDM). NDM defines how experts make decisions in a dynamic environment, acknowledging time constraints, varying cases, and innate characteristics experts have (Mosier et al., 2018). These innate characteristics, or traits, held by experts include perceptual learning skills and tacit knowledge and metacognition. This will be further explored in the literature review (Mosier et al., 2018).

Expertise research has been frequently associated with defining who is an expert but in recent literature, research has shifted towards determining how to obtain expertise. With the definition of who is an expert, and what traits they have, the theories of how to obtain expertise can be introduced. There are three theories of expertise used in this master’s thesis: Dreyfus and Dreyfus’ theory of expertise (1986), Bereiter and Scardamalia’s theory of expertise (1993), and Schön’s model of expertise (1983). The details of these theories will be described further but broadly, these theories describe how an expert develops over time, from the novice learner all the way to an expert, and the daily functional processes and thinking at work to obtain expertise. These theories also address how experienced non-experts fall short of obtaining expertise and the processes these individuals lack.

There are several examples of how these theories of expertise have been applied to medicine. For instance, one concept of expertise in surgery that has been suggested is that more experience (time) performing a procedure leads to improved surgical mortality rates, and decreased cancer recurrence (Vickers et al., 2008, 2007, 2009) especially compared to non-surgical subspecialties. Surgery allows for some degree of immediate feedback which the surgeon uses to make judgements about their performance. This immediate feedback, combined with an increased volume of procedures, is one hypothesis for why surgical expertise can be associated more readily with time as compared to non-surgical specialties. This will be expanded upon in the background and literature review (Ericsson, 2011).

A second example of how expertise is represented in surgery is how experts have difficulty explaining their thought processes and/or the steps taken to perform a task, whether the task is routine or complex (Crandall et al., 2006; Moulton et al., 2007). This difficulty likely occurs because experts use decision-making strategies that allow them to accurately manage a lot of information through script creation or pattern recognition using a form of automaticity to make decisions (Flin et al., 2007; Moulton et al., 2007). For example, radiologists are able to formulate accurate hypotheses in milliseconds using pattern recognition by accessing their decision-making strategies (Norman et al., 2012). The efficiency of these decision-making processes resides in their automaticity: in the fact that they do not need conscious processing to be accurate (Flin et al., 2007). This concept of automatic thought processing and expertise will be elaborated, and the methods used to obtain expert decision-making in this master's thesis accommodates for this automaticity.

Methodology.

This master's thesis aims to obtain robotic prostatectomy surgical decision-making information and knowledge. As such, the appropriate stakeholders should be consulted to ensure key issues are addressed, and a breadth of educational needs are met, including gaps in learner understanding. The needs assessment requirement for this master's thesis was conceptually more focused on a *knowledge gap* needs assessment to determine what the learners did not grasp or understand during a robotic prostatectomy. The survey combined questions that used Likert rating scales and open-ended questions to provide a thorough description of the thinking and perspectives of both the residents and staff related to gaps in resident knowledge and understanding.

Kern's model of curriculum development will be used as a framework to guide the research. Although there are six steps in Kern's model of curriculum development, this research will focus on the first two: problem identification and needs assessment (Thomas et al., 2015). In order to gain the bulk of the surgical steps and surgical decision-making during a robotic prostatectomy, a cognitive task analysis (CTA) was used. CTA is a methodology used to elicit automatic expert knowledge and decision-making through a series of structured interviews and has been used in multiple settings (Crandall et al., 2006).

Research objectives.

The research objective of this master's thesis is to document how expert surgeons make decisions during a robotic prostatectomy and how this differs from what is perceived by novice surgeons. The robotic prostatectomy, or removal of the prostate with the aid of robotic technology, was chosen based on the ubiquity of the procedure and the need to teach this skill to

multiple generations of learners. Documenting how experts make surgical decisions during a robotic prostatectomy will allow novice learners to have this available resource and insight into both its basic elements and its complexities. This thesis will also provide a reference for procedural pearls of wisdom which could refresh learners' knowledge for their future careers in robotic surgery.

As a first step in understanding the decision-making of experts, the residents' level of knowledge related to robotic surgery is required. By identifying the knowledge of residents around robotic surgery and comparing it to experts, we can better identify gaps that can then help identify how experts make decisions and potentially how to teach residents. As such, the research objective of this thesis can be divided into primary and secondary objectives. The primary objective is to determine the cues and patterns experts use to complete a robotic prostatectomy. The secondary objective is to describe the knowledge gaps existing between novice surgical learners and expert robotic surgeons. These gaps could be in the form of anatomical knowledge, surgical decision-making and/or complication recognition and management. These two components of my master's thesis will provide the foundations of what learners do not understand of a robotic prostatectomy and produce a robotic prostatectomy grid for novices and surgeons to consult pre-operatively, post-operatively and for years to come.

Applications.

This study will help identify critical steps that novices must learn to be able to perform this procedure competently. Once identified, these steps will help guide the design of teaching interventions, including dry-lab simulations and intra-operative teaching assessments. It is hoped that the findings will not only inform teaching of robotic prostatectomy in urology but serve as a

model for other surgical fields to design robotic surgery curricula. The realm of robotic surgical education is not completely developed but the integration of CTA into educational models could encourage new training advancements in this specialty. Synthesizing the knowledge from the CTA of robotic surgery could serve as a resource for post-operative review and teaching; perhaps to solidify a component of the procedure or review trouble-shooting maneuvers with residents. CTA of robotic surgery can also serve as the fundamental building blocks to produce surgical education modules for residents, teach theoretical knowledge, and advance concepts and complexities of surgical decision-making. This information can be incorporated into an electronic learning module for urology residents and educational programs delivered through professional associations, like the Canadian Urological Association and American Urological Association and expand surgical expertise nationally.

Structure of the thesis.

As described in the outline, the thesis will be structured to give the reader the background information and a history of expertise in surgery, introduce the field of robotic surgery, describe the methods and results of the survey and CTA and their implications. The thesis is organized in this fashion to provide the reader with a frame of reference and knowledge to ground and support the results and their analyses.

As the main goal of this master's thesis is to identify expert robotic surgical knowledge and decision-making expertise, Chapter 2 provides an overview of theories of expertise and how these are at play in medicine and surgery. This chapter describes what is currently missing in robotic educational programs and how the main objectives of this thesis will address those gaps.

The CTA methodology will be defined, as well as the success this method has had over the years in obtaining expert knowledge in many fields, including medicine.

Chapter 3 describes the mixed methods research design used for this thesis and why it is the most appropriate choice to answer the research questions. The survey, including its development, piloting and delivery will be explained. The CTA methodology, the sample selection for the CTA, and how it was conducted will also be addressed.

Chapter 4 describes the results of both the survey and CTA, as well as their analyses. The rating scale and open-ended question survey results will be shown. More specifically, the statistical percent agreement and kappa values of the Likert rating questions will be shown. The coding, including coding tree and content analysis of the open-ended questions will also be provided. The coding grids analyses, and interpretation of these results will be given.

Chapter 5 summarizes the research findings and provides final conclusions for the thesis. This section will show how the survey results and CTA can be used for real-world educational programs in both urology and other robotic surgical programs. This section also suggests future research endeavours and limitations of the work.

Chapter 2. Background/Theory/Literature Review.

This chapter will provide the background information for this thesis. It will describe the theoretical framework and ground the field of expertise and the conceptual framework guiding this research. Finally, a literature review of the major themes of the thesis is presented, including expertise research, urology training programs, minimally invasive and robotic surgery, robotic teaching programs, cognitive load theory, situational awareness, and cognitive task analysis.

Theoretical framework.

The theoretical framework that will structure this master's thesis includes defining the terms "expert" and "expertise" and how the theories that have been developed to explain expertise are represented in medicine and surgery. For this thesis the definition of expert is someone who "has a mastery of specific skills that allows for performance that is beyond one's peers" and will be used as it includes both knowledge and skills in the description as well as a comparison to a larger group of peers and colleagues (Ericsson, 2014). To expand the understanding of this concept of expertise, this packaged definition of an expert must now be unwrapped, and its components further described.

Experts make decisions in an environment that is dynamic and includes time constraints and new situations (Mosier et al., 2018). This description of how experts make decisions in naturalistic environments is one theory of expertise called Naturalistic Decision Making (NDM). The concept of expertise as it relates to NDM involves many variables or traits held by experts, including perceptual learning skills, tacit knowledge and metacognition (Mosier et al., 2018).

Perceptual learning skills describe how experts perceive patterns, cues and deliberately consolidate and sort through information and make decisions using this information (Mosier et

al., 2018). Perceptual learning skills are not simply obtained by watching a skill or task but require active analysis of what is being seen. In this way, experts are able to discriminate between what they are seeing and what they know. Further, experts perceive a broader area of their field of view and incorporate configurations of information that non-experts do not (Hoffman et al., 2015; Reingold et al., 2001). The expert, for example, can process and perceive an event or image more globally, without falling victim to selective attention. The novice is unable to see all the visual information available to make an accurate decision. In facial recognition studies, Landy (2018) demonstrated this difference in perceptual learning skills when they showed that experts were able to correctly identify a face with misalignments or purposeful alterations, while novice learners could not shift their attention and appreciate the whole picture (Landy, 2018).

Tacit knowledge is an idea tied to expertise that describes knowledge experts have but have difficulty verbalizing (Mosier et al., 2018). A familiar response an expert might give that highlights their tacit knowledge would be when they “just know” something, finding it difficult to describe their own knowledge. Norman et al. discuss tacit knowledge when they describe that a surgeon with increased surgical volume has superior outcomes to a less experienced surgeon as they have acquired this knowledge over time, helped in large part to the immediate determination of success or failure of their technical performance (Norman et al., 2012).

Metacognition, or thinking about thinking, is another concept of NDM that explains how experts complete uncomplicated tasks automatically but recognize the presence of new or different situations and can “slow down” their performance to manage these new scenarios (Moulton et al., 2007). In their paper, Moulton et al. describe how expert surgeons perform tasks automatically, while simultaneously engaging with residents, or listening to music. However,

when complexity increases, or the procedure deviates from their norm, they slow down and use more of their cognitive processes to perform (Moulton et al., 2007). The concepts of perceptual learning skills, tacit knowledge and metacognition are the foundations for NDM, and have been instrumental in explaining and unlocking expert cognition and what it means to be an expert.

Expertise research has been frequently associated with defining what or who is an expert, but in recent literature, this concept has shifted towards how to *obtain* expertise rather than who to *label* an expert. Theories describing how expertise is obtained have included Dreyfus and Dreyfus' model of a staged acquisition of skill which depicts the gradual evolution of a learner, climbing levels of achievement towards expertise (Dreyfus & Dreyfus, 1986). Dreyfus and Dreyfus' model focuses on automatic processing performed by an expert and how this automaticity becomes more prevalent as an individual moves through the theory's described stages of novice, advanced beginner, competence, proficiency, and finally expertise. Although Moulton et al., state that this theory does not enhance our ability to determine how experts gain expertise, it is an important feature of expertise that should be noted.

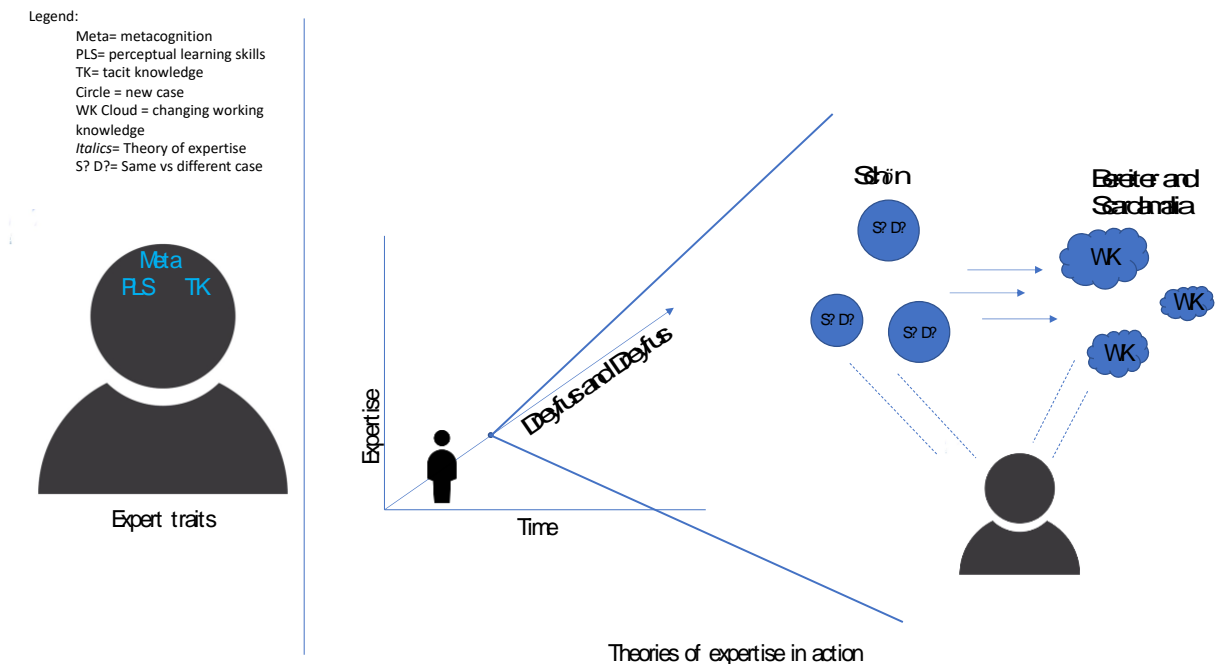
Another theory of expertise that is relevant to NDM is that of Bereiter and Scardamalia. This theory centres around the concept that to obtain expertise, the expert is frequently reassessing and reframing their working knowledge, which is not performed by an experienced nonexpert (Bereiter & Scardamalia, 1993). For example, the experienced nonexpert might reflexively diagnose appendicitis in the setting of right lower quadrant pain and a positive Rovsing's sign. The expert physician however will include other information, signs and symptoms that do not match their working knowledge, reframe the situation and diagnose an intestinal volvulus. Bereiter and Scardamalia's theory makes the distinction between experienced

nonexperts who reflexively apply automatic thinking and experts who can identify and acknowledge cues and reshape their knowledge.

A third model of expertise was described by Schön. Schön's model takes the approach that to obtain expertise one must be able to identify when a situation is different, or represents new challenges, being able reflect on this and frame this novel scenario to act accordingly (Schön, 1983). An example of this could be how a surgeon manages unanticipated or sudden bleeding or how to reconstruct a surgical defect with limited remaining tissue after a lesion is removed. These would be new challenges the surgeon must reflect on and react to.

These theories describe how an individual can obtain a level of expertise and, although these have been used in the field of medicine, can also be used to describe the acquisition of expertise in other fields as well. When combined, Dreyfus and Dreyfus, Bereiter and Scardamalia and Schön's theories of expertise comprise a model of how expertise is achieved, with Dreyfus and Dreyfus occurring over time at a macro level and Bereiter and Scardamalia and Schön occurring daily, at a micro level. Figure 1 shows both the traits held by experts on the left and the theories of expertise and how expertise is obtained over time, on the right. The traits shown include perceptual learning skills, tacit knowledge, and metacognition, as described by NDM. The depiction of the Dreyfus and Dreyfus theory shows this theory in action throughout the working lifespan of the individual, whereas at a single point in time, Bereiter and Scardamalia and Schön's theories of expertise are being used as much as daily to shape their development of expertise.

Figure 1. Conceptual depiction of the contrast between “expert traits” and “theories of expertise”.



Research in expertise has been performed in the field of medicine to elaborate how expertise is achieved compared to other fields. As an example, research assessing expertise in surgery, compared to other non-procedural disciplines, has shown that more experience or time performing a procedure leads to improved surgical mortality rates, and decreased cancer recurrence (Vickers et al., 2008, 2007, 2009). Surgery allows for some degree of immediate feedback which the surgeon uses to make judgements about their performance. This immediate feedback, combined with an increased volume of procedures, is potentially why surgical expertise can be associated more readily with time as compared to non-surgical specialties (Ericsson, 2011; Norman et al., 2012). There are a few caveats to the evidence concerning surgical expertise. To be an expert at one surgical task is generally limited to that one task and is not generalizable to other, seemingly similar tasks, which will be discussed further (Wanzel et

al., 2002). The three theories of expertise, described above, are grounded in using previous knowledge and past experience and complements my conceptual framework.

Conceptual framework.

The conceptual framework for this paper is centered around constructivism. The constructivist approach is learning that is based on previous experience and past knowledge that helps frame new teaching. This is a natural fit to frame this research since surgeons use their previous experience to shape their working knowledge (Creswell & Guetterman, 2019; Lavelle et al., 2013). Charmaz was one of the first to define the constructivist approach as a type of grounded theory design. This design type has the advantage of having fewer pre-prescribed codes, allowing the experiences of the participants to drive the data findings as well as allowing the researcher to make more active decisions about the data categories throughout the study (Charmaz, 1990). Charmaz's research of "what it means to have a disease" used the constructivist approach, allowing patients to produce their own labels and allowing the research to produce more rich, descriptive and authentic themes than previous grounded theory approaches, with pre-prescribed codes and/or followed preconceived rules and procedures (Charmaz, 1994). This master's thesis will focus on asking expert surgeons how they perform robotic surgery and much of the steps taken by these surgeons will be based on their previous experience. Surgeons access their vault of surgical memories of past cases to help tackle difficult future cases. There are few absolute truths that are guaranteed to work during every surgery because every surgery involves a different patient with different anatomy and presentation. Therefore, when performing this research, I will have the frame that the responses given by the surgeons will be based on their own past knowledge, that there is no one single, overarching

truth, but multiple truths that will be based on the surgeons' own past experiences (Creswell & Guetterman, 2019; Lavelle et al., 2013).

Figure 2. Constructivism conceptual framework for surgical expertise.

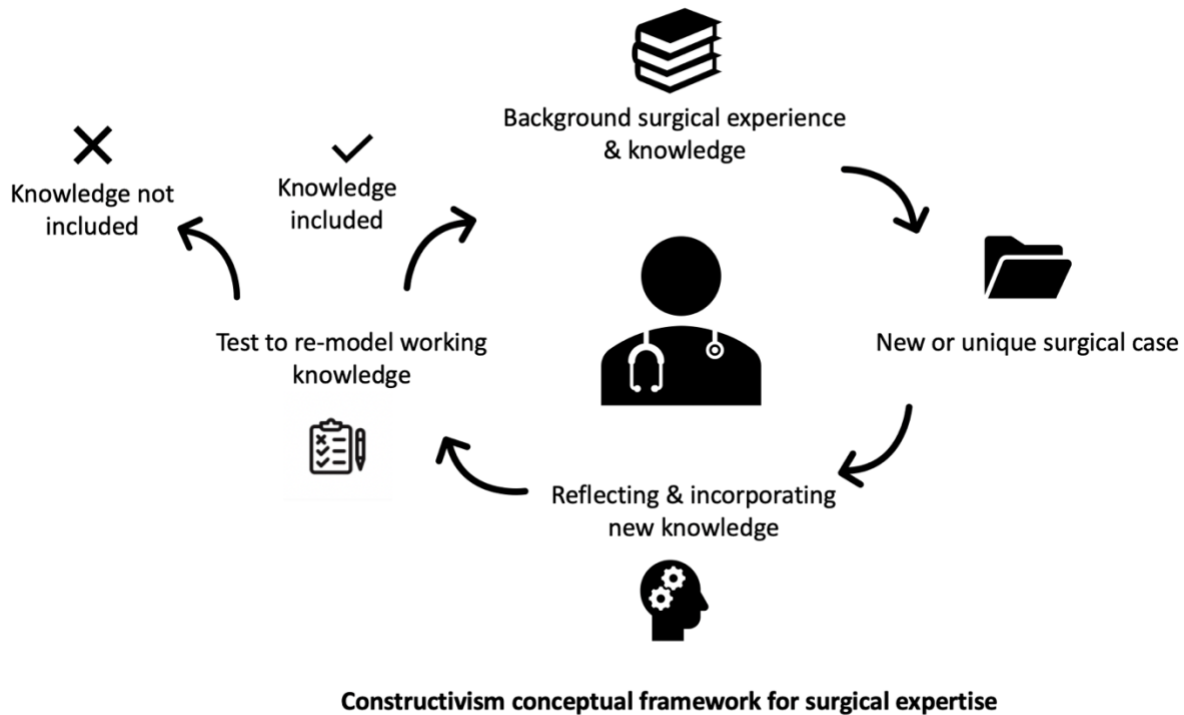


Figure 2 demonstrates how expert surgeons come to the operating room with their vault of surgical cases and experiences and navigate a new surgical encounter using the constructivist conceptual framework. With this new information, the expert surgeon can reflect on this knowledge and incorporate that into their working knowledge. Before solidifying that knowledge into their base surgical experience, this information will be tested and a judgement on whether or not to incorporate this new information will then follow.

Literature review.

Expertise.

Individuals have always been interested in how to gain expertise. Generally, people do not want to learn from any one person but from those who have been identified by society and proven themselves better than the rest. This idea of learning from an expert, researching what they know and, in a more contemporary setting, how they know, has been the focus of expertise research for decades.

The initial focus of expertise research was to determine how experts make accurate decisions and therefore do something well. In the realm of cognitive psychology, this meant measuring how information is processed in the brain and more specifically how experts do this compared to non-experts. These experimental studies focused more on designing models that used expert thinking and reasoning to make a conclusion, solve a problem or propose a correct answer (Feltovich et al., 2012). These studies were critical to the subsequent expansion of the study of expertise research as they provided the initial rules and processes used by experts. At this same time in history, the field of computer science was gaining momentum and more research was being performed in computational problem solving and coding. The development of computer code that could model human thinking and therefore processing was at the forefront of cognition research in the 1950s and 1960s (Crandall et al., 2006). Cognitive psychologists then teamed with computer scientists to birth a new field of science, *cognitive science*, that would go on to use computer models to help describe human thinking, problem-solving and decision-making (Buchanan et al., et al, 2018) as well as aid in analysing and processing the cognitive data (Feltovich et al., 2012).

Experimental research of mental processes and decision-making, previously accomplished in a controlled environment, has subsequently shifted to the uncontrolled, dynamic environment of the real-world experience (Mosier et al., 2018). Research in a complex real-world environment permits the incorporation of variation and an entire picture of a multi-faceted scenario. The problems experts are faced with in a natural setting would not only include drawing on their past experiences to solve them, but also include the knowledge of previous events of *that* case on *that* day, what they have at their disposal to help solve the problem (Mosier et al., 2018; Orasanu & Connolly, 1993). This concept, in essence, introduces the research of naturalistic decision making (NDM) that was already explored in the theoretical framework of this thesis. NDM takes into account the fluid nature and complex environments experts function and work in. This framework was introduced in the late 1980s and has since dominated the arena of expertise research (Mosier et al., 2018). In NDM research, the goal is not to find an answer based on statistics or probabilities, but to explore expertise acknowledging and defining experts' past experiences and traits and how they apply those to the situation at hand. NDM framework allows for an explanation of decision-making which occurs in dynamic environments, providing a more complete description of expert thinking (Mosier et al., 2018). Further, it includes the incorporation of high-level functions, which are not captured in controlled laboratory settings, including team collaboration, sense-making and re-thinking of decisions (Klein, 2003; Schraagen et al., 2008).

The following is a description of some of the main tenets of expertise research. A concept intrinsic to the study of expertise is that expertise is *domain specific*, using domain-specific skills. Domain-specific skills will be discussed further when the topic of surgery is introduced, however this largely means that an expert in a single field, for example music, is not

automatically an expert in another field, for example chess. These domain-specific skills are what is defined as content versus context specificity, that what an individual knows (their judgement and reasoning) or does (their performance) is influenced by the unique situation in which they find themselves, the context (Durning et al, 2011). Although this may seem obvious, it is important to distinguish as it encourages a more deliberate interrogation of the acquisition of expertise rather than the easier, complacent point of view that an expert is simply good at one thing and therefore must be good at many things. Another tenet of expertise is that experts, and those with a broader knowledge base, are better able to integrate and structure new information, have deeper functional processing of information and are able to *group information*, or chunk information, into bigger overarching categories. Unlike novices, experts are also able to *self-regulate* and *self-monitor* when performing which allows them to accommodate for new encounters and experiences. Self-regulation and motivation is described as the proactive, self-directed actions of individuals to improve performance (Zimmerman, 2008). One final concept of expertise is that of *deliberate practice*, or the practice of activities that are most effective and designed to improve (Ericsson et al., 1993). A generation of surgeons for example who have graduated at the same time and have the same amount of operating “experience” are not all automatically experts; experience alone does not equate to expertise. Expertise comes from experience *and* deliberate practice, which suggests intrinsic motivation by the individual to practice, allow constructive feedback from peers and reflect on the scenario.

The field of medicine has a long history of studying expertise. The initial expertise research in medicine focused on clinical decision-making and reasoning and incorporated the concept of dual processing, a theory of thinking used by experts (Brush et al., 2017; Norman et al., 2012). This theory of thinking states that experts use two types of thinking systems. System 1

is non-analytical and is typically performed quickly and automatically whereas System 2 is analytical and slower and more measured (Norman et al., 2012). The expert performer can be highly functioning in System 1 thinking until a pattern or cue or heuristic is identified that triggers the individual to use System 2 thinking, slow down and reassess the situation (Brush et al., 2017; Moulton et al., 2007; Moulton et al., 2010; Norman et al., 2012). Multiple studies have suggested that a broad group of previous experiences that grounds System 1 thinking improves clinical reasoning and this non-analytic reasoning is crucial for accurate problem solving (Brush et al., 2017; Norman et al., 2012)..

Although the focus of research on dual processes has been on clinical reasoning, it is still relevant to procedural based disciplines like surgery. System 1 processing occurring during surgical procedures has been shown in various studies including cardiac surgery (Flin et al., 2007; Massetti et al., 2008) and general surgery (Way et al., 2003). These studies argued that System 1 processing allows surgeons to navigate a procedure and make decisions in a time-sensitive space. Moulton et al. (2010) eloquently described the incorporation of System 2 processing in surgery and how this is inherent to expert judgement and thinking. In their study, 28 surgeons were interviewed to explore how analytical thinking (“slowing down”) was accomplished in surgery (Moulton et al., 2010). Surgeons slowed down and switched into System 2 processing when they encountered unexpected events intraoperatively (Moulton et al., 2010). Moulton et al’s research also highlighted how surgical decision-making is partially unique, in comparison to non-surgical decision-making and judgement, in that surgeons explained preoperatively areas of the surgery that might be challenging and *anticipated* or *planned* to slow down at these times.

There have been mixed results showing how volume, which can be extrapolated to the time spent becoming well-versed in a skill in medicine, or practicing in a medical specialty, results in expertise. This concept however has been proven more consistently in surgery. Birkmeyer et al. and Vickers et al. have demonstrated that increased surgical volume translates to decreased mortality rates in cardiac surgery and prostate surgery (Birkmeyer et al., 2013; Vickers et al., 2007, 2009). Vickers et al., also found that increased surgical volume, and therefore surgical expertise, is associated with decreased cancer recurrence (Vickers et al., 2007, 2009). Their retrospective cohort study of ~7800 prostate cancer patients found that the difference in cancer recurrence could be as large as 7.2%, with cancer recurrence of 10.7% for large volume urologists compared to 17.9% for small volume urologists (Vickers et al., 2007). Surgeon volume is therefore a component of surgical expertise and should be included when deciding which surgeons to include in surgical expertise research. The sheer surgical volume of a surgeon however should not be the only identifying feature of a surgical expert. Deliberate, pre-conceived planning of how a procedure should be performed as well as self-regulation and self-monitoring intraoperatively and post-operatively are key (Ericsson et al., 1993; Zimmerman, 2008). As the previous discussion about expertise and traits unique to experts suggest, labelling an individual as an expert, in the field of medicine or otherwise, is a complex and multi-faceted task.

Another component of expertise relates to context specificity. Context specificity is paramount as surgeons previously performing open operations switching to the robotic approach are not the same expert surgeon anymore. The reason is that someone can be an expert performing a procedure with the relevant knowledge and expertise to do this procedure, but this skill is specific to the context in which they learned and practiced (Durning et al., 2011). For

surgery, context specificity would mean that a surgeon with expertise performing an open cholecystectomy or open prostatectomy, is an expert of that procedural content in the context of an *open approach*, but place that expert surgeon in the context of a laparoscopic cholecystectomy or robotic prostatectomy and their surgical expertise no longer holds weight.

Evidence that skill in one surgical procedure does not transfer to another was reported by Starkes et al. They assessed the surgical competency of novice surgical residents compared to experienced open neurosurgeons (Starkes et al., 1993). The task was to perform a procedural component of a neurosurgical operation but using a microscopic technique. The open neurosurgeons' vast experience did not translate as the microscopic technique was a different context and the novice learners performed well in comparison (Starkes et al., 1993). Another study (Vickers et al., 2009) that demonstrates context specificity compared the surgical learning curve of laparoscopic radical prostatectomy to open radical prostatectomy. This retrospective cohort study compared the learning curves of the open versus laparoscopic procedures based on patient outcomes, measured as biochemical recurrence and positive surgical margin (Vickers et al., 2009). This study, of over 4700 patients, found that the learning curve of laparoscopic surgery was slower for surgeons who had previously learned the open technique (Vickers et al., 2009). One would have expected that anatomical and procedural knowledge of an open prostatectomy would have allowed for a quicker laparoscopic learning curve of the same procedure. Further, surgeons with previous open prostatectomy experience had poorer outcomes than those performing a laparoscopic prostatectomy and had no previous open experience, irrespective of patient characteristics (Vickers et al., 2009). The results from the studies reported above support the fact that both novice learners and experienced surgeons alike need adequate and sufficient training to learn a new surgical technique or procedure, regardless of surgical

background. Context specificity will be an issue for robotic surgery because surgeries will be performed via different approaches and will show patient anatomy and tissues from different perspectives. Therefore, context specificity needs to be acknowledged as an important factor in learning because surgeons previously performing surgeries with the open operative technique will now be moving to the robotic technique and will need to learn an entirely new skill set.

Urology training programs

Urology is a surgical subspecialty, specializing in diseases of the genitourinary tract. In Canada, successful candidates enter this postgraduate medical education program directly after medical school. While each program has their own educational curriculum, they all teach national standards of practice set by the governing body of the Royal College of Physicians and Surgeons of Canada. The goal of all programs is to produce safe and competent surgeons knowledgeable in the illnesses and diseases of urology and technically proficient in urologic operations and surgical techniques (Specialty Committee in Urology, 2017). There are a variety of urologic procedures that range from small, short procedures, where the patient can be awake, as for a circumcision, to large, extensive procedures, where the patient could be put to sleep for several hours, for example for a bladder removal procedure. The operations also vary with the surgical technology used, including classic scalpel and cautery, laser technology for kidney stone removal, and minimally invasive techniques, including laparoscopic and robotic technology, for kidney or prostate cancer surgery.

Urology training programs are required to teach both surgical skills and surgical decision-making to perform these procedures (Specialty Committee in Urology, 2017). Mandatory reviews of urology training programs are conducted to ensure teaching standards are met. A

systematic review however has shed light on the status of aspects of urology training programs, specifically laparoscopic surgical skills, based on both resident and program director perspectives of laparoscopic exposure and the ability to perform laparoscopic procedures (De Oliveira et al., 2019). The overwhelming majority of urology residents were not confident independently performing laparoscopic procedures upon completion of residency (De Oliveira et al., 2019). These results were taken from studies assessing laparoscopic urology training worldwide, including residents from Spain, the United Kingdom, Israel, Belgium and North America (De Oliveira et al., 2019). The studies conducted by Duchene et al and Preston et al, from the United States and Canada respectively, evaluated laparoscopic exposure and resident experience, and were the only studies identified in which residents reported that their laparoscopic surgical skill training was adequate and were comfortable performing these surgeries in their own independent practices (Duchene et al., 2006; Preston et al., 2010).

The surgical educational training model has typically followed the Halstedian “see one, do one, teach one”, with urology as a surgical subspecialty also following this model. This apprenticeship model of learning surgical skills has been implemented for residents to perform operations with their surgical mentors and coaches and after a specified amount of time, between five and seven years of surgical residency, residents should be surgically competent. The results from studies previously described however illustrate that this method is not producing the required operative experience or confidence for newly minted surgeons to practice gold standard surgical techniques independently (De Oliveira et al., 2019).

This evidence of decreased resident confidence comes at a time where surgical experience is harder to access with work hour restrictions, more clinical patient duties to attend to, and fewer resident bodies for the clinical load (Okhunov et al., 2019). A recent study of

United States chief residents, in their final year of training, found that less than 50% of residents felt competent performing laparoscopic procedures and less than 1/3 felt competent performing robotic procedures (Okhunov et al., 2019). These responses were given alongside others which stated that 82% of residents and 67% of program directors described that trainees did not have protected time to practice their technical skills in simulation laboratories and over half of residents reported working more than their capped 80 hours of work per week (Okhunov et al., 2019).

The focus for surgical training programs, urology included, has been to teach the technical skills of the procedures, with minimal formalized teaching on the surgical decision-making required to safely operate and troubleshoot unexpected events in the future. The giants of surgical teaching, like Dr. Frank Spencer, have stated that a large portion of surgery and completing a successful operation is about the surgical decision made to get there and less about the surgeon's technical skills— "A skillfully performed operation is about 75% decision making and 25% dexterity" (Spencer, 1978). Although this declaration has yet to be proven, expertise literature agrees with these sentiments that to be an expert and gain expertise, a learner must go beyond their surgical textbook examples and past cases and be able to recognize new or unanticipated events, make difficult surgical decisions and accommodate in a high-pressure scenario (Norman et al., 2012). The Royal College of Physicians and Surgeons of Canada state that surgical decision-making must be taught to trainees however it has yet to be formalized how can this be accomplished without the information or training techniques available to teach or assess surgical decision-making (Specialty Committee in Urology, 2017).

The argument may be made that the goal of urology training programs is not to shape every urology resident into an expert surgeon, but to create safe and competent surgeons. The

standard, however, that these programs aim to achieve does not seem to be met in regard to the laparoscopic skills training required, as relayed by the trainees (De Oliveira et al., 2019). The realization of these gaps in urology residents' training programs comes at a time when further new technologic advancements have been developed, introduced, and for some procedures, become the new gold standard in urologic surgery, like laparoscopic surgery and robotic surgery.

Minimally invasive surgery

Although the first minimally invasive procedure was performed in 1910 on dogs, it took several decades for the medical community to embrace this technology having a resurgence in the 1930s and finally to stay in the 1990s (Kelley Jr, 2008). Laparoscopic technology allows surgery to be performed through small, keyhole incisions, using laparoscopic instruments without the large open incision that can have a longer recovery and potentially worse side effects. Laparoscopic technology was adopted broadly, in multiple surgical fields, including general surgery, gynecology and urology (Kelley Jr, 2008). In the field of urology for example, the difference to patients made by using minimally invasive techniques could be a difference of 1.7 days in hospital, potentially fewer complications post-operatively, and less blood loss (Ploussard, 2018). There are limitations to this laparoscopic technique as there is always a need for an assistant to hold a laparoscopic camera throughout the surgery and the surgeon is limited by the loss of the tactile feedback that was given with open surgery. One of the greatest limitations, however, to traditional laparoscopic surgery is the straight instruments used. Laparoscopic surgery is performed with straight instruments positioned and inserted into an insufflated abdomen, or body cavity, to carry out the desired procedure. These instruments do

not rotate or have the dexterity the surgeon would naturally have with their fingers, wrists, and hands. Conversely, robotic technology does have these capabilities.

The surgical robot was first developed and used in 1985 to perform neurosurgical brain biopsies (Lanfranco et al., 2004). Since that time robotic technology has advanced significantly with multiple functioning arms, 3-dimensional image processing monitors and master control finger grips. Most robotic surgical devices have three robotic arms with seven degrees of freedom which allow the instruments to be rotated with ease, and with the same seven degrees of freedom of a human wrist. This advantage greatly improves operative dexterity and decreases laparoscopic learning curve (Choussein et al., 2018). As with the introduction of laparoscopic surgery, robotic surgery has been incorporated into many different surgical subspecialties including, again, general surgery, gynecology and urology as well as ENT and neurosurgery (Lanfranco et al., 2004). This further advancement in surgical innovation and technology has been revolutionary for surgeons suturing laparoscopically, for example, in urology to repair the collecting system for a pyeloplasty or to reconnect the bladder to the urethra during a prostatectomy. The robotic technology, as was mentioned, uses 3-dimensional imagery for optimal depth perception to perform operations that were previously lost in 2-dimensional laparoscopic surgery (Lanfranco et al., 2004). The surgeon is also able to flip between the multiple robotic arms being used during the surgery seamlessly, with the tap of a foot pedal at the master console. The robotic console is unique in its ability to have a second robotic console where a learner can operate and the primary surgeon can still take over at any time with the touch of a button, much like in drivers' education. Further, the robotic consoles have the ability to have the non-operating surgeon demarcate and mark on the monitor using their console markers. This is extremely useful for the primary surgeon to either point to an area for the learner, to show

them where to proceed or areas to avoid, as well as allow the learner to mark the 3-dimensional image and to ask questions based on what they are seeing. There have been multiple studies assessing the statistically significant advantages of robotic surgery and for urology, these include decreased post-operative pain, quicker recovery and decreased blood loss (Ploussard, 2018).

There are limitations to using robotic surgery technology. With the docking of the robotic arms to the patient, the surgeon must manipulate these arms at the master console and now loses their haptic feedback. Where in laparoscopic surgery, the surgeon lost the tactile sensation of open surgery, they were still manipulating the laparoscopic instruments and had the feedback of pressure and tension. In addition to the tactile sensation lost with traditional laparoscopic surgery, robotic surgery also loses the haptic feedback of pressure and tension.

Another limitation of robotic surgery is the negative impact it has in an educational setting. The bedside assistant, a learner, is now located at a significant distance away from the primary operating surgeon, losing the direct teaching and physical communication had with laparoscopic and open surgery. The role of the bedside assistant in the operation is mainly for suctioning, and clip placement for vascular control, while the primary surgeon performs the entire procedure. In both open and laparoscopic surgery, the assistant would have an opportunity to switch back and forth to complete portions of a procedure, however as a bedside assistant, there is no opportunity to switch back and forth. Only if the learner is at the console *and* if the primary surgeon relinquishes those controls, does the learner have the ability to operate. This combination of changed verbal communication, decreased operative role and ability for a primary surgeon to perform the procedure solely, can take away from a learners' educational experience if not purposefully addressed. This sentiment has been supported and echoed by a survey of surgical residents that found that 46% of surgical residents believed robotic technology

interfered with their resident training (Green et al., 2019). It is of the utmost importance to acknowledge these negative implications of robotic technology from a training perspective as an independent review in 2015 found of the top 10 risks to patients from health technology was insufficient robotic training (Devices, 2015).

Robotic teaching programs

For urologists and residents to learn the fundamentals of robotic surgery and robotic surgical procedures, robotic surgical training programs need to be built. A first step in sound curriculum development requires a needs assessment of what should be included in the curriculum. Next, opinions and suggestions of the current and future stakeholders can be gathered, the curriculum can be developed, and finally, reviewed (Thomas et al., 2015). For a robotic urology training program, this curriculum would be organized to seek out the opinion of academic program directors, curriculum development committees, resident learners, early robotic adopters, and robot naïve urologists, as well as the robotic technology companies and developers (Thomas et al., 2015). The information from these stakeholders would be used by the curriculum development program, potentially with some variation or addition to address the different requirements of novices versus trained urologists, to develop electronic modules and, in collaboration with robotic companies, training resources would be assembled and acquired. Also, piloting of the robotic program would be performed. Assessment tools would also be needed to assess the trainees' robotic skill and tools specific for a given procedure. The training program would then be deployed and subsequently reviewed. Robotic training curricula would also need to address two new educational concepts to residents without inducing cognitive overload: foundational surgical techniques and robotic technology (Green et al., 2019). The real

story of the development of robotic training programs and how it is currently unfurling is that it has occurred in tandem with the adoption of robotic technology in the clinical environment, and with usage in operating rooms and hospitals. The development of the technology has been at such a pace that surgical training programs and committees were having to play catch up. In the United States, the *Fundamentals of Robotic Surgery* association was created and was modeled from the surgical training committee created with the introduction of laparoscopy, *Fundamentals of Laparoscopic Surgery* (Fisher et al., 2015). These associations were active in following prescribed practices of curriculum development, however with widespread incorporation of the robot, multiple groups were siloed, trying to achieve the same goal—a cohesive, comprehensive robotic surgical training program. At this time, significant effort and resources have been directed toward the assessment of robotic technique and skill compared to the development of robotic educational curricula (Goldenberg et al., 2018) and although there are several curricula in different stages of development and validation, with the EAU/ERUS and recently *Fundamentals of Robotic Surgery* being assessed (Brook et al., 2019; Dulan et al., 2012; Fisher et al., 2015; Green et al., 2019).

The field of urology has developed robotic training programs specifically for the robotic prostatectomy, where the entire prostate gland is removed mainly due to prostate cancer. International urological associations, including the European Association of Urology (EAU) and the American Urological Association (AUA), have made progress to address the systematic training for this procedure. In 2015, EAU urologists and expert prostatectomists, gathered to develop a robotic prostatectomy training program. This meeting developed a comprehensive program that included robotic technology training, electronic modules, and a graduated operative experience from bedside assistant to primary surgeon on the robotic console (Ahmed et al.,

2015). The training program, agreed upon by the EAU committee, is a longitudinal curriculum that novices and urologists would travel to participate in, and when completed, return to their respective hospitals to perform robotic prostatectomies. This curriculum was validated with a pilot study of 11 participants and has now been adopted for the European robotic prostatectomy training experience (Lovegrove et al., 2017, 2016).

The robotic prostatectomy training programs are centered around teaching the procedural steps of a robotic prostatectomy, which were determined using consensus methods like the modified Delphi. Learners are then graded using validated assessment tools (Lovegrove et al., 2016; Morris et al., 2017). Several assessment tools with valid results exist and can assess surgical technique and robotic competence including Global Evaluative Assessment of Robotic Skills (GEARS) and Robotic Anastomosis Competency Evaluation (RACE). GEARS aims to assess whether an individual is competent with overall or global robotic technique but is not surgery specific (Hung et al., 2017). RACE was designed to specifically assess competence performing the anastomosis or reconnection of the bladder to the urethra once the prostate gland is removed (Raza et al., 2015). The training programs teach the procedural and technical skills and then assess these skills with established tools—but herein lies one of the gaps in robotic prostatectomy training needs. These robotic training programs do not focus significantly on cognitive skills or surgical decision-making (Ahmed et al., 2015; Fisher et al., 2015; Goldenberg et al., 2018; Rashid et al., 2006).

These programs focus mostly on the technical skills required to perform robotic surgery, both foundations of robotic skills and surgery-specific skills, and assessment tools to evaluate technical proficiency. While these portions of a robotic educational program are crucial, they do not describe how cognitive skills and surgical decision-making are taught or assessed for the

surgical trainees. There is no clear incorporation of surgical decision-making included in the training programs to assess this while they progress through their prostatectomy training (Brook et al., 2019). One main reason robotic prostatectomy surgical decision-making is not deliberately taught at this time is that this topic has not been given significant attention. The natural progression to teach robotic prostatectomy surgical decision-making would be to establish what decisions, reasoning and maneuvers urologists are performing. This information could then be packaged, used in training programs, and individuals could then be assessed prior to completing their robotic prostatectomy training programs.

Cognitive load theory

Learning a new skill is mentally taxing, whether that is for an open, laparoscopic, or robotic surgery. There is a combination of visual stimuli, surgical decision-making and active teaching occurring when a learner is completing a surgical task or procedure. This combination of mental processes that occur during learning is described as cognitive load theory (CLT) (Sewell et al., 2019). CLT is composed of intrinsic load, and extraneous load with working memory being the main focus of CLT and the bottleneck for how learning is acquired (Sewell et al., 2019). Intrinsic load refers to the cognitive tasks that occur to complete, for example, a procedure, and is influenced by the complexity of a task and by prior experience. Extraneous load refers to the times when working memory is occupied with non-essential tasks, like managing environmental distractions or poor procedural teaching, requiring the learner to expend extra working memory understanding the task. The ideal scenario for working memory to promote good learning is to optimize intrinsic load while minimizing extraneous load as well as the amount of information and the time that a learner has to process the information are balanced

(Young et al., 2014). When these factors are unbalanced this is what leads to *cognitive overload* and a subsequent decrease in information, including procedural and decision-making information, acquisition and retention (Sewell et al., 2019).

Robotic surgery is a prime example of a surgical environment in which cognitive overload can occur. Using a robotic prostatectomy as an example, there are several procedural steps where complex surgical decision-making occurs and affects intrinsic load, like the bladder neck dissection, and the neurovascular bundle spare. Further, extraneous load can be overwhelmed during robotic surgery because of difficult and decreased communication between the primary surgeon on the robotic console and bedside assistant, as well as the decreased need for the assistant to manipulate the laparoscopic camera (El-Hamamsy et al., 2020). Current robotic surgery curricula seem to focus more on the technical tasks required to perform procedural steps and do not explicitly address how cognitive overload is or will be incorporated into the teaching.

Situational awareness

Along with cognitive load theory, situational awareness is another concept key to expertise and decision-making. Situational awareness is defined as the combination of perceiving the elements within a situation, understanding what these elements mean, and knowing how they affect near future events (Endsley, 1988). Situational awareness has been described as the defining feature of some exceedingly famous experts in their fields, for example in the field of athletics where Wayne Gretzky could read the play and anticipate near future events or Phil Mickelson who consistently read the putting greens expertly and accurately in multiple Masters' championships (Endsley, 2018). This is in contrast to novices who have difficulties in perceiving

all of the relevant information of a scenario as well as fully understanding the meaning of the information (Endsley, 2018). That makes the final component of situational awareness, anticipating future events, a very difficult task to accomplish.

In medicine and surgery, situational awareness is included as a key non-technical skill that is critical for patient care and error avoidance (O’Keeffe et al., 2020). Being able to visualize all the events taking place during an operation, recognizing key blood vessels and nerves, synthesizing the information, recognizing diseased tissue and how the organ in question will be dissected, and using the information simultaneously, is paramount for the successful completion of the procedure. Over the last several years, the field of surgical expertise has paid significant attention to the concepts of situational awareness and other non-technical skills, and has created validated assessment tools like the Non-Technical Skills for Surgeons (NTSS) and Interpersonal and Cognitive Assessment for Surgery (ICARS) (AlJamal, et al., 2020). The development of these assessment tools comes from the literature showing that a lack of situational awareness can lead to patient morbidity including retained surgical items (Hibbert et al., 2020) and infection control issues (Soncrant et al., 2020).

Situational awareness during robotic surgery has the potential of being more difficult than open surgery as there are added complexities that muddy the surgical environment, including a narrowed and magnified surgical field of view as well as increased physical distance from the primary surgeon to bedside assistant, making it more difficult to communicate and ground the surgical situation.

Cognitive task analysis

One of the challenges faced by experts, in medicine or otherwise, is their difficulty verbalizing the thought processes behind their decision-making (Crandall et al., 2006). This difficulty occurs as the experts' performance, after years of experience, becomes automatic; that is, they seem to be unaware of the actions they are performing and the decisions they are making (Crandall et al., 2006). An example of this unconscious processing is seen in Boreham et al.'s research, that showed, when questioned, experienced surgeons are at an impasse in describing their surgical judgement as they function frequently at an automatic level (Boreham, 1992).

Expertise research was pioneered by a select few including Simon and Chase who explored high-level processing of chess players (Chase & Simon, 1973). Around this time, professional fields, like medicine, the military, and fire rescue, reached out to cognitive psychologists to try and unravel this automatic expert functioning (Crandall et al., 2006). This is when the field of cognitive psychology began to study expertise and helped determine ways to extract the what's, how's and why's of their specific disciplines and methods to assemble a blueprint of their expertise. The initial research into expertise focused on Think-Aloud protocols and free recall. Although the information obtained with these techniques was novel, it lacked granularity, depth of information and a deeper understanding of expert thinking (Crandall et al., 2006). Cognitive psychologists collaborated with industry and government and developed frameworks and interview protocols to gather this information. Examples of this type of collaboration include military commanders seeking to develop improved training programs for frontline soldiers and fire departments seeking out expert information on how to assess a burning building from seasoned fire chiefs.

The information gained by cognitive psychologists was refined over the years and a key model was developed to elicit expert knowledge: cognitive task analysis (CTA). The umbrella of the CTA framework attempts to gain in-depth expert knowledge by using methods like knowledge audit and critical decision method (Crandall et al., 2006). Knowledge audit refers to the interview and extraction of a general body of knowledge by gaining performance and perceptive skills, however it differs from Critical Decision Method (CDM). CDM is classically more rigorous and situation specific as it asks the expert to identify a critical incident, describe the incident using a predefined interview format and methodically comb through the incident with more probing questions (Crandall et al., 2006). Both methods are useful for describing specific types of scenarios and extracting different types of information. This method of cognitive task analysis has been used in different fields of medicine, including nursing, internal medicine, and surgery. In their book, *Working Minds: A Practitioner's Guide to Cognitive Task Analysis*, Crandall et al. describe how CDM, and CTA were used successfully with experienced neonatal intensive care unit (ICU) nurses to determine how these neonatal ICU nurses were able to identify babies that would become septic (develop a blood infection) earlier than their peers. CDM protocol was able to clarify cues, patterns and sequences of events that helped nurses to identify and potentially start treatment earlier for septic babies (Crandall et al., 2006).

The full potential of CTA in medicine, as in other fields, was especially noted when this method of information acquisition was compared to previous methods like the Think-Aloud approach or free recall. By using CTA methods, researchers are able to obtain ~70% more information from experts, not because experts do not think the information useful or were deliberately withholding, but because their actions and expert processing occur automatically. Although the omission of as much as 70% of task description may seem high, this figure has

been reproduced in several studies. Clark et al. reported that up to 70% of critical information was omitted compared to traditional free recall when trauma surgeons were asked to describe an emergency shunt procedure (Clark et al., 2012). Yates et al. found similar results when they asked expert surgeons to describe their actions and decisions taken to perform open cricothyrotomy, with 72% of the decision steps omitted with traditional recall method compared to CTA methods (Yates et al., 2012).

These studies prove the volume and breadth of information lost when CTA methods are not used for expert knowledge acquisition. The community of surgeons involved in expert research and surgical education have taken notice, with CTA methods being used more frequently in the last decade. CTA methods have been used to determine the procedural steps and decision-making needed to perform plastic surgery procedures (Yeung et al., 2017b), laparoscopic appendectomy (Smink et al., 2012), central venous catheter placement and cricothyrotomy (Yates et al., 2012), colonoscopy (Sullivan et al., 2008), and liver resection (Ho et al., 2018). With the use of these CTA methods, studies have shown, time and again, that they are superior to traditional explanation for knowledge acquisition as well as knowledge application when used as the foundations for training programs and educational curricula (Smink et al., 2012; Sullivan et al. 2014; Wingfield et al., 2015; Yeung et al., 2017b).

Surgical researchers have used CTA methods to improve surgical training programs as well, just as firefighting and the military have done in the past, to feed the information back and shape new educational programs. The initial step of disseminating expert procedural knowledge is to know *what* that knowledge is, and the next step is to incorporate and use that in training and educational curricula. Yeung et al. used CTA results to produce electronic modules to teach plastic surgery skills for residents and Tijam et al. incorporated CTA results to develop a

simulation-training program for nephrostomy tube placement (Tjiam et al., 2012; Yeung et al., 2017a). The research conducted by DaRosa et al (2008) went one step further by not only collecting the CTA data and incorporating these results into a training program, but by testing this program against their standard surgical training program to assess its effectiveness (DaRosa et al., 2008). General surgery residents were randomized to the standard laparoscopic cholecystectomy training program or the CTA-incorporated training program and when the residents completed the training and were tested, results showed improved intraoperative judgement of residents randomized to the CTA training (DaRosa et al., 2008). Campbell et al performed a similar study assessing the effectiveness of a CTA-informed curriculum (Campbell et al., 2011). They randomized surgical learners to either a CTA-informed open cricothyrotomy teaching curriculum or the traditional curriculum and found both improved performance of the procedure and improved self-efficacy scores for the learners in the CTA-informed group (Campbell et al., 2011). Fundamentally, CTA can aid experts to uncover their expert knowledge and deliver this to novice learners, whether that is for short procedures, open surgery, or laparoscopic surgery. The next logical application of CTA in medicine is for its use in robotic surgery.

Summary

This master's thesis aims to expand on the fundamental components of robotic surgery using CTA to understand how experts make decisions during surgery rendering their decision-making processes explicit and potentially more teachable. The theories of expertise described including NDM, Dreyfus and Dreyfus, Schön, and Bereiter and Scardamalia, provide the foundation to understand surgical expertise and decision-making, while the constructivism

conceptual framework grounds the research question in the real-world clinical environment surgeons live and surgically perform within. The literature review gives a broad but thorough synopsis of surgical expertise, why this surgical expertise is needed for new technologic advancements in surgery, and what the current standards are for urologic surgery teaching programs and robotic programs. Finally, CTA is defined, explored, and supported as the method that will be used to gain the unconscious aspects of expert surgical performance.

This master's thesis will document how expert surgeons make decisions during a robotic prostatectomy, a urology specific procedure where the entire prostate is removed and will respect the foundational theories and knowledge of expertise as they apply to surgery and will use the methods of CTA to obtain this information. This procedure was chosen as it includes a different anatomical approach of prostate removal compared to an open prostatectomy, which is the previous traditional method of removing a prostate. Another benefit of robotic prostatectomy is that it is an approach that includes new and/or different steps of the procedure. The robotic approach needs to be taught to new trainees and seasoned urologists alike and would therefore be applicable to a large cohort of postgraduate learners or those continuing their professional development. Furthermore, the robotic prostatectomy is one of the most commonly performed robotic procedures (Yu et al., 2012) and as such could serve as an obvious example for other surgical subspecialties to use CTA as scaffolding to create their own robotic curricula. For this project, the first research question is: what is the knowledge gap of urology residents in relation to robotic prostatectomy. This information will help identify gaps between novices and experts which can then inform the second question which is: what are the heuristics, patterns and cognitive rules used by experienced surgeons to complete a robotic prostatectomy.

Chapter 3. Research design and methodology

Research Approach

One of the goals of this master's thesis was to determine the surgical cues, patterns and decision-making skills used by expert surgeons and to deliver this data to those who both *need* the information and to *use* it to produce educational modules. I used qualitative, semi-structured interviews to obtain this information and answer my research question. However, by only using this single method, I could have potentially missed valuable and crucial areas of the procedure that *learners*, those unfamiliar to the surgery, either misunderstand or do not fully appreciate. Capturing this information by surveying novices, before the interviews, would reveal frequently challenging aspects of the procedure that I could develop deeper probing questions for and use during my interviews.

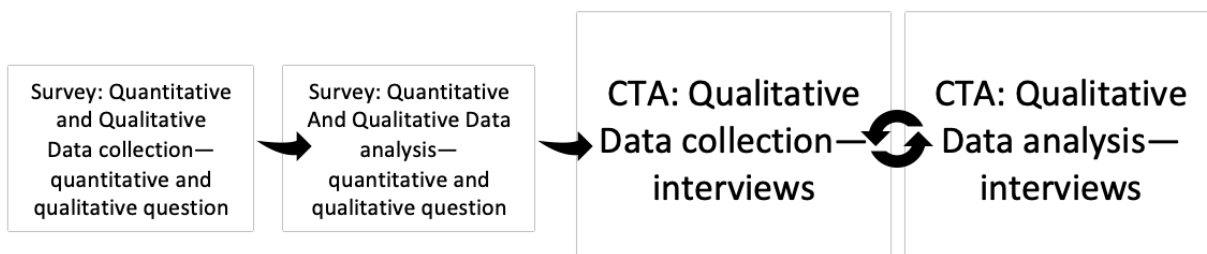
This master's thesis will be a sequential, explanatory mixed methods research study (Creswell & Plano Clark, 2018). Previous research has suggested that mixed methods research can include both qualitative and quantitative methods, with one being more valued than the other given the situation (Maudsley, 2011). My research takes the view that combining both quantitative and qualitative methods are valuable and the integration of both methods in design, data collection and analysis will elevate the study (Maudsley, 2011). Further, a mixed methods design supports Dreyfus and Dreyfus' theory of expertise as well as Schön's theory of expertise. For example, the pre-CTA surveys, discussed later, will highlight if a difference exists between novice and expert knowledge (Dreyfus & Dreyfus, 1986). These surveys will inform a subsequent CTA, which will describe how experts recognize new or different situations (Schön, 1983). In addition, the mixed-methods design supports a constructivist conceptual framework by recognizing that the working knowledge of experts is varied (Creswell & Plano Clark, 2018). By

combining the survey data with a CTA, this acknowledges the breadth of expertise, how it builds upon itself, and encourages the flow and conversation between the two methods of this research (Creswell & Plano Clark, 2018).

Qualitative CTA interviews were completed to understand expert surgical decision-making. To ensure key points of the understanding and complexities were explored, a knowledge gap, if there indeed was a knowledge gap, would have to be assessed. Therefore, a survey, including both a rating scale and open-ended questions, was conducted. The findings from the survey would *inform* and *enrich* the CTA (Lavelle et al., 2013; Ramani & Mann, 2016) (Appendix A).

The description above is the basis of mixed methods research design. By combining two research designs, the knowledge gap outcomes, the qualitative and quantitative survey data, and the surgical decision-making process, the robotic prostatectomy CTA data can provide a detailed description of a robotic prostatectomy (Green & Caracelli, 1997). Using a mixed-methods design allows for multiple stakeholders to provide their perspectives of the robotic prostatectomy and better inform the research question. This is with the caveat that the novice viewpoint potentially lacks key anatomical or procedural knowledge which can be used to enlighten surgical misconceptions and/or pitfalls.

Figure 1. Depiction of mixed methods design integrating knowledge gap survey and CTA.



The visual representation of the research design of Figure 1 depicts the research occurring sequentially so that the survey is performed first, then the results are collected and analyzed. The CTA builds on these survey results and is visually represented as larger textboxes. The CTA is the major component of the research as it is the piece of the research that will answer the research questions of surgical decision-making in a robotic prostatectomy, whereas the survey provides just one piece of the puzzle. In this study, the qualitative interviews have a greater weight to support and provide the evidence for the primary objective, which is to determine the patterns, visual cues and strategies urologists use to complete a robotic prostatectomy. The circulating arrows of the figure demonstrate that the data collection and analysis during the CTA occurs concurrently so that each interview can build off the previous interviews. The interview analysis continued throughout the series of interviews, meaning between interviews one to four.

Mixed methods research designs require a large, multidisciplinary team to ensure that the design is methodologically sound, and that content and processes are followed appropriately. Once the research method required to answer the question, as well as research design, data collection method and statistical analysis needed was identified, experts for each of these topics were found. These experts included content experts, quantitative and qualitative methods experts, experts on study design, survey experts and statisticians. In each of the following sections describing the knowledge gap survey and CTA, the multidisciplinary team members who were consulted have been referenced and acknowledged.

Knowledge gap survey

Knowledge gap survey development

A survey was chosen as the ideal way to gather the information and determine the knowledge gap residents had regarding performing a robotic prostatectomy and the surgical decision-making needed to complete a robotic prostatectomy. There are currently no surveys or questionnaires that have been developed and are context or content specific to a robotic prostatectomy. The context specific questions in the survey would be directed toward a difference in surgical understanding by a novice learner combined with content specific information that would be focused on robotic prostatectomy questions. The knowledge gap survey was developed and based on an AMEE guide that describes survey design (Artino et al., 2014). Additional input was solicited from content experts, the urologic oncologists at The Ottawa Hospital (TOH), as well as members of my thesis supervisory team and experts in the field. For the knowledge gap survey, Drs. Isabelle Raïche, Doug Archibald, Timothy Wood and Jaime Brehaut were consulted to assist with survey design. Dr. Raïche is qualified in both the medical education literature, survey design, cognitive task analysis trained, and is a fellow surgeon. Dr. Doug Archibald is qualified in medical education and assessment and research method design. Dr. Timothy Wood is qualified in medical education research design, methods, assessment, and survey design. Dr. Jaime Brehaut was consulted for his expertise in survey design and piloting. The premise was for the survey to be completed by urology residents observing and assisting with robotic prostatectomies and urologic oncologists performing the same robotic prostatectomies. The answers would be compared to one another. The content experts, the urologic oncologists of TOH, were taught, by myself, the meaning of “heuristics”, “reading a case” and “management of unexpected outcomes” as defined in the three silos of

Klein's cognitive task analysis theory (Crandallet al., 2006). With this background, the content experts, via email, produced questions for the survey and these were reviewed by me and Dr. Raïche for applicability.

The survey was a combination of both quantitative, Likert rating scale questions, and qualitative, open-ended questions. The quantitative portion of the survey required consultation of a statistician, Dr. Ranjeeta Mallick. Dr. Mallick performed the data analysis but was also involved in aiding with quantitative survey design, weighting of question variables, number of variables per question, suggesting which statistical tests would best assess a difference in resident response and data synthesis. To ensure the absence of a neutral option, an even number of response variables was chosen. Designing the scale in this fashion, forces the participant to make a judgment one way or the other. (Appendix A)

The survey was piloted with ten urology residents and six urologists to refine and reformat any questions that were flagged by these stakeholders. Prior to piloting the survey, however, it was sent back via email and checked with the content experts. Urology residents assisting with robotic prostatectomies were recruited, by convenience sampling, to pilot the survey. The rating scale was piloted to ensure residents understood each item and they provided clarification of the questions asked. Finally, the survey was also piloted to ensure there was a difference in resident and staff responses to confirm that this survey elicited a quantifiable knowledge gap.

The sample size was based on a convenience sample of those residents rotating at The Ottawa Hospital, General Campus, who were assigned to assist with robotic prostatectomies. Residents in their PGY-2, PGY-3, and PGY-4 years assist with this procedure, and as the Division of Urology at the University of Ottawa accepts four candidates per year, this would

result in a possible twelve residents to participate, depending on the needs of the oncology service at that time. There are approximately 15 robotic prostatectomies performed per month at TOH, resulting in approximately 45-60 cases surveyed with a combination of these residents over ~three months of performing the survey.

Survey participants

After ethics approval, the urology residents rotating through the urologic oncology service consented to participate in this survey and their residency level was captured. Once the surveys were completed and collected, the anonymous data was kept in a password protected file. The responses given by the residents were viewed by me, ensuring their responses were not viewed by any urology faculty member and would not affect their academic standing or be used as a tool for progression. Staff urologic oncologists of TOH also consented to be surveyed.

The urology resident and urologic oncologist performing the robotic prostatectomy were surveyed directly after each robotic prostatectomy was completed, and they were asked to complete the survey with myself, in person, with a paper copy of the survey. The survey took less than five minutes to complete. I reviewed the list of each robotic prostatectomy scheduled to take place at TOH, printed the surveys to be completed each week, and I made myself available at TOH each day a robotic prostatectomy was completed.

Survey analysis

To determine the level of agreement between participants on their answers to each question, ratings were analyzed by a statistician (RM). Examples of comparisons included whether there was agreement on the width of the pelvises (wide, moderately wide, moderately narrow or narrow). Additional analyses grouped responses into related categories. For example, wide and moderately wide were grouped into one category and narrow and moderately narrow

were grouped into another category. Answers to the open-ended questions were reviewed by both AJL and IR. The responses were first assessed for their agreement: whether the responses did or did not agree in terms of the wording, phrasing and/or overall understanding of the responses. They were then assessed for response meaning and were coded into categories and themes and a coding tree was formed (Table 1). The final coding tree consisted of surgical step, exposure, quality of tissue, anatomy, maneuver, ease of performance, and bleeding. The subsequent content analysis was performed twice, with each iteration of qualitative analysis compared between AJL and IR and produced three categories including positive versus negative, negative versus positive and consequence versus cause.

Table 1. Coding tree variables for knowledge gap survey.

Coding Tree Variables	
Exposure	Size of pelvis Bowel vs pelvis ratio Fat
Quality of tissue	Oozing tissue Tissue plane Dense plane
Bladder neck dissection	
Anatomy	Bulky nodes Crossing vessels BPH Urethra Previous TURP Large prostate
Bleeding	
Ease of performance	
Step of procedure	
Surgical maneuver	

CTA

A series of semi-structured interviews were completed in which incident-probing questions were used to make the experts explain what they were thinking, what cues they were looking for, and what heuristics they used during task performance.

CTA interview—synthesis and mixing of survey results

The CTA interview protocol, including the interview structure and format, was previously used in another study. The results from both the qualitative and quantitative components of this study were used to highlight discrepancies of residents in the understanding of a robotic prostatectomy. For the quantitative component, the kappa values that showed significant disagreement were noted. For the qualitative component of the knowledge gap survey, the major themes that described discordance in understanding were formed. These results were then used during the CTA interviews to focus the probing questions and highlight areas of either misunderstanding and/or knowledge gaps. When the procedural steps or topics in question were discussed during the interview, the interviewer, AJL, would provide further questioning into the what's, how's and why's of the pre-determined topics.

CTA participants

A key informant sample technique was used to select participants to the interview. They were chosen for their expertise in robotic prostatectomy, defined as >500 robotic prostatectomies performed, their diverse background, their interest in teaching (willingness), and their recognized communication skills (communicability). These experts were contacted directly by me in an informal meeting during which the purpose of the study was explained, and the methods and approach were discussed, including the experts' potential role in the study, and the process of the semi-structured interviews. Previous literature has researched the steps of a robotic

prostatectomy using a modified Delphi technique, and some of the experts at TOH have even participated in this research. As such, extra time and explanation was invested to highlight the difference in those modified Delphi surveys and the semi-structured CTA interviews I was using for this masters' thesis.

The expected sample size was four urologic oncologists at TOH who routinely perform this procedure. The number of interviewees required for CTA interviews to be robust and ensure sufficient expert knowledge was based on a study by Yates et al., (2012). They interviewed six trauma surgeons about an open cricothyrotomy procedure. This study found that 72% of expert decision steps was omitted, and obtained CTA interview methods, with 3-4 experts interviewed, and 34% of expert action steps were omitted (Yates et al., 2012). This finding from Yates et al., has been the landmark trial suggesting appropriate saturation of expert knowledge is achievable with 3-4 experts, with the caveat that appropriate CTA interviewing techniques are upheld and abided by (Yates et al., 2012).

At the end of the informal meetings, the participants were asked for their consent to participate. All interviewees were in practice at the time the interviews were conducted and were available for repeated interviews, another factor identified by Crandall et al. (2006) as being critical.

CTA interview protocol

The interview protocol was used successfully in another project (Raïche, 2016). The CTA interviews were held after the survey was completed and were led by members of the research team who were trained in CTA and performed mock CTA interviews (AJL). All interviews were conducted alone with a single expert and me, with the investigator taking notes and recording the discussion. Of note, for quality assurance purposes, two recording devices were used. Four

semi-structured interviews were conducted with each expert, each interview lasting between one and two hours. The first interview of the series of four was used to select a case and to obtain a first detailed description of a robotic prostatectomy. Each “interview one” was reviewed by me to highlight areas to focus on and probe with questions prior to completing interview two. This process of re-listening to each interview was completed twice prior to moving on to interview two. During the second interview, the table generated from the analysis of the first interview was reviewed and completed and was used to support and deepen the understanding of the procedure. During this second interview, the experts were given the information they had provided in their first interview and were asked to elaborate on any information, make any corrections, as well as answer pre-written questions I transcribed when the interview recordings were reviewed.

Interview three consisted of the expert and me reviewing a full, video-recorded robotic prostatectomy from start to finish and was edited to remove any extraneous footage, for example camera wiping, or time waiting for the assistant to acknowledge the primary surgeon, etc. The fourth interview consisted of each expert viewing surgical videos of intraoperative complications and/or errors to review complication and/or error avoidance as well as management.

Video production

The video for interview three was selected by me and was chosen to be a “standard” robotic prostatectomy without significant anomalies, abnormalities, or complications. This would allow the experts to focus on describing commonly encountered patterns or surgical decisions made and avoid cognitively overloading the interview with difficult scenarios. The video was edited using iMovie on a MacBook. These interviews were recorded, and the notes focused on the time during the video when the experts were discussing what, where, and how they decided what was transpiring in the video. The robotic prostatectomy case was selected based on the

patient characteristics and anatomy, not based on which one of the four experts completed the procedure. Interview four consisted of the expert and me viewing a compilation of cases of difficult patient anatomy, complications and management techniques performed. The aspects chosen to be included in this second video review were based on a combination of resident knowledge gap survey results, common anatomical difficulties as well as significant patient complications. Multiple recorded robotic prostatectomies were reviewed to find the appropriate footage. These videos were edited in iMovie with experts being shown a final version that included management of bleeding; challenging exposure secondary to hemostasis and patient anatomy; a cystotomy; a rectal injury; and a large median lobe.

Interviews

The interviews were recorded, and notes were made focusing on when the experts detected important information during the interview, which would ensure accurate interview review and analysis. A coding grid for each expert was made to describe the cues they recognized and how to manage errors and complications throughout a robotic prostatectomy. The experts were encouraged to elaborate and review their CTA grids and a final CTA of a robotic prostatectomy was completed for each urologic oncologist.

Survey and CTA implementation

One main resource required for this thesis was people to conduct the piloting of the survey, gathering the survey data, analyzing the qualitative survey data, conducting the CTA interviews, and analyzing the CTA results. The surgical language and procedural understanding are both aspects that limit this part of the thesis to an individual with a surgical background and as such I surveyed the participants and conducted the CTA interviews. The analysis of both the open-ended comments of the survey and CTA grid was performed by me with the aid of IR.

Conducting the interviews with the expert urologic oncologists however could only be properly done by a urologist, or senior trainee with experience with the *robotic* techniques, as the steps and language are specific, and the types of CTA questions could not be thought of by a non-urologist. As such, I carried out all four interviews with the four expert urologic oncologists of TOH.

CTA data analysis

Each CTA interview was listened to twice and an interview summary was created for each individual interview. Direct transcription of each interview was not performed as per the instruction of Crandall et al (Crandall et al., 2006). The data were then deconstructed and coded into themes and reconstructed and organized into a single CTA grid for each surgeon. The interview summaries were analyzed for: visual cues, surgical steps, simplification maneuvers, error/complication recognition, error/complication management and avoidance. The CTA grid headings were determined using Crandall et al's CTA analysis template as well as from a surgical CTA literature view to ensure a surgical focus was highlighted (Crandall et al., 2006). The interviews with video review were listened to with simultaneous video playback to ensure accurate data extraction was performed. Of note, the interview process and interview review were performed simultaneously to allow subsequent interviews to be informed and expand upon previous interviews. After each interview grid was completed, each urologic oncologist was presented their own CTA robotic prostatectomy grid for review to check for accuracy and allow for any modifications to be made.

Time

Good organization, time management, and communication with the surgeons and their administrative assistants, allowed the allocating and successful, timely completion of the interviews.

Chapter 4. Results and Discussion

Knowledge gap survey results

The goal of the first part of the master’s thesis is to identify the knowledge gap between urology residents and staff urologists when performing a robotic prostatectomy. This knowledge gap was assessed using the survey outlined in Chapter 3 and was completed by both urology residents and staff (see Appendix A). Please see Chapter 3 for the survey protocol.

Qualitative survey results and discussion. Agreement.

The data from the open-ended questions of the survey found several areas where there was agreement between resident and staff responses (Table 1). Most of the residents agreed with the staff when this portion of the procedure was defined as “easy” (by both residents and primary staff surgeon), the difficulty of the nerve spare, difficulty of the bladder neck dissection, the difficulty of the lymph node dissection and anticipated bleeding (Table 1).

Table 1. Agreement between resident and urologist responses.

Open-ended questions	Rating scale
Nerve spare	Nerve spare (if defined as “easy”)
Bladder neck dissection	Bladder neck dissection
More bleeding than anticipated	Lymph node dissection

Neurovascular bundle spare

The residents also provided similar responses to the staff in their descriptions of the difficulty of the neurovascular bundle spare. If the nerve spare was not thought to be difficult, residents were able to identify that this was secondary to good, clear or clean tissue planes, responses which were echoed by the staff surgeon.

“There were good tissue planes with no significant bleeding.”—Resident

“The patient had good tissue planes.”—Staff

This difference is important to note. When this part was “easy”, there were fewer visual stimuli to overwhelm or be processed by the residents, for example in a case with good visualization and less bleeding. Residents were able to take in and process the intraoperative maneuvers and were able to explain why the dissection was easy, similarly describing tissue planes and anatomy. As soon as the neurovascular bundle sparing became challenging, the residents were unable to similarly describe the events that took place, which both resident and staff agreed posed a challenge. This concept of learning and understanding with increased cognitive load was studied with engineering students. When presented with complex problems with greater information, in other words when cognitively overloaded, like the urology residents, their performance declined but when a decision support system to reduce complexity was introduced, their performance was improved (Hsieh et al., 2012). Again, without being overwhelmed with visual stimuli, and therefore managing cognitive overload, residents were able to process what they saw and make a similar judgement about the operation as the staff surgeons (Bharathan et al., 2013; Hsieh et al., 2012).

Bladder neck dissection

Although the bladder neck dissection has been listed in multiple different studies as one of the more difficult steps of the procedure to perform, the residents were able to similarly describe how difficult the dissection was as well as provide similar explanations in their description of this part of the surgery. The residents’ descriptions were very similar to the ones

provided by staff. An example of the similar descriptions given by residents is the anatomy and tissue variations. During the bladder neck dissection, residents were able to describe the prostate anatomy, whether that was a large median lobe or small overall gland size. Residents were also able to similarly describe good tissue planes or thin bladder mucosa. The prostate anatomy is information that can be obtained prior to the operation from preoperative staging imaging, frequently in the form of a CT scan or MRI or from pre-operative cystoscopy. By having this preoperative information available, residents would be able to anticipate the prostatic anatomy that would be encountered intraoperatively, requiring less in-the-moment informational processing that residents could use for other active thinking, for example determining where the primary surgeon is dissecting at the bladder neck, where the prostatic junction is located, etc.

Another explanation for the agreement in descriptions could be that this portion of a robotic prostatectomy does not involve a significant amount of work by the bedside assistant. This limited amount of work could be a potential reason behind the residents reporting similar results because residents do not have as high a cognitive load during this portion of the operation and can therefore focus on all of the visual stimuli at hand, process the surgery taking place, and have fewer stimuli to occupy their attention and learning. This portion of the operation also has less significant bleeding that could distract a bedside assistant and outstrip their cognitive load. Young et al., describe this component of cognitive load theory, that of working memory, as being limited in the *amount of information* that can be processed and the *amount of time* a learner has to process (Young et al., 2014). With fewer stimuli to fill a learner's working memory and exceed their cognitive load, residents were able to provide similar description of the bladder neck dissection. The bladder neck dissection also occurs around the pelvic inlet, in full view of the endoscopic camera. The pubic arch, the prostatic contour, and pelvic sidewall are in view,

providing the surgeon with frames of reference of how tissue or the bladder neck dissection occurs in relation to these other structures. Wade (1996) described this as a *patterncentric frame of reference* that allows the surgeon to understand how objects move in relation to one another. Having this patterncentric information available for residents, they could understand and more accurately describe this part of the procedure (Wade, 1996). Fewer stimuli to occupy the attention and cognitive load of the trainee as well as being in full view of the camera with defined frames of reference, are plausible hypotheses that can explain the agreement between the residents and staff (Wade, 1996; Young et al., 2014).

Lymph node dissection

When the responses describing the difficulty of lymph node dissection were consistent between the resident and primary staff surgeon, the two groups described similar surgical anatomic variations, whether that was “*straightforward anatomy*” or “*aberrant, unanticipated vasculature*”.

“The patient had easy retraction with clear anatomy.”—Resident

“The patient had no crossing veins with normal node size.”—Staff

“The patient was skinny with a wide pelvis.”—Staff

“The patient had a lean body habitus.”—Resident

There are a few possible explanations for the agreement between residents and primary staff surgeons of the lymph node dissection. The lymph node dissection takes place in a larger field of view, which does not require the primary surgeon to be zoomed in (Breedveld et al., 2000). This allows for more anatomic landmarks to be visualized and provides learners with

reference points like the pubic arch, Cooper's ligament, and the lateral edge of the bladder. Breedveld et al describe this phenomenon, that residents' visual perception of laparoscopic procedures is less handicapped when the surgical field is less magnified and there is a larger field of view (Breedveld et al., 2000). Another potential reason there was agreement could be due to a lack of cognitive overload. The task of the resident during this part of the procedure is less involved than other portions with less need for active retraction or suction to understand the surgery taking place. Bharathan et al found the same when they assessed gynecology residents performing simulated surgeries of varying levels of difficulty (Bharathan et al., 2013). With increasing activity and increasing complexity, their cognitive load also increased while their performance declined (Bharathan et al., 2013). These factors allow for a comparatively decreased cognitive load, better field of view and decreased magnification with subsequent similar understanding of the intraoperative events as the primary staff surgeon (Breedveld et al., 2000).

Qualitative survey results and discussion. Questions with unclear consensus.

Of note, there were sections of the qualitative portion of the survey that had very few responses, specifically why a capsular incision occurred, why there was a delay in progression or why there was potentially more bleeding than expected. These questions were not answered if they did not physically occur during the robotic prostatectomy for either the residents or staff to comment on. It is to be expected that there might be a limited number of intraoperative misadventures or complications, like capsular incisions or excessive bleeding, to take place at an academic oncologic centre with one of the highest volumes of cancer cases performed in Canada to comment on. As such, based on the limited number of responses, it is unclear if there was

agreement or disagreement in the understanding of the residents for the potential surgical events of a capsular incision, delay in progression or excessive bleeding.

Qualitative survey results and discussion. Disagreement.

There was disagreement found between resident and staff responses to some narrative comments. These responses were noted at different steps of the procedure, including describing the most difficult part of the surgery, describing the difficulty of the seminal vesicle (SV) dissection, the posterior dissection from the rectum, the apical dissection, and difficulty of the vesicourethral anastomosis. When these questions were reassessed and further examined for interpretation, the disagreement between resident and staff responses was also found in the different question categories selected for the survey, including complication identification, surgical anatomy, and surgical decision-making (Table 2).

Table 2. Disagreement between resident and urologist responses. Rating scale and open-ended questions combined.

Open-ended questions	Rating scale
Positive versus negative	Nerve spare (difficulty)
Negative versus positive	Difficulty of operation
Cause versus consequence	Seminal vesicle dissection
	Posterior dissection
	Delay in progression

To further understand why there was disagreement noted in resident responses, each description given, by both residents and staff surgeons, was coded into eight different groups, including: exposure, quality of tissue, anatomy, bleeding, ease of performance, step of procedure and surgical maneuver (see Coding Tree from Chapter 3). After the responses were coded, they underwent content analysis and produced three main categories that described how residents

explained their conclusions differently to the staff surgeons, which were: positive versus negative, negative versus positive and cause versus consequence.

Positive vs negative

The positive versus negative theme can be described as the residents' justification for responses that used affirmative language describing something that went well during the operation compared to the staff surgeons' responses that were describing negative, difficult, or problematic portions of the operation. The positive versus negative category could also be secondary to a lack of primary surgeon description or due to the absence of resident recognition of near misses or hazard recognition. The ability of an expert surgeon to perform a difficult operation and make it seem as if it were a standard procedure could be due to the surgeon not describing the maneuvers they are performing in order to complete the procedure successfully. There are examples from a robotic prostatectomy where this automatic performance can be demonstrated. The primary surgeon could shift the robotic arms in order to assist the dissection, gaining range of motion in the robotic arms or facilitate further dissection in deep areas.

Additionally, the primary surgeon could change the retraction of a robotic arm to facilitate visualization or tension of tissues which are frequently not in view, and because they are not directly in the operative field, the resident would not be able to appreciate these maneuvers. These movements of the instruments that are out of view of the laparoscopic camera and not relayed to the resident learner can be a missed surgical maneuver for the resident and a lost learning point. Without this description, residents could believe this operation is the same difficulty as one where the primary surgeon did not have to perform these maneuvers. One possible explanation for surgeons not describing the troubleshooting maneuvers they perform

could be the result of the surgeons not being consciously aware they are actually performing these maneuvers. Yates et al found that even when surgeons were probed, they omit a significant portion of their surgical technique as these acts have become automatic in their operative practice (Yates et al., 2012). Pugh et al however found surgeons used a significant amount of knowledge-based behaviours when they were troubleshooting a maneuver or in error-rescue mode (Pugh et al., 2011). Their research, a CTA of six surgical procedures, found surgeons used more conscious rules to solve intraoperative errors than previously suggested (Pugh et al., 2011). Whether it is a combination of automatic behaviour or conscious knowledge-based decision-making, this information is critically important for trainees to learn in order to perform successful operations and this surgical decision-making facilitates successful operations.

Another reason that could explain residents' positive explanations of negative operative experiences as deemed by staff surgeons could be that they were not recognizing hazards that were apparent to the primary surgeon. These hazards, or potential near misses, occur during operations but they can be identified and avoided, and the procedure can continue. If the residents could not recognize that these events occurred, they would not recognize this for future operations and this could potentially result in an actual intraoperative complication, as compared to avoiding the error altogether (Bonrath et al., 2015). Bonrath et al assessed this concept of identifying error-event patterns by reviewing successful laparoscopic procedures and technical intraoperative event patterns (Bonrath et al., 2015). They were able to categorize these events, for example as inadequate force placed on tissue or inadequate visualization, for better error awareness (Bonrath et al., 2015). The results from this study show residents do not have a complete grasp of error awareness which can be addressed in the future for improved resident learning and potentially help avoid errors.

Negative vs positive

The negative versus positive category explains the language residents used to justify their responses which were describing negative categories, like difficult patient anatomy or challenging surgical steps, compared to the staff surgeons' responses which were positive explanations, characterizing an operative event or step that was going well or easily during the procedure. Residents identified visual information that they perceived to be negative when in fact the primary surgeon understood the same visual information to be acceptable or even beneficial for the operation. The category of negative versus positive could be explained by residents not synthesizing all the intraoperative information available and not understanding the surgical decision-making behind maneuvers that allow for subsequent surgical steps to occur.

This category was displayed when the residents defined what they perceived to be excessive bleeding or when a large bladder neck incision was made that required reconstruction. These same surgical events were viewed by the primary surgeon to be good or acceptable. For example, staff surgeons purposefully allowed bleeding to occur around the neurovascular bundles and avoided the use of cautery to avoid nerve injury. The end goal, by avoiding nerve injury, would be to preserve erectile function. Surgeons also described deliberately creating a larger bladder neck opening that subsequently required reconstruction. By creating this larger incision, it avoided incising into the prostate, potentially having a positive surgical margin and subsequently avoiding leaving cancer behind. The potential consequence of a resident perceiving a portion of a procedure as a fault, when it is in fact a positive event, relates to how they would perform as the primary surgeon. This concept is the same for a learner in general, where if a learner cannot perceive all the information presented, or synthesize the information available, they will not be able to reach the level of expert performance. The idea of residents missing a

positive or beneficial maneuver has not been studied and it would be exceedingly difficult to measure the downstream consequences. Further, surgeons typically teach around errors in resident performance and less around their own explicit and beneficial surgical techniques (Roberts et al., 2012). In fact, Sutkin et al.'s description of surgical verbal teaching found that explanation by attending surgeons was a small fraction of how attending surgeons communicate with residents intraoperatively (Sutkin et al., 2015). Without being able to identify a surgical event as acceptable and/or beneficial, the primary surgeon might not progress in the surgery and could risk injury or intraoperative complications.

Cause vs consequence

The cause versus consequence theme can be described as the resident describing the cause or result of an intraoperative event, patient anatomic variant or operative step. This is in contrast to the staff surgeon describing the steps that led up to and produced what the resident was seeing during the operation, in other words the cause that produced the intraoperative consequence. The category of cause versus consequence for resident explanations versus staff surgeon explanations perhaps is not entirely unexpected for trainees trying to learn intraoperative procedures. First and foremost, when learning how to perform a procedure, the residents are focused on a limited number of elements occurring during the operation secondary to the cognitive load principle, or overload in this scenario (Sewell et al., 2019). The resident is focused on the problem at hand and not *why* the problem occurred. An example of this category is the description of the posterior dissection. The posterior dissection off the rectum occurs with several key structures encroaching the working area, including the rectum, neurovascular bundles, and the prostatic capsule. When these structures were not abnormal or diseased or of

difficult quality or consistency, the residents were able to report similar descriptions of the difficulty of this portion of the procedure as the staff surgeons. When the posterior dissection became difficult, as described by both the residents and staff surgeons, the residents had difficulty describing their reasoning *why* this occurred. The residents described what they had seen, like bleeding tissue or poor visualization, instead of the elements that resulted in a difficult posterior dissection. Their description is in contrast to the staff surgeons' description of sticky tissue planes or a small pelvis that led to bleeding tissues or poor visualization and ultimately a difficult posterior dissection.

One possible reason for this discordance in explanation is a decreased situational awareness of the resident. Situation awareness refers to “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988). The expert is able to combine these elements of perception, comprehension, and projection whereas the novice is not. For example, during the apical dissection, the resident could perceive bleeding surgical planes of the prostatic apex. This same surgical scenario was perceived as sticky tissues by the expert surgeon who had situational awareness. The expert surgeon could see how tissues were not separating as anticipated, understood this could be either the wrong plane or diseased tissue or anatomic variation, and then planned how to manage this tissue, allowing minor bleeding to occur (Endsley, 2018). Cope et al describe similar situational awareness results of experienced surgeons in the operating room. Their qualitative study investigated the perceived learning and skills of surgeons in the operating room where they described the factual knowledge they learned as well as surgical techniques, but also included in their descriptions was their situational awareness (Cope et al., 2015). Once excerpt describes perceiving the audible decrease in oxygen

saturation from the anaesthesia machine, how this could affect their surgery and their reaction of interacting with the anaesthetist, the hallmarks of situational awareness (Cope et al., 2015). The results from this thesis described a lack of ability by the residents to understand the situation at hand and may be linked to the characteristic system of robotic surgery.

Determining why a problem occurred or managing an intraoperative difficulty is key to successfully solving a problem; however, learners at the beginning of their training would have difficulty with this challenge as they lack the decision-making knowledge and experience to do so (Raïche et al, 2019). They are also not the primary surgeon or the surgeon dictating the operation. Although this may seem redundant to state, the onus of responsibility that shifts from being the primary assistant to the primary surgeon should include a time when the assistant should be attempting to make the decisions to solve the problem. These results, with the residents' explanations of their responses, highlights that they might not be aware of inciting factors that lead to an end result. Dror et al. describe this concept to minimize error by active teaching of error recovery in conjunction with error reduction. Error recovery combines identifying an error, defining how the error occurred and finally challenging learners to produce recovery maneuvers (Dror, 2011). This teaching method would allow residents to identify an upstream cause rather than just the downstream consequence and support their understanding as well as reduce errors (Dror, 2011). Pugh et al.'s recent review of residents performing laparoscopic ventral hernia repairs found only 47% of errors were recognized by residents, but of the errors that were identified, 86% were successfully recovered (Pugh et al., 2020). In summary, being able to identify and understand *how* an event occurs is critical in surgical problem solving, using the appropriate tools to do so and, importantly, attempt to avoid this in the future (Dror, 2011).

Furthermore, in the case of robotic surgery, the bedside assistant is locked into being at the patient bedside and using the instruments to assist, with minimal opportunity for the bedside assistant to manage intraoperative difficulties. This is unlike open surgery where the assistant would have the ability and opportunity to be an active participant, use the same instruments as the primary surgeon, and potentially manage the complexities of an operation. One could argue that the time to understand the causes of surgical misadventures, errors, or surgical difficulties comes with experience on the console. This statement however brings the concept of surgical education backwards to the times of learning by doing, in a high cognitive overload environment with real patients. The cause versus consequence theme acquired from this research, highlights areas where learners can be taught the causes of downstream consequences pre-operatively as well as actively intraoperatively, as the bedside assistant *before* using the console to consolidate and confirm their understanding. Robotic prostatectomy curricula and simulation define the steps of the robotic prostatectomy and allow for simulated practice but without error identification, or understanding (Aydin et al., 2016; Lovegrove et al., 2017, 2016). This fact is particularly interesting as practicing error recovery in a simulated environment allows for increasingly complex problems to be performed (Dror, 2011), without the error-provoking time pressure of an operative environment (Dror et al., 1999).

Quantitative results and discussion

Statistical analysis

Percent agreement comparing staff and resident responses was determined for the ratings given from the knowledge gap survey. Agreement refers to how consistent the responses are to one another. If the staff and residents gave the same responses, there was a high percent

agreement versus if they gave very different responses there would be a low percent agreement (McHugh, 2012). The research in this thesis differs slightly in that the percent agreement is measured between the resident's response and the gold standard, or correct interpretation of the robotic prostatectomy, which is the staff's response. The four-point Likert scale was collapsed to binary data, by combining easy and moderately into one category and difficult and moderately difficult into another category for percent agreement analysis. The use of the kappa statistic takes this measurement one step further by taking into account random chance. While percent agreement is obviously measured by percentage, kappa values range from -1 to +1. 0 represents the agreement from random chance, and +1 represents perfect agreement (McHugh, 2012). Values less than 0 are very rare in practical research (McHugh, 2012). By convention, the lowest kappa value that is acceptable in the scientific community is an agreement of 0.60, below which means you cannot be confident that 40% of the results could be due to error between responses or due to faulty data (McHugh, 2012). The following analysis used a statistically significant p-value of < or equal to 0.05.

Quantitative data results

There were statistically significant differences of low agreement noted between the residents' responses and the staff surgeons' responses, specifically for the following questions: difficulty of the operation (k 0.39, p=0.12), patient anatomy (size of prostate) (k 0.25, p=0.04), seminal vesicle dissection (SV) (k 0.34, p=0.03), posterior dissection from the rectum (k 0.32, p=0.03), difficulty of nerve bundle spare (k 0.47, p=0.04) and delay in progression (k 0.34, p=0.03). There were also statistically significant similar responses or agreement between residents and staff surgeons which were statistically significant, including: whether the

neurovascular bundles were spared (k 0.80, p<0.001), difficulty of the bladder neck dissection (k 0.71, p<0.001) and whether there was more bleeding than expected (k 0.59, p<0.001).

Quantitative data discussion

The training pathway for RARP published by Lovegrove et al includes the description of the levels of difficulty for each step of a robotic prostatectomy (Lovegrove et al., 2016). This list of steps, along with their corresponding level of difficulty, underwent international content validation prior to its use (Table 3 Condensed EAU RARP Level of Difficulty Score). The results from both the rating scale and open-ended responses show that there is a disconnect between perceiving and understanding a portion of the procedure and the difficulty in actually completing that step of the procedure. The RARP Assessment Score Levels of Difficulty range between I (the lowest level of difficulty) and IV (the highest level of difficulty). The residents disagreed with the staff surgeons' responses for steps with higher levels of difficulty, specifically SV dissection, posterior dissection, apical dissection and vesicourethral anastomosis. These steps have been identified as steps that are challenging portions of the robotic prostatectomy to complete and, if they are challenging for practiced surgeons, they would likely be difficult for a trainee to follow, understand and produce a similar assessment as a staff surgeon. There are however steps that were identified as an increased level of difficulty to perform that residents *were* able to agree and come to similar conclusions as the staff surgeons, namely the lymph node dissection and bladder neck dissection.

Table 3. EAU RARP Condensed Level of Difficulty Score.

Level of difficulty	Step
I	Robot set-up Pneumoperitoneum and port placement Initiation of console Inspection of abdomen at end Finalizing-removing instruments and ports
II	Adhesiolysis Drop bladder Exposure of prostatic apex and fascia Dividing DVC
II/III	Anterior bladder neck dissection
III	Posterior bladder neck dissection SV dissection Posterior dissection Vesico-urethral anastomosis Lymph node dissection
IV	Pedicles/neurovascular bundles Apical dissection

This observation would mean that there is a potential difference in how difficult it is to understand a step of the procedure compared to how difficult it is to perform and master a step of the procedure. Further, this could mean that the levels of difficulty to perform a step are different or on a different scale of difficulty than to understand that step of the procedure. The bladder neck dissection is a step of the procedure that involves anatomic assessment and intraoperative surgical decision-making that was identified in both the qualitative and quantitative portions of the survey as having agreement or similar responses between both residents and staff. As previously stated, this portion of the procedure takes place in view of the camera, with surgical and anatomic landmarks in sight and in a larger abdominal working space, all of which could be reasons why there is agreement between resident and staff responses. The same is true for the lymph node dissection, which is performed in view of key anatomic landmarks, at regular magnification and a larger working space.

By identifying this continuum of resident understanding and surgical level of difficulty, these results can show why different parts of a procedure are difficult to perform. This constellation of factors that make a surgery difficult to navigate, including smaller field of view, magnification, and lines of sight, combined with the limitation of robotic surgery, specifically lack of haptic feedback, are what categorizes a part of the procedure to be both difficult to understand as a novice learner and difficult to perform surgically (Table 4). This difference in the difficulty of understanding of a procedure versus the difficulty performing a procedure, can be applied to many surgical subspecialties. The general surgical principles of teaching for example tissue dissection or achieving hemostasis, in general surgery or urology or gynecology are similar. However, based on the above results, surgical principles would have to be taught differently to incorporate the extra knowledge needed in surgical scenarios with smaller fields of view or difficult lines of sight so that the learner has better understanding of these surgical elements prior to performing surgical tasks, either at basic or more advanced levels.

Table 4. Continuum of resident understanding to level of surgical difficulty.

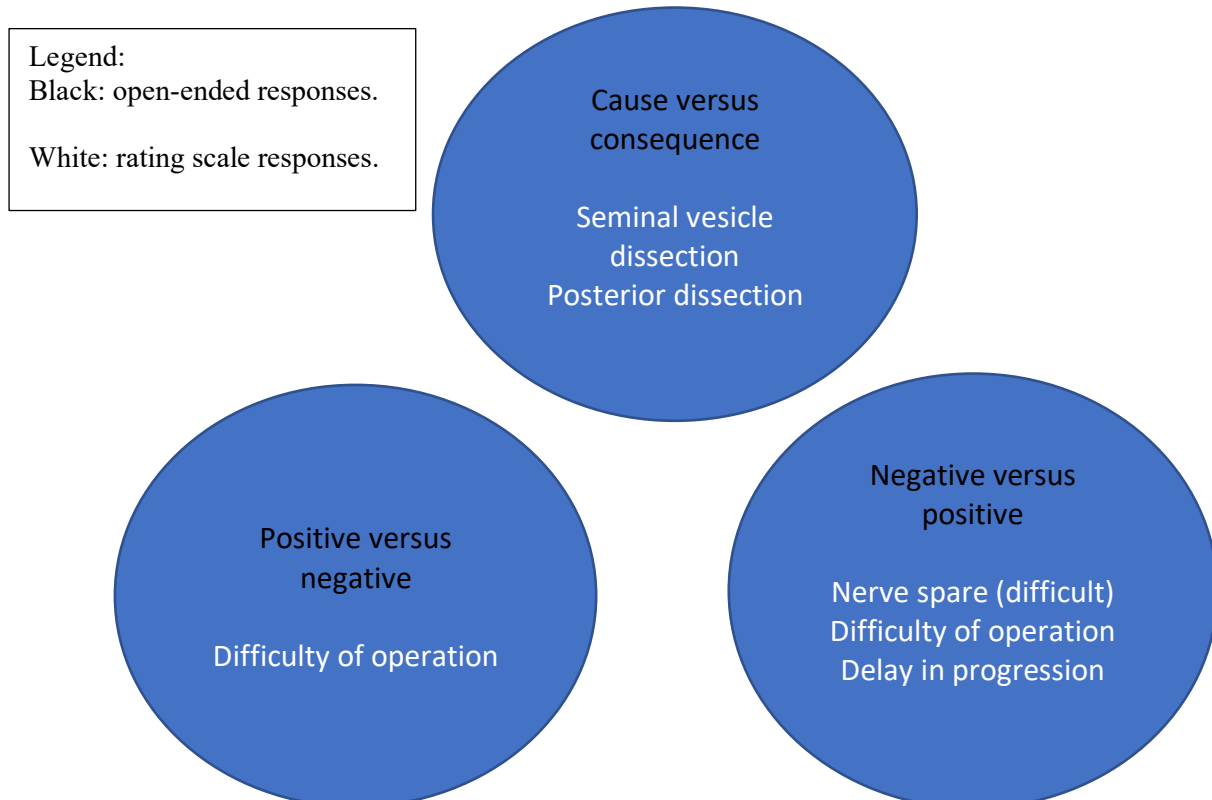
		Resident understanding	Reasoning
Level of surgical difficulty	I/II	✓	
	III/IV	✓	Regular magnification +/- large field of view +/- anatomic landmarks seen
	III/IV	✗	Smaller magnification +/- decreased field of view +/- fewer anatomic landmarks

Summary of knowledge gap survey results and discussion

In conclusion, the knowledge gap survey demonstrated resident understanding of a robotic prostatectomy as well as deficiencies in their knowledge and understanding of this procedure. The deficiencies in both resident knowledge and resident understanding of a robotic

prostatectomy were noted from both components of the survey, including the rating scale and the open-ended questions. The reasoning behind the residents' responses that demonstrated their deficiencies in the rating scale component were explained in the open-ended responses, specifically the anatomy, steps of the procedure and surgical decision-making and were captured in the categories groups of cause versus consequence, positive versus negative and negative versus positive (Table 1 and 2; Figure 1). The discrepancies found in the data were explained by expertise theory and situational awareness and could be used by educators to teach learners how to navigate challenging steps in robotic surgery. These challenging steps include smaller field of view or larger magnification, fewer anatomical or surgical landmarks or, as will be described, the lack of haptic feedback. The results and discussion of the knowledge gap survey produced data and knowledge for the CTA and ensured these aspects of the interviews were mined to unearth these concepts for future learner knowledge and curricular development.

Figure 1. Synthesis of disagreement. Rating scale and open-ended questions combined.



CTA robotic prostatectomy results and discussion.

Cognitive task analysis grids were made from the sixteen CTA interviews with the urologic oncologists of TOH; four interviews were held with four uro-oncologists. Content analysis was performed from the interviews, as was described in Chapter 3, and the data produced themes that allow the surgeons to successfully complete a robotic prostatectomy as well as avoid and manage errors and complications. The final CTA grids describe a map of a robotic prostatectomy including the steps and goals of the procedure, landmarks for steps of the procedure, key visual cues for each step, complications that could be encountered for each step and complication prevention and management. An example of the CTA grids describing this information is seen in Table 5.

Table 5. Example of CTA grid of a robotic prostatectomy.

Steps	Maneuvers for steps	What experts do to simplify	What cues experts are looking for	Common errors/possible complications Strategies to avoid errors/complications and management
Step 6: Bladder neck dissection	<p>Identify the fat lateral to the midline of the DVC on both sides</p> <p>Push to see the prostate coming around. incise the fat laterally on the detrusor apron fascia and that fascia is going down. Opening the fascia allows the bladder to fall easily. incise through the detrusor apron and the fascia</p> <p>Divide in the midline and divide the detrusor apron that's bunched up with the suture and carry the dissection down and follow the contour of the prostate during the anterior bladder neck dissection</p>	<p>Opening up the detrusor apron fascia laterally allows the bladder neck to be opened more easily in the midline</p> <p>Follow the contour of the prostate during the anterior bladder neck dissection</p> <p>Posterior and lateral bladder attachments are where the vessels will be <u>located</u> and this is where clips will be placed more often than simple cautery</p> <p>Follow the bladder contour during the</p>	<p>If you're in the fatty layer, you know you're not in the bladder or prostate</p> <p>When the bladder appears soft between the robotic arms, this confirms the detrusor apron fascia has been opened sufficiently; which means only the bladder muscle is hanging on to the prostate. When learning it's nice to use the catheter balloon to move the junction between the balloon and prostate/bladder neck</p>	<p>Getting into the prostate</p> <p>People seem to stay closer to the bladder because they want a tighter or small bladder neck because it's easier to do the anastomosis urethra.</p> <p>Mistake the catheter balloon for the prostate because they look similar.</p> <p>If the bladder goes straight down, this could change the incision inferiorly, get into a BPH plane and leave some of the prostate on the bladder neck.</p> <p><u>Button-hole</u> the bladder.</p> <p>If mucosa without detrusor is attached for the anastomosis, this could necrose and lead to an anastomotic leak. People with BPH are at a higher risk of anastomotic leak. Patients usually leak on POD#2-3.</p> <p>If you're out laterally and get into either prostate or bladder, you could get a positive margin or too much bleeding.</p> <p><i>Follow the contour of the prostate and continue to reassess the dissection plane</i></p>

Goals and objectives

Each step of the procedure was described, as well the goal of each step. There were 14 steps described by the four uro-oncologists, including: port placement, sigmoid release, posterior dissection, bladder drop, lymph node dissection, endopelvic fascia and dorsal venous complex, bladder neck dissection, pedicle dissection, neurovascular bundle sparing, apical dissection, urethral dissection, hemostasis, vesicourethral anastomosis, and closure. The goals and objectives of each step were described by each urologist, grounding each step with a purpose. Not only did the urologists describe what is done during each step of the procedure, but they also included the framework needed for a learner to understand *what* the sequence of events are, as well as *why* the sequence of events occurred. For example, one of the first steps of a robotic prostatectomy is to release the physiologic sigmoid attachments from the peritoneum and any bowel adhesions. The steps to do this were described and include releasing any bowel at its adhesion point, avoiding opening the peritoneum or injuring bowel during this step. The objective of releasing the sigmoid attachments is to ensure the bowel falls out of the pelvis and allows for good visualization for both the posterior dissection and bladder neck dissection. Another example of describing both the steps and goals of the procedure would be the apical dissection. The steps needed to perform the apical dissection were described, with the overall objectives being to visualize the urethra and prostate apex and set up for a vesicourethral anastomosis with sufficient urethral length. It is the addition of this objective that accompanies the description of the procedural steps that differentiates these CTA results from previous robotic prostatectomy procedural analysis or modified Delphi survey (Lovegrove et al., 2016; Morris et al., 2017). By providing these anchors for learners, their thinking of *how* a part of a procedure is

performed is given a reference point for when they are assisting, as well as for when they are the primary surgeon.

Landmarks

Landmarks were frequently described throughout the CTA by the surgeons as signposts to orient themselves during the operation. The landmarks described either where to begin a section of a procedure, where to proceed, as well as where to end a section of a procedure and move to the following portion. For example, for the posterior dissection, the landmark to make the initial entreaty into the peritoneum is given by the rectovesical impression. During the posterior dissection, this is completed sufficiently on the anterior SV when the posterior portion of the prostate is encountered and this landmark, the prostate, comes into view. Future robotic surgical curricula should follow the medical education curriculum template that includes outlining the learner goal and objective (Thomas et al., 2015) but this should also include landmark information. By including landmark detail, as identified by the urologists for this CTA, into robotic surgical curricula, this would complement the goals and objectives of the procedure as well as highlight the cognitive domain the learner should access (Thomas et al., 2015). The questions of where to start or begin a step, or when and where a step is complete can be challenging for learners when they are first given the chance to be the primary operator and this landmark information is crucial for learners to successfully complete a surgery. Mayer et al describes this type of learning in his article on the superiority of guided learning, and how a novice learner performs better with guidance than without (Mayer, 2004). This guided discovery learning compared to pure discovery learning is analogous to the novice being directed to the initial location of the posterior dissection incision in a robotic prostatectomy, the landmark of the

rectovesical impression. Guided discovery learning compared to pure discovery learning has been shown, time and again, to better promote learning, better transfer knowledge to new concepts and improve long term retention of knowledge (Mayer, 2004). This information is key to informing robotic educational curricula so the pure discovery learning occurring as a bedside assistant is not over valued and purposeful, guided discovery learning is included in teaching.

Visual cues

The visual cues used and provided by surgeons are where the CTA of the robotic prostatectomy expands the surgical decision-making and knowledge of this surgery. The visual cue information provided in the CTA grid was retrieved from the urologists using the CTA interviewing techniques, taking them several steps further in their descriptions. The descriptions given by the urologists using the initial interview questions gave basic or first order data and responses, like “... *the plane looks good...*” or “... *something doesn't look right...*”. With the CTA technique, granular detail about how to perform and progress during the operation was given by the urologists. This type of information, the visual cues, included colour of tissue, the shape of structures, the movement of tissue, not only of the main visual field or working area, but also of the adjacent or surrounding structures.

Example 1. Evolution of the description during the CTA:

Surgeon: “The tissues look right.”

Interviewer: “Why do they look right to you?”

Surgeon: “The tissue looks thin, not like thick prostatic tissue, and coming around to where the urethra would be. That spot looks fine to me.”

Interviewer: “What are you looking for to know you're in the right spot.”

Surgeon: “The contour of the prostate is the biggest thing to use as a guide, anterior to the urethra. A little bit of bleeding which sometimes can be an indication you’re around the urethra. The blood supply is different.”

Example 2. Evolution of the description during the CTA:

Surgeon: “I wouldn’t be so aggressive going into the prostate there.”

Interviewer: “What are you seeing to say that?”

Surgeon: “Because the bladder neck is quite tight. It looks like the bladder neck is tight, so you don’t need to go so close to the prostate. This tells you that you can go more proximal on the bladder. Again, I think they could be even further back.”

Interviewer: “What are you looking at to show you where you’re supposed to be?”

Surgeon: “I would divide the posterior urethra so you can put your instruments inside the bladder, look inside the bladder so you can see.”

The descriptions given are very much where the wealth of expertise and previous surgical experience become evident (Campbell et al., 2011; Clark et al., 2012; Pugh et al., 2011; Smink et al., 2012; Yates et al., 2012; Yeung et al., 2017b). An example of one visual cue was the description of how the tissue on the bladder neck moves during the bladder neck dissection. If the tissue being retracted up towards the head appeared soft, mobile and/or pliable, this would cue the surgeon that this was likely bladder muscle, and not prostate, and was positive reinforcement that the incision was not cutting into the prostate or leaving prostate on the bladder neck. Another example would be the description of the filmy, wispy, areolar tissue that is seen and visualized when the bladder is being dropped. This visual information cues the surgeon that

this is the correct plane to dissect into, and it is not leading either into the bladder or into the rectus abdominus muscle. The visual cues, and landmarks previously described, give learners a buoy to hold onto in a sea of similar tissues and colours, or during times of cognitive overload. The landmarks serve as the boundaries of the procedure and the visual cues serve as the crumbs leading the progression of the procedure for the learner. These nuances and subtleties provided by the urologists comprise the vault of experiential nuggets that novice learners lack and give the details needed for a complete and thorough robotic prostatectomy curriculum. A future, robust robotic curriculum should contain both landmark and visual cue information to ensure maximal learner comprehension and understanding.

Complication and error prevention and management

This chapter has already described that when performing a procedure, the roadmap includes the directions, the landmarks to keep within the limits, signposts to direct the surgeon, and the visual cues to light the path and ensure forward progression of the surgery. Some of the most critical information to have includes the knowledge of the pitfalls that can be encountered that could either prolong the operation or cause morbidity or worse outcomes for the patient. Therefore, learners should know, and a curriculum should include a description of potential errors or complications and/or procedural difficulties, error or complication prevention and, if they do occur, error or complication management. Without alerting the learners, the expert surgeon could be using prevention techniques while operating to avoid injuries or manage difficult anatomy. Surgical learners may not be exposed to the variation of potential surgical errors or complications, and this lack of exposure is compounded by the restricted work hours for surgical residency and overall lack of exposure to robotic prostatectomies. This lack of exposure

was supported by Okhunov et al, who found potential deficiencies in current urology training programs, as perceived by residents, recent graduates, and program directors (Okhunov et al., 2019). They found that less than one third of residents felt comfortable performing robotic procedures (Okhunov et al., 2019). Farivar et al also found similar results in their study of general surgery residents, where only 18% of general surgery residents stated they were allowed access to the operating console in robotic surgery (Farivar et al., 2015).

One such surgical error described by the urologists during a robotic prostatectomy could be an injury to the obturator nerve during the pelvic lymph node dissection. The potential injury could be clipping the nerve and/or transecting it. This potential injury could be avoided by using a few different techniques, including keeping the visual field dry of blood, having direct visualization of the nerve, explicitly showing the nerve to the assistant, and directing their clips with the robotic arms. If the nerve was clipped, the surgeons could: use the clip remover or break the clip at its apex using the robotic arms and avoid further crushing of the nerve. The synthesis of these results can be seen in Table 6 where the techniques and surgical pearls are described by each surgeon, taken from their respective CTA grids. The surgeons describe similar techniques, like how to use the bipolar cautery to spread the neurovascular bundle away from the prostate and how the hemostatic stitches in the pelvis should be thrown backhanded to avoid incorporating the neurovascular bundle into the stitch. Similarly, the surgeons describe the visual cues and patterns for this dissection, including the shape of the prostate and the junction between the prostate shoulder and neurovascular bundle to follow (Table 6). The subsequent Table 7 summarizes this surgical expertise into steps for nerve sparing, avoidance maneuvers and surgical techniques combined from all four surgeons.

Table 6. Approaches and expert knowledge for neurovascular bundle spare.

Surgeon 1	Surgeon 2	Surgeon 3	Surgeon 4
<p>If nerve spare, follow the contour around the prostate for the correct plane. If wide, dissect down to where the neurovascular bundles are located entering the periurethral space.</p> <p>Leave the very end of the neurovascular bundle attached until the anterior dissection is completed.</p> <p>Laterally, all dissection is done sharply to free up the nerves off the apex. Snip and push to free up the nerves off the apex.</p> <p>To achieve hemostasis around the bundles, avoid taking too big of bites on the nerve with the stitches.</p> <p>If there was a wide dissection, the distal aspects of the neurovascular bundles are over sewn no matter what.</p> <p>Techniques to throwing the hemostatic sutures: do not angulate too much and they should be thrown smoothly.</p>	<p>Nerve sparing procedure: grab the lateral anterior surface of the prostate and bipolar and scissors are used to identify a nerve spare plane on each side.</p> <p>To find the correct nerve spare plane, a junction between the nerves and prostate is identified at the base of the prostate.</p> <p>Periprostatic fascia is mobilized bluntly and try to avoid cautery. Sharp dissection is performed here to ensure minimal nerve injury with the use of generous irrigation and improve visibility.</p> <p>Medial traction placed on the prostate around the apex and ensure the nerves are swept away laterally.</p> <p>When the contour of the prostate at the lateral edge is seen, that makes the nerve sparing plane easier.</p> <p>When in a tight nerve spare plane, use a lot sharper dissection and tolerate ooze and bleeding. Tolerate bleeding at this nerve spare plane to avoid damaging nerves.</p> <p>If the lateral identification of the nerve bundle is very difficult may abort or minimize dissection and identify from posterior approach instead.</p> <p>As it gets closer to the apex, sharp cutting is used more and accept that there might be bleeding that would be sewed or clipped later.</p>	<p>Incise the prostatic fascia and move the nerve bundles down and away.</p> <p>Use the bipolar and place it into the plane that separates the bundle down and the prostate up. As long as the prostate is followed closely, it will be a nice nerve sparing plane.</p> <p>Dissecting the distal bundle, close to the prostatic apex is done with cold metz.</p> <p>Once the pedicle is dissected, and the curve of the underside of the prostate is visualized and the neurovascular bundle, cut and perform gentle pushing and dissect the whole nerve cold. Cold cut to avoid neurovascular bundle injury. This could potentially do less damage than the assistant coming in and clipping the nerve.</p> <p>If the majority of the neurovascular bundle vessels are down low, come above those with clips.</p> <p>If the assistants are not looking beyond the tips of clips the end of the clip can catch the next step in the neurovascular bundle.</p> <p>Small clips rather than large clips can hold better and do less damage.</p>	<p>To make the incision, define the lateral prostatic fascia and neurovascular bundle, identify mid-way/halfway up on the prostate to make that initial entreaty.</p> <p>The anterior portion of the nerve dissection can be seen better with pulling the prostate over, down and to the contralateral side of the nerve dissection.</p> <p>Use the 3rd arm and grab the base of the prostate and sharply incise along the lateral prostatic fascia and sweep this downwards to identify the neurovascular bundles.</p> <p>Sharp cutting to release the nerve avoids sweeping into it.</p> <p>When clipping the pedicles, be cognizant not to clip across the entire pedicle and nerve.</p> <p>Bleeding within the neurovascular bundle can cause difficult visualization. If the incision is carried to close to the apex, the nerve would have to be swept off more and this might increase bleeding.</p> <p>The hemostatic stitch throws are backhanded</p>

	<p>When hemostasis is being achieved, avoid any damage or ligation of the neurovascular bundle during this procedure, by pinpointing and selectively controlling bleeders. If bleeding is identified, it is controlled using hem-o-lock clips or suture.</p> <p>Using a stitch can be more accurate than a clip. Pinpoint 3-0 figure of eights along the nerve, instead of using clips that could cross the nerve.</p>	<p>During hemostasis, figure of eight stitches can be more precise and do less damage on the nerve bundles.</p> <p>Take as little surrounding tissue as possible and get the bleeding controlled without tying off the bundle.</p> <p>Cinch the stitch down without being too tense. Do not tent the tissue. Throw the tie flat across, the tissue is not lifting cephalad.</p>	<p>which is easier to get inside and stay away from the nerve and the torque needed to get in the appropriate position. Place the hemostatic sutures inside/ medial to where the nerve tissue is.</p>
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Table 7. Summary of neurovascular bundle spare expert knowledge.

Surgical pearl	Description
Step	<p>Nerve sparing procedure: grab the lateral anterior surface of the prostate or lateral prostatic fascia and identify mid-way/halfway up on the prostate to make that initial entreaty. Bipolar and scissors are used to identify a nerve spare plane on each side.</p> <p>Laterally, all dissection is done sharply to free up the nerves and bluntly move the nerve bundles down and away.</p> <p>Use the bipolar and place it into the plane that separates the bundle down and the prostate up. As long as the prostate is followed closely, it will be a nice nerve sparing plane.</p> <p>To find the correct nerve spare plane, a junction between the nerves and prostate is identified at the base of the prostate.</p> <p>When the contour of the prostate at the lateral edge is seen, that makes the nerve sparing plane easier.</p> <p>If the majority of the neurovascular bundle vessels are down low, come above those with clips.</p> <p>As it gets closer to the apex, sharp cutting is used more and accept that there might be bleeding that would be sewed or clipped later.</p>
Avoidance maneuver	<p>Periprostatic fascia is mobilized bluntly and try to avoid cautery. Sharp dissection is performed here to ensure minimal nerve injury with the use of generous irrigation and improve visibility. When in a tight nerve spare plane, use a lot sharper dissection and tolerate ooze and bleeding. Tolerate bleeding at this nerve spare plane to avoid damaging nerves.</p> <p>Cold cut to avoid neurovascular bundle injury. This could potentially do less damage than the assistant coming in and clipping the nerve.</p>

	<p>When clipping the pedicles, be cognizant not to clip across the entire pedicle and nerve. If the assistants are not looking beyond the tips of clips the end of the clip can catch the next step in the neurovascular bundle.</p> <p>When hemostasis is being achieved, avoid any damage or ligation of the neurovascular bundle during this procedure, by pinpointing and selectively controlling bleeders. If bleeding is identified, it is controlled using hem-o-lock clips or suture.</p> <p>To achieve hemostasis around the bundles, avoid taking too big of bites on the nerve with the stitches.</p> <p>Take as little surrounding tissue as possible and get the bleeding controlled without tying off the bundle.</p>
Technique	<p>Medial traction is placed on the prostate around the apex and ensure the nerves are swept away laterally.</p> <p>The anterior portion of the nerve dissection can be seen better with pulling the prostate over, sometimes with the use of the 3rd arm, down and to the contralateral side of the nerve dissection.</p> <p>If the lateral identification of the nerve bundle is very difficult may abort or minimize dissection and identify from posterior approach instead.</p> <p>Small clips rather than large clips can hold better and do less damage.</p> <p>Using a stitch can be more accurate than a clip. During hemostasis, figure of eight stitches can be more precise and do less damage on the nerve bundles. Cinch the stitch down without being too tense. Do not tent the tissue. Throw the tie flat across, the tissue is not lifting cephalad. Techniques to throwing the hemostatic sutures: do not angulate too much and they should be thrown smoothly.</p> <p>The hemostatic stitch throws are backhanded which is easier to get inside and stay away from the nerve and the torque needed to get in the appropriate position. Place the hemostatic sutures inside/ medial to where the nerve tissue is.</p>

Another potential injury that could occur is an injury to the neurovascular bundle during a nerve sparing procedure. The surgeons acknowledge that this is one of the key functional outcomes important to patients and significant time is spent maintaining these nerves for erectile function if this is amenable for the patient's disease. Techniques that were described to avoid injury included: avoiding cautery laterally during the SV dissection, avoiding cautery during the pedicle dissection, directing the clips placed by the assistant, so as not to clip distal nerve tissue as well as angling the sutures during hemostasis, so as not to incorporate the nerve tissue into the

stitches (Table 5 and 6). As described, several error prevention strategies were employed by the surgeons including the use of landmarks, slowing down during the surgery, and instructing and using their assistant wisely. Without this explicit information, with the learner learning by observing, it could be difficult for learners to understand these scenarios during their training, especially if they are working with expert surgeons. Jentsch et al.'s study of airline pilots describe this concept of observational learning (Jentsch, Bowers, & Salas, 2001). Their study assessed whether pilots recognized targeted behaviours differed based on the level of detailed instructions (Jentsch et al., 2001). They found that with less detailed instruction, pilots produced fewer recognized targeted behaviours (Jentsch et al., 2001). Further, they found that negative behaviours were better recognized than positive behaviours (Jentsch et al., 2001). These results correlate with surgeons' positive behaviours and maneuvers to avoid surgical injury being missed and not identified by the resident learner. Rosen et al.'s review of key instructional features for demonstration-based teaching also supports the above findings (Rosen et al., 2010). Their systematic review of both applied and basic science literature on demonstration-based training found evidence to support the use of both positive and negative performance examples for instructional teaching (Rosen et al., 2010). They also found evidence to support the explicit vocalization of "cognitive aspects of performance" or instructional narrative. Positive and negative surgical examples and explicit instructional narrative are both key points that should be considered for future surgical education curricula (Rosen et al., 2010).

Surgical findings specific to robotic surgery

There are several components of this CTA which are unique in comparison to previous CTAs, as it involves a robotic procedure. This CTA of a robotic prostatectomy includes the

descriptions of how to use the bedside assistant and their involvement in the case, as well as how visual cues compensate and/or substitute for the lack of haptic feedback.

Haptic feedback

Previous CTAs have described open procedures, like the placement of central venous catheters or an open cricothyrotomy (Yates et al., 2012), as well as laparoscopic procedures, like a laparoscopic appendectomy (Smink et al., 2012) or a laparoscopic cholecystectomy (Way et al., 2003). Both types of procedures, both open and traditional laparoscopic, have the advantage of pressure and tactile sensation, or haptic feedback, providing extra information about the tissue and physical steps being done. This could include how the tissue feels, what is the resistance against the procedural instruments, and the amount of force required to perform portions of the procedure. This information is lost in robotic surgery. Urologists described what they “felt” during different parts of the operation without necessarily being conscious of their inability to physically feel the structure. Multiple follow-up questions were needed to define the substitute information or compensatory information the surgeons were using for their loss of haptic feedback. This visual information included descriptions of how tissue moved in relation to surrounding structures or the ease with which a needle would or would not slide through tissue. Key operative evaluations of this visual cue information are constantly being processed by the primary surgeon but not necessarily relayed to the learner. Previous research has echoed this finding, stating that robotic surgery still possesses the challenges of traditional laparoscopic surgery including attention to the peripheral visual fields and avoiding off-screen injuries (Green et al., 2019). The field of urology, as a whole, has limited CTA-based surgical education material to use in their surgical teaching curricula, other than placement of a percutaneous nephrostomy

tube or performance of a partial nephrectomy. Further, none of the current robotic prostatectomy curricula include visual cue information in their educational resources to make up for the loss of haptic feedback because granular CTA information of this robotic surgery has not yet been available (Ahmed et al., 2015; Fisher et al., 2015; Lovegrove et al., 2016).

Bedside assistant

The other novel information obtained by the CTA was the description of the assistant: how the bedside assistant could be used to better progress through the surgery and how to mitigate errors they themselves could cause. This surgical assistant information is different than what has been included in previous surgical CTAs (Pugh et al., 2011; Yates et al., 2012; Yeung et al., 2017b). Small open procedures can be completed without the aid of an assistant, or else a surgical assistant can be used to perform singular tasks, for example applying retraction or cautery. In the event that an assistant is needed more actively, the primary surgeon is in direct contact with their assistant to guide them to what the procedure needs. In a standard laparoscopic operation, the assistant's main role is to hold the laparoscopic camera and not necessarily play a key supporting role, either to retract or aid in the surgical dissection. In robotic surgery, the assistant is actively using suction, placing clips, retracting structures, and aiding with visualization, all of which can either help, or if performed inadequately, hinder the operation. In this CTA of a robotic prostatectomy, the surgeons described how they direct the clip placement for the assistant during the neurovascular bundle dissection, to help the assistant avoid clipping the nerve bundles. The same is true when the surgeons actively direct the clip placement during the pelvic lymph node dissection to avoid clipping the obturator nerve. The assistant can also be used to help actively retract the bowel out of the pelvis during the posterior dissection for better

visualization or put traction on a large bladder during the bladder neck dissection to improve visualization. The concept of using an assistant like a fourth arm, as the primary surgeon has three robotic arms to aid in the operation, is a different concept for learners to adjust to and use to their benefit when learning to perform robotic surgery. This highlights again how standard laparoscopic surgery is different from robotic surgery because the resident is actively directing the field of view with the camera and communicating directly beside the operating surgeon in laparoscopic surgery. These differences and adjustments need to be deliberately and explicitly emphasized for learners using the robotic console and operating as the primary surgeon.

Summary of the CTA results and discussion

In summary, the CTA produced the goals and objectives, landmarks, visual cues and complication and error recognition, prevention, and management of a robotic prostatectomy. It further provided insight into robotic surgery-specific knowledge and expertise, including haptic feedback information and the unique role of the bedside assistant. The data obtained within this thesis is supported by previous surgical, robotic and expertise literature. With this information available, it can be used for the development of robotic educational curricula.

Chapter 5. Conclusion

The aim of this master's thesis was to determine how expert surgeons perform and make surgical decisions during a robotic prostatectomy and how that differs from novices. The topic of expertise in surgery and the implications of harnessing expert knowledge in surgical education was introduced and the foundation for the importance of this topic in the field of robotic surgery was described. Further, the conceptual framework of the thesis was guided by a constructivist approach and theories of expertise including Dreyfus and Dreyfus (1986), Schön (1983) and Bereiter and Scardamalia's (1993) grounded the research methodology.

Knowledge gap survey

The knowledge gap survey demonstrated a clear discordance of robotic prostatectomy surgical understanding and decision-making between urology residents and urologists. Both the rating scale and open-ended questions of the survey showed that the urology residents did not fully appreciate the surgical events that the urology staff were performing or managing. The percent agreement and kappa levels were not in agreement for: assessment of pelvic anatomy, difficulty of seminal vesicle dissection, apical dissection, or difficulty of the vesicourethral anastomosis. There was agreement between resident and staff responses, specifically the bladder neck dissection and lymph node dissection and agreement for the neurovascular bundle spare, if this portion was "easy". These similar responses could be secondary to decreased cognitive load and situational awareness, allowing for visibility of landmarks and larger field of view. There were also several portions where the residents did not perceive or understand certain aspects of the procedure similarly to the primary staff surgeons. These components were grouped as either describing patient anatomy or disease characteristics that consequently lead to difficult exposure,

difficult hemostasis, or difficulty of the overall operation. The disagreement found in the open-ended question component of the survey was described and categorized into categories, including positive versus negative, negative versus positive and cause versus consequence. The interpretation of these categories produced several potential hypotheses for the disconnect in resident knowledge and understanding, including surgical field of view, visual frames of reference, cognitive overload, and situational awareness.

CTA of robotic prostatectomy

The CTA of a robotic prostatectomy documented the cognitive rules, patterns and surgical cues expert surgeons use to avoid errors, compensate for difficult patient anatomy and/or disease, and to manage intraoperative surgical complications. The goals and objectives of the robotic surgery were explicitly stated, and a blueprint of the robotic surgery was outlined, including landmarks, visual cues, and potential complications and/or errors, to successfully complete the operation. Robotic surgery-specific knowledge was also gained including the unique role of the bedside assistant and how they are involved with the operation. The lack of haptic feedback, also a robotic surgery-specific entity, was described, including the visual cues that can be used to compensate for the loss of pressure and tactile sensation.

The CTA of expert surgeons performing robotic prostatectomies is unique for a few reasons. This research is the first time CTA has been used in robotic surgery, as well as the first time this methodology has been used to inform a prostatectomy, open or robotic. The data obtained from the CTA is novel information identifying patterns and cues that expert surgeons use to inform their surgical decision-making. Although the literature has described the steps

needed to complete a robotic prostatectomy, this thesis provides the details for skilled experts to navigate a robotic prostatectomy successfully and safely.

Contributions

This thesis, including the results and interpretation, is unique in that it has combined a conceptual framework based on constructivism and a theoretical framework based on theories of expertise. These views are seldom combined because they reflect different views of truth. For example, the perceptive learning skills, metacognition, and reframing of working knowledge, are demonstrations of the urologists' expertise of the robotic prostatectomy. However, these are unique experiences and information and therefore reflect individual truths of how experts perform a prostatectomy.

A second contribution of this thesis is related to practical contributions to the broader medical education arena. It demonstrates the granular surgical content that can be obtained by this CTA methodology as well as the impact this can have when incorporated into robotic educational curricula, as will be discussed.

Future directions

Currently, this CTA of a robotic prostatectomy is the first CTA of a robotic procedure and aims to have a significant impact on the development and content of not just robotic prostatectomy curricula, but other curricula for teaching other robotic procedures as well. Findings from my research suggests that future robotic curricula should include the discussion of how to use a bedside assistant during robotic surgery, including the problems they can create or

ways they can be better utilized. Curricula should also include the compensatory movements surgeons perform and the substitute visual cue information used for their loss of haptic feedback.

The robotic prostatectomy curriculum proposed would be as follows. As previously stated in Chapter 2, a needs assessment should be done as a baseline for all new educational curricula, and for curricula that are seeking to improve. The knowledge gap survey completed in this thesis, the initial needs assessment, showed what residents knew and what they did not, providing a clear starting point to inform the CTA, as well as educational components that should be included for a robotic curriculum. Inherent to the robotic curriculum is the anatomic knowledge required and procedural steps performed to complete a procedure, which would be included, in tandem with the surgical decision-making rules and knowledge needed to complete this procedure. The synthesis of these elements would describe why and how a surgery is completed.

The robotic prostatectomy curriculum would be developed as electronic modules that describe the basics of prostate anatomy, followed by modules of the steps of a robotic prostatectomy taught with surgical videos and incorporated video animation, highlighting surgical landmarks, patterns, and visual cues. The CTA-based information would be fundamental in the successful development of these modules as this is the pivotal information found by the CTA. The robotic curriculum would also provide modules for challenging surgical scenarios and use the complication and error prevention and management information obtained.

The assessment of the learners accessing the robotic curriculum, both urology residents and urologists continuing their professional development, could be either formative or summative depending on the educational space specific to the individual. The assessments would be at the end of each module summarizing and testing the learning objectives of each module,

including anatomy, goals and objectives, and surgical decision-making. The robotic curriculum would be reviewed, and feedback given from questions posed to the learners at the end of the modules to ensure the content, context, and display variables and level of difficulty are appropriate. The modules may need to be modified by learner skill level, whether that be for a novice learner or urologist in practice, and this can be determined by piloting the robotic curriculum to both learner levels. This framework would also fulfill the curriculum development steps outlined by Thomas et al which, as previously discussed in Chapter 2, include needs assessment, curriculum development, assessment of learners and evaluation of the curriculum (Thomas et al., 2015).

The end product would be a robotic surgery curriculum that incorporates specific needs assessment information, expert surgical decision-making knowledge and detail and modern multimedia advancements available to facilitate robust, up-to-date, robotic surgery learning that adheres to medical education curricular standards.

In addition to curriculum planners, there are several different groups who can use the findings from this thesis, from the individual level and more broadly at the organizational level. The survey results provide information to improve the education goals for the bedside assistant as well as focus the procedural and surgical decision-making goals during console training. These two areas of further training development could be used by urology training programs, robotic surgery curricula, and robotic technology development.

The CTA information can be used by both novice learners and urologists seeking to continue their professional development. The emphasis to inform already practicing urologists is key in that the robotic principles captured by the CTA could be incorporated into teaching this new surgical technique, which differs from the traditional open prostatectomy. This CTA

information can help guide the design of teaching interventions from the introduction of a robotic prostatectomy prior to entering the operating room, to intraoperative teaching, to post-operative review. Pre-operatively, dry-lab simulations and electronic learning modules, as previously described, could not only teach theoretical knowledge, but also teach advanced concepts and the complexities of surgical decision-making. The knowledge from robotic CTA can serve as a resource for intraoperative teaching tools and post-operative review, to solidify a component of the procedure or review trouble-shooting maneuvers with residents. Like previous studies, this research has shown that a CTA method is successful in extracting surgical decision-making knowledge. These findings can not only inform the teaching of the robotic prostatectomy in urology but can also serve as a model for other surgical fields which are designing curricula around robotic surgery. The number of surgical subspecialties that currently use robotics to assist in their surgeries is vast, including general surgery, gynecology, ENT, cardiac surgery, and thoracic surgery to name a few. Several surgical subspecialties are in the stages of developing robotic surgery curricula and could benefit from highlighting these two themes, not only to produce robust educational curricula but also to provide learners with the resources and material to perform robotic surgery safer and more efficiently and with good patient outcomes (Dulan et al., 2012; Fisher et al., 2015).

Future education research could explore whether the instruction of landmark and visual cue information could impact surgical performance and/or surgical decision-making. Other future research endeavours could determine if novice and expert surgeons would want surgical content presented similarly or if they have specific surgical information that would be more relevant to their training level. At this time, neither of these questions have been answered in the literature.

Limitations

There are some limitations to this research. The CTA data was obtained from a single centre with uro-oncologists who have received similar training. There are variations to the technique of a robotic prostatectomy and therefore information or different techniques used at other institutions could have been neglected. Also, all the uro-oncologists interviewed are Canadian and therefore the generalizability of these results to other nations or educational settings in Europe or Asia is in question. That being said, there is not a large variation in the performance of a robotic prostatectomy and as such a significant amount of the educational teachings would be transferrable.

Conclusion

In conclusion, this thesis has shown a gap in resident understanding of a robotic prostatectomy as well as described the key surgical decision-making skills and knowledge experts use to perform a robotic prostatectomy. The elements of cognitive overload, situational awareness and the development of surgical expertise identified in this thesis should be incorporated and be major components of future educational curricula. These findings can now be used to complete previous robotic prostatectomy curricula and will provide a guide for other surgical specialties who wish to design a robotic surgery curriculum in a rigorous manner.

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Appendix A. Pre-CTA Prostatectomy Survey—concordance of operative assessment between residents and staff.

1. How difficult was the operation? Please circle one response.
1= Very easy 4= Moderately difficult
2= Easy 5= Difficult
3= Moderately easy 6= Very difficult

2. What was the most difficult part of the operation? In a few words, please describe below.

3. What was the relative prostate size? Please circle one response:
1= Small 2= Moderate 3= Large

4. What was the pelvic depth? Please circle one response.
1= Shallow 2= Moderately shallow 3= Moderately deep 4= Deep

5. What was the pelvic width? Please circle one response.
1= Wide 2= Moderately wide 3= Moderately Narrow 4= Narrow

6.
 - a. How difficult was the SV dissection? Please circle one response.
1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult
 - b. Describe in a few words what contributed to making this portion easy or difficult.

7.
 - a. How difficult was the posterior dissection off the rectum? Please circle one response.
1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult
 - b. Describe in a few words what contributed to making this portion easy or difficult.

8.
 - a. How difficult was the lymph node dissection? Please circle one response.
1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult
 - b. Describe in a few words what contributed to making this portion easy or difficult.

9.
 - a. How difficult was the apex dissection? Please circle one response.
1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult

b. Describe in a few words what contributed to making this portion easy or difficult.

10.

a. How difficult was the bladder neck dissection? Please circle one response
1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult

b. Describe in a few words what contributed to making this portion easy or difficult.

11.

a. How difficult was the vesicourethral anastomosis? Please circle one response.
1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult

b. Describe in a few words what contributed to making this portion easy or difficult.

12.

a. Were the neurovascular bundles spared:

- i. Yes
- ii. No
- iii. Unsure

If you responded **yes** to question 12. a), which **side(s)** (right, left or both)?

If you responded **yes** to question 12. a), what **percentage** of the neurovascular bundles were spared. Please give a single numerical value, not a range.

Left	%
Right	%

13.

If no nerve sparing occurred, please move to the next question.

a. If nerve sparing was performed, how difficult was it to find the correct plane to nerve spare? Please circle one response.

1= Easy 2= Moderately easy 3= Moderately difficult 4= Difficult

b. Describe in a few words what contributed to making this portion easy or difficult.

14.

a. Was there a delay in progression of completion of the prostatectomy? Please circle one response.

- i. Yes

If you responded **yes** to question 15. a), please describe in a few words **why** the delay in progression of dissection occurred.

- ii. No
- iii. Unsure

15.

- a. Was a capsular incision created? Please circle one response.
 - i. Yes

If you responded **yes** to 15. a), **where** was it made in the prostate? Describe in a few words the reasoning behind your selection.

If you responded **yes** to 15. a), **why** did the capsular incision occur? Describe in a few words the reasoning behind your selection.

-
- ii. No
 - iii. Unsure

16.

- a. Was there more bleeding than expected? Please circle one response.
 - i. Yes
 - ii. No
 - iii. Unsure

If you responded **yes** to 16. a), **where** was there more bleeding than expected? Describe in a few words the reasoning behind your selection.