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FIRST, DO NO HARM:
EXPERTISE AND METACOGNITION IN
LAPAROSCOPIC SURGERY

A dissertation submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

By

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I HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER MY SUPERVISION BY Cynthia O. Dominguez ENTITLED First, Do No Harm: Expertise and Metacognition in Laparoscopic Surgery BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy.

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ABSTRACT

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Minimally invasive surgery is a double-edged sword, presenting both advantages and dangers to a patient. On the one hand, damage to healthy tissue is reduced and recovery periods are shorter. On the other hand, the surgeon is handicapped by degraded perceptual information so that the probability of certain types of errors is increased (e.g., cutting or damaging the common bile duct during laparoscopic cholecystectomy). In challenging cases, surgeons continually assess whether the patient's best interest might be served by converting a laparoscopic case to an open-incision one. Converting widens the scope and quality of perceptual information available, providing hands and eyes with direct access to the operative area. This research focuses on surgical decision making in the context of the decision to convert. A cognitive task analysis effort, involving field observations and a research study, was undertaken to elicit information about decisions made during surgery. Ten experienced (staff) and ten senior resident surgeons were shown videotape from a difficult laparoscopic surgery case. The surgeons responded to structured questions at critical points in the procedure and also provided running commentary as the operation unfolded. Based on their observations, approximately half of the surgeons decided that the case should be converted to an open procedure at some point during the operation. The verbal protocols were analyzed to identify differences as a function of expertise (staff vs. resident) and of the conversion decision (opener vs. nonopener). Staff surgeons made significantly more inferences and predictions from perceptual information and expressed awareness of boundary conditions to safe operation more frequently than resident surgeons interviewed. Further, there was evidence for a lack of situation awareness for the residents who chose not to open. These surgeons showed inappropriately high levels of confidence and showed little evidence of self-criticism (metacognition). The residents who stated they *would* convert this case used self-knowledge to avoid danger, possibly compensating for an acknowledged lack of perceptual expertise. The results are discussed in terms of theories of dynamic decision making, expertise, and metacognition. Preliminary recommendations are made for training surgical decision making.

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1 Introduction

> *In a very real way every time a surgeon operates, he is making book on himself. Besides the enormous amount of theoretic and technical expertise that is his cognitive capital, the surgeon carries in his head an odds-book for each procedure he performs; he knows the mortality and morbidity attached to each procedure he performs; and he is able to revise these odds up or down on the basis of each patient's age and physical condition. . . Because of the nature of the surgeon's risk taking on the patient's behalf, a comprehensive look at surgeons lays bare many social and ethical dilemmas which modern medicine faces. Among these are How is the Hippocratic injunction, "First, do no harm" to be interpreted? What is acceptable risk?* (Bosk, 1979, pp. 30-31)

Day after day, around the world, patients are wheeled into operating rooms for surgical procedures. A multitude of factors influence whether each procedure will be successful; many of those factors hinge on the performance of the surgical team. As a candidate for surgery, the patient has a condition which either cannot or has not been cured by medication, diet, or modification of life style. External tissues must be cut to allow internal access so that a diseased organ may be removed, or some other manipulation may be performed, to return the patient to better health. Each time a surgeon makes an incision and cuts into the internal structures of the patient's body, the delicate balance of the Hippocratic Oath is challenged.

A cornerstone of the medical profession, the Hippocratic Oath originated with the Greek physician Hippocrates in the 5th century BC. In taking this oath, physicians and other medical professionals pledge to work for the good of the patient and to "first, do no harm."[1] A surgeon must typically cut through healthy tissue in order to make the intended removal or repair; cutting through this healthy tissue is a necessary (and easily healed) departure from the "first do no harm" principle, so that the greater goal of the surgical procedure may be accomplished.

In the past 20 or so years, however, medical technology and techniques have been developed which have significantly reduced the damage to healthy tissue required in surgery; as a whole, these advances are known as minimally invasive surgery. Tiny incisions have replaced larger ones, and tubular fiber-optic cameras now provide the means

[1] Leape (1994) attributes the "first, do no harm" interpretation of the Hippocratic Oath to Florence Nightingale in 1863. The Hippocratic Oath also includes prescribing no deadly drugs, keeping medical information confidential, and giving no advice which might cause death.

for viewing the internal structures and for controlling the manipulation of long-stemmed instruments. The "first do no harm" principle has been seemingly maximized by this reduction in incision size; patients are out of the hospital, back on their feet, and back to normal activity within days of a gallbladder removal, since they do not need to wait for incisions in abdominal muscles to heal. With older patients, a quicker recovery can make a critical difference in whether they ever return to full health.

However, as with all complex systems, such seemingly marvelous advances have their cost. The new surgeon/patient interface adds a barrier between the surgeon and the work environment so that essential perceptual information is more difficult to ascertain, and the motor skills required are more technically demanding (Cuschieri, 1995). A side effect of the increased difficulty is that the time in surgery, under anesthetic, may be increased for minimally invasive procedures. When a surgical procedure is especially challenging, involving a patient with unusual anatomical configurations and/or acute inflammation of tissues, these minimally invasive technologies and techniques present a situation where risk of major injury to a nearby structure is increased. The surgeon has to decide which is more important, minimizing tissue damage from the incision *or* minimizing risk of collateral damage to important bodily structures.

The complexity of this decision cannot be overstated. It is not made from evaluating a static set of alternatives at just one point in time; on the contrary, it is extended in time and it involves the integration of changing goals and information from many sources. Assessing risk of unintended injury involves knowledge of one's own capabilities and those of other members of the surgical team. Further, it is clear that there is no normative or "right" decision, and that twenty surgeons might describe twenty differing courses of thought and action in projecting how they would act in the best interests of a specific patient.

1.1 Goals

This research targeted three primary goals which interact with each other, and which follow from the above-described tension between minimizing access trauma and minimizing operative complications. The first goal was to examine the decision to open in a manner which acknowledged the complete context of surgery as much as possible. The second goal was to understand staff-resident differences, in how each group differs in approaching the decision to open as well as how surgeons with different levels of experience overcome perceptual handicaps inherent in laparoscopy. The third goal was to take an exploratory look at surgeons' verbal protocols. As transcript analysis progressed, surgeons' verbalizations and our measures of them pointed to the importance of the concept of metacognition. The goal which has resulted is to understand how metacognition interacts with expertise in laparoscopic surgery. Examining this interaction has led to questioning the concept of metacognition as it is defined in the literature today.

1.2 Brief Methodology Overview

Because Chapter 2 uses some of the results of this research to provide a context to the reader, I will briefly outline the methodology used here. A videotape of a challenging laparoscopic cholecystectomy (gallbladder removal) case was used as a research simulation during interviews with twenty surgeons. Ten of the surgeons had completed residency training, and were on the staff at local area hospitals; they will be referred to as "staff" surgeons. The remaining ten surgeons were in their fourth or fifth year of residency, and will be referred to as residents. Surgeons were asked to role-play as the supervising surgeon on the case shown, and to talk (think aloud) about what they saw and what actions they would take as the case unfolded. At three different points the videotape was stopped and standardized questions (such as "What do you think is going on here?") were asked to gain an elaborated version of the surgeon's situation assessment. Methodology will be described in greater detail in Chapter 4.

1.3 Road Map

It is typically easier to read any document if one knows what to expect. This dissertation does not follow a standard introduction-methods-results-discussion format. There are several reasons for this. First, the research has exploratory aspects which would not fit well into a traditional format, wherein specific hypotheses are developed and tested. Second, understanding this work requires an understanding of the domain of laparoscopic surgery, and hence a chapter is needed to provide this material. And third, the breadth of the psychological concepts examined in this research would result in a lengthy and disjointed literature review. Reviewing relevant literature in the chapters in which corresponding data is presented provides better cohesion and tie-in between literature and findings. To prepare the reader for the organization of this document, and to allow quick reference to specific areas of interest, a road map of this dissertation is presented here.

In the first chapter, I have already provided a brief introduction, specified the goals of this research, and briefly described my methods.

In Chapter 2 the domain of laparoscopic surgery is introduced, using the context of one laparoscopic case which was explored in depth as a part of this research. A description of this patient's case is interspersed with information about gallbladder disease, laparoscopic surgery in general, the surgical team, and the importance of identifying structures. In some instances, quotes and other raw data from the interviews conducted are used to help illustrate the domain. This is intended to give readers both a feel for surgery and a first look at the raw uncoded interview data.

Chapter 3 outlines conceptual and theoretical underpinnings which have been my starting point in undertaking a scientific research effort in a naturalistic domain. Three questions are posed and answered: (1) What is a stimulus? (2) What is a decision? and (3) Where does cognition take place?

Chapter 4 introduces cognitive engineering methodologies in general. I discuss different approaches used to gain background knowledge to conduct this research, and how they are rooted in others' cognitive task analysis approaches. Goals of this research are outlined in a more elaborated manner than in Chapter 1. Finally, issues typically considered when using verbal protocol data are outlined and discussed.

In Chapter 5 the methodology for this research is presented.

Chapters 6, 7, 8, and 9 comprise the heart of this dissertation. Within each of these chapters you will find literature review, theoretical discussion, and findings interweaved. The concepts covered in these chapters are organized so that a progressively more complex view of cognition is revealed, and so that the transitions between chapters (chapter summaries) highlight the nature of the progression. Rule-based thought is the subject of

Chapter 5. Chapter 6 extends a rule-based view of cognition to include other aspects of expertise, such as goals, predictions, and perceptual expertise, which were captured in the interviewed surgeons' verbal protocols. Studies pertaining to goals, predictions, and perceptual expertise are reviewed, and corresponding findings from this research are presented in each of these three areas, so that literature review, findings, and discussion are interspersed three times within this chapter.

Chapter 8 and 9 focus on the concept of metacognition. Metacognition was not a conceptual target when this research began; rather, it emerged from data exploration. Chapter 8 presents an initial literature review on metacognition and how it relates to expertise. How metacognition was operationalized as a measure for our study is reviewed, and a cluster of variables which illustrate possible functions of metacognition for surgeons are presented. The data presented in this chapter is aggregated across surgeons, in contrast to the data in Chapter 9, which is based on individual surgeons' verbal protocols. In Chapter 9 I return to definitions of metacognition in the literature, and question whether monitoring and regulation of self can be separated from monitoring and regulation of the situation. A figure which ties the major variables from this study together under functions of monitoring and regulation is offered, and individual surgeons' verbalizations are presented and analyzed for evidence of monitoring and regulation of self and the situation. Chapter 10 presents a summary, lessons learned, and conclusions.

2 The Domain of Laparoscopic Surgery: One Tough Case

> *Not in the past 100 years has such an upheaval in medicine occurred: The "discipline of surgery" is joining the technologic revolution and advancing the state of the art with laparoscopic surgery. This represents a radical shift in the concept of surgical practice. The "great leap of faith" has occurred; for the first time in history, surgeons are performing surgical procedures without physically seeing or touching the organs they are removing or repairing."* (Satava, 1993, p. 111)

The domain of surgery is an extraordinary one to examine from a cognitive engineering viewpoint. General surgery is an activity system comprised of several interweaving aspects. Knowledge is critical: a surgeon's understanding must include principles of anatomy, physiology, chemistry, pharmacology, and electricity. These principles must be considered in offering treatment, making diagnoses and other decisions under uncertainty and high risk. Perceptual-motor skill is imperative! Surgeons must learn delicate as well as gross motor movements, along with an understanding of the appropriateness of each. Understanding which tools will yield the best results in a particular situation, and how to use them, is a critical part of skill development in surgery. Finally, there is surgical judgment, which involves applying knowledge and skill in a way which provides the best care for the patient. It is surgical judgment that keeps surgeons clear of situations that would overtax their skills and threaten the health of the patient. It is not surprising that a surgeon undergoes five years of residency training beyond medical school in order to be qualified to take state board exams for independent surgical practice.

The confluence of these demands, knowledge, perceptual-motor expertise and judgment, along with the sheer nerve required to cut into another human being's living tissue and the high risk that results, elevate surgeons into the ranks of the world's most respected professionals. Arising from this status, or perhaps contributing to it as well, is another aspect of surgery which must be understood, the aspect of culture. The immense risk and responsibility inherent in surgery go hand in hand with internal control structures which define the culture of surgery (Bosk, 1979). In this chapter, a case will be presented which weaves together these three aspects of knowledge, perceptual-motor skill, and cultural constraints, to illustrate that laparoscopic surgery is a rich opportunity to study situated cognition.

2.1 The Patient's Background

It was clear that the 80 year old woman had an acutely infected gallbladder; the surgeon noted a palpable mass in the gallbladder's location when he physically examined her. She had a two-day history of fever, pain in the right upper quadrant of her abdomen, and a high white blood cell count (leukocytosis). The ultrasound confirmed that she had a distended gallbladder, and also showed that it had a thickened wall and contained gallstones. Pericholecystic fluid, indicating inflammation of gallbladder tissues, was also found. This information is from an actual case, the case which provided the central stimulus for eliciting surgeons' knowledge and judgment in this research. In this section, background information about laparoscopic gallbladder surgery (laparoscopic cholecystectomy) will be presented in the context of this challenging case.

2.2 The Disease Itself.

This woman's disease is not a new one. Gallstone disease has been documented in a case as ancient as 1500 BC (Rubio, 1996), and surgeons have been performing cholecystectomy (removing gallbladders) to alleviate the condition since 1882 (Soper, Stockmann, Dunnegan, & Ashley, 1992). In fact, the operation was even then considered to be relatively low risk, as evidenced by this quote from the *Lancet* in 1885: "Amongst all the many advances which modern abdominal surgery has seen, I claim that there is none so certain, nor so free from risk, nor so brilliantly successful as the surgical treatment of gall-stones." (Tait, 1885) We would then expect the prognosis for our 80 year old woman to be fairly good, over 100 years later. But this case is a complex one, for many reasons. Before getting into those reasons, I will digress to give some background on gallstone disease.

The gallbladder is a part of our biliary system, through which bile is produced and used for various functions in the intestinal tract. Bile is formed in the liver, and is stored and concentrated in the gallbladder for secretion into the duodenum, the first portion of the small intestine, where it helps digest fat. The main components of bile are pigments, cholesterol, and bile salts. Gallstones can be composed of bile pigments or cholesterol, and sometimes from a mixture of both; pigment-only stones are the least common. Cholesterol stones form when there is a deficiency of bile salts in proportion to cholesterol molecules. Although not definitively proven, it is believed that a diet high in cholesterol and low in fiber is a risk factor for these stones. Estrogen is also a factor; older women are more at risk for gallstone disease than any other group (M. Dunn, personal communication, October, 1995). Some cultural groups, such as the Pima Indian tribe of North America, have an extremely high incidence of gallstones in young people, suggesting a genetic predisposition to gallstones (Johnson & Triger, 1987).

Often stones exist for years without causing symptoms. Smaller stones may exit the gallbladder into the ductal structure and the duodenum and pass out of the body. Symptoms indicating gallstones include varying degrees of indigestion (gas and burning discomfort) and intermittent pain in the right upper quadrant of the abdomen (known as biliary colic). If stones do leave the gallbladder, they may travel down the cystic duct to the common bile duct, which connects the liver and the duodenum, causing additional pain and jaundice. When stones are lodged in the cystic duct at the neck of the gallbladder, they may either cause acute infection, leading to an emergency cholecystectomy (gallbladder removal), or chronic inflammation; the former is suspected for our 80 year old woman. Stones at the lower end of the common bile duct can cause pancreatitis by activation of pancreatic digestive enzymes, leading to an even more serious condition.

Although many alternatives to gallbladder removal have been tried, including dissolving stones, fragmenting them, and simply removing the stones from the gallbladder, the symptoms and stones almost invariably return. Cholecystectomy has been shown to be the most reliable cure for relief of symptoms associated with gallstones.

2.3 The Benefits and Drawbacks of Laparoscopic Cholecystectomy.

> *We are training a new generation of surgical residents as "Nintendo" surgeons, adept at the video-assisted operation working in the two-dimensional world of television. Unfortunately, our patients' problems are three dimensional, and often judgment is enhanced by tactile response. Sometimes the real nature of the pathologic findings can be appreciated only by holding tissue between the fingers. (Munson & Sanders, 1994, p. 741)*

Benefits. Patients with gallbladder disease are attracted to the laparoscopic technique because it offers major relief of pain with minimal impact on their lives. The resulting scars are far smaller, less pain is experienced, the hospitalization is very brief (same or next day release, instead of 3-7 days), and return to fully normal activity is on the order of one week, rather than one month for the open procedure (Cooperman, 1992; Cuschieri, 1995). For an 80 year old woman, we were told that laparoscopy would not only lead to a quicker recovery, but it could result in lowered mortality from lung problems such as pneumonia. In general, she would be likely to breathe better, eat sooner, be moving around sooner, and have fewer bladder problems with a laparoscopic procedure.

Drawbacks. Although a laparoscopic procedure can be more beneficial for the patient, the surgeon experiences a far greater challenge with this type of procedure. Depth perception is degraded by the monoscopic image and loss of information from dynamic head movement around the operative area. Tactile sense and force feedback are significantly reduced, degrees of freedom of instrument movement are limited, and vision is restricted to a more narrow field of view[2] (Tendick, Jennings, Tharp, & Stark, 1993). Further, the hand-eye coordination of open surgery is compromised. The surgeon previously looked down a single operative axis (the eye-hand axis) from the eye, through the hands and instruments, into the body cavity (Satava & Ellis, 1993). Now, with the insertion of a camera-TV medium between the surgeon and the patient, the surgeon's "eye," meaning the camera, is displaced from the normal axis of coordination. The surgeon must adapt to the new angular relationships, the partial loss of control over what is seen in the visual field, and the new way of manipulating structures within the space.

When the patient's tissues are acutely inflamed, as they are with the 80 year old woman, differentiating between an actual bodily structure and it's surrounding connective or fatty tissue becomes far more difficult; all of the tissues look and feel the same. Oozing blood from the inflammation further obscures the operative area. During a laparoscopic cholecystectomy procedure (and in other surgery), the structures which have to be identified must be isolated by dissecting away surrounding tissue; when structures cannot be differentiated from connective or fatty tissues, it is far easier to tear these structures apart

[2] Although the field of view is limited, the viewed size of the structures inside the abdomen is increased, and there is a far greater sharing of information about the patient's anatomical condition among the surgical team with laparoscopic procedures. (Graber, Schultz, Pietrafitta, & Hickok, 1993)

in the course of dissection. Another risk inherent in biliary tree operations is injury to the nearby common bile duct. This duct connects the liver and the small intestine; if it is injured or severed accidentally in an 80 year old woman, it is possible that she would not survive the ensuing operation to repair it.

Another risk presented by an acutely inflamed gallbladder is the added operative time needed to clear off blood and identify structures. A difficult acute case may easily take two hours to remove laparoscopically: the same gallbladder taken out in an open procedure might take a half hour to forty-five minutes. The added time under anesthesia and insufflation is more likely to have adverse effects upon older patients, whose pulmonary and circulatory systems are less healthy to start with.

The Learning Curve. Another complication exists due to the fact that practicing general surgeons who finished their residency prior to 1989 have had to learn laparoscopic operating techniques outside of a resident training program. It was only as recently as 1987 that doctors in France pioneered gallbladder removal with the use of a laparoscope. Soon after, in 1988, the technique was introduced in the United States. The laparoscopic cholecystectomy procedure has since become the "gold standard" for treatment of gallstone disease: today, about 500,000 laparoscopic cholecystectomy procedures are performed annually in the US (Dunham & Sackier, 1994). The following editorial graphically illustrates the difficulties and frustration of a general surgeon trying to adapt to the new technology. He concludes:

> "No one could have predicted that here he would be, 56 years old and at the peak of his surgical prowess, grappling with a new technology that was changing the nature of the field right before his eyes . . . he was too young to retire, but he also felt uneasy about being a general surgeon who couldn't remove gallbladders. The question was simple. Was he fit enough to make it up the slope of his next learning curve?" (Gaster, 1993, p.X)

Surgeons have had to climb this learning curve with varying educational opportunities to help.[3] Some institutions authorized practicing surgeons to perform laparoscopy after a short course using inanimate objects (Dunham & Sackier, 1994). The early lack of standardization in credentialling between hospitals has led

[3] In the past, a new procedure slowly gained acceptance through academic research at universities; however, the medical instrument companies were at the forefront of developing both instruments and procedures for laparoscopic cholecystectomy.

to medical societies' stepping in and recommending a series of steps for ensuring better postgraduate training and monitoring.

Before operating on the 80 year old woman, the surgeons involved would meet and discuss possible approaches. Whether to even begin this case laparoscopically is an important consideration, and if it is begun laparoscopically, the issue of whether the case should be converted to a conventional one might surface again and again during the procedure. Converting to an open procedure is the most drastic and certain technique for reducing risk and ensuring correct identification of structures, simply because more information, both tactual and visual, is available to the surgeon. A critical part of a surgeon's decision whether to convert to an open procedure hinges on consideration of his or her capability to continue safely with the laparoscope; this is commonly referred to as comfort level. The phrase, "if you're not comfortable, you should open" was a ubiquitous creed among the surgeons we interviewed. Surgeons seemed to keep running tabs on whether events were beginning to be outside their own limits of knowledge or capability, or comfort level. This self-regulation, which we will refer to as metacognition, is a consistent and significant theme, and is the focus of chapters 8 and 9.

The overall drawbacks and benefits of laparoscopic cholecystectomy for this 80 year old patient have already been discussed. These drawbacks and benefits can be appreciated in light of the overall goals of surgery. Constructing an abstraction hierarchy for a system of surgery (see Rasmussen, 1986) led to identifying the highest level goals for surgery, which are (1) to fix the patient's problem, and (2) minimize collateral injury (i.e., first, do no harm). The second goal can be interpreted in two ways. First, a surgeon might minimize injury required to access the operative area by removing this gallbladder laparoscopically. Second, and in contradiction to the first, a surgeon might minimize potential to cause injury to structures such as the common bile duct by converting to an open procedure, which permits better visualization and tactile feedback. In our 80 year old patient, removing her gallbladder laparoscopically might prevent her death from pneumonia, but might hasten her death if her common bile duct were unknowingly severed. The risks and decisions involved in this case must be weighed carefully.

2.4 The Procedure

By the time this patient has been anesthetized, the surgeon has already decided what general course of action to take at the operating table. However, preoperative information provides only a 'guesstimate' of what might be found in the abdomen. Thus, the early goals of the surgeon are to confirm or deny, or simply revise, the preoperative assessment of action needed for this patient. Other critical objectives are to visualize the important structures in the operative area, identifying them with 100% certainty, before freeing the gallbladder of its connective structures and dissecting it out of its 'bed' in the liver. The two structures which must be visualized and identified in laparoscopic cholecystectomy are the cystic duct and the cystic artery; these structures connect the gallbladder to the biliary tree and its blood supply, respectively.

2.4.1 Preoperatively

All of the twenty surgeons we interviewed were asked about their concerns for this 80 year old patient, whether they would approach the case laparoscopically, and what additional information they would want to have about her. They were primarily concerned that this patient might have gallstones obstructing her common bile duct, or that she might be septic (have disease-bearing bacteria in her blood or tissues). Whether this woman's gallbladder could (or should) be removed laparoscopically was a common concern as well. Two of the twenty surgeons indicated they would not begin this case laparoscopically; all of the others would "at least take a look" with the laparoscope. One of the two was a resident; this surgeon indicated that a laparoscopic procedure would be outside of his competence, as well as that of the average surgeon. He felt that dissection, grasping a thick-walled gallbladder, and finding tissue planes would all be more difficult with this acute case. The other surgeon, who was a staff surgeon, felt that laparoscopic surgery would put too much stress on the pulmonary and cardiac systems of an older patient; it was his experience that sick, old people do better with open procedures.

2.4.1.1 The Rest of the Team.

Surgery is undoubtedly a team effort. It's important to understand who the players forming the functional and social context of the surgeon's environment might be.

The group of surgeons operating might consist of a combination of supervising surgeons (known as 'attending' surgeons) and students or residents; we have observed mostly procedures where one or two residents or medical students are assisting a staff, or attending, surgeon. In a laparoscopic Nissen fundoplication procedure that we watched, three experienced staff surgeons did the procedure together. However, it is possible for a surgeon to complete a laparoscopic cholecystectomy without other surgeons assisting, and one surgeon we interviewed preferred to operate alone, using both hands and a remotely controlled camera. If three surgeons are present, one will hold the camera, one will "assist," by providing retraction, and one will operate, either one-handedly or two-handedly (in the latter case, the second hand operates the infundibular grasper).

Hartwig (1993, p. 58-59) states that "the operating team should include a surgeon, the operating assistant, an anesthesiologist/anesthetist, 1 to 2 scrub nurses, a circulating nurse, and a video specialist." This staffing varies according to availability and local policies. A scrub nurse may also hold the camera or may assist. Normally, the scrub nurse stands directly beside the surgeon and acts as the interface between the equipment table and the surgeon. The circulating nurse performs many different functions, to include ensuring that needed equipment and materials are located where the scrub nurse can reach them; providing an accountability for equipment used; annotating the patient's chart with the surgeon's assessment; and facilitating the operation in numerous other ways. The circulating nurse often must function as video specialist as well.

The other physician in the room is the anesthesiologist. Anesthesia prepares the patient for a surgical procedure, providing what is known as the anesthesia triad: sleep, pain relief, and muscular relaxation (Xiao, 1994).

As to how the surgeons, anesthesiologist, nurses, and other OR personnel all interact with each other, there are as many variations as there are personalities and levels of competency. Xiao (1994, p. 39) states,

> "Historically the surgeon has played a dominant role in the OR, and many surgeons still feel that way today. The interactions between the surgeon and the anesthesiologist have become complex and the rivalry between the two is not always subtle. The impact of social relationships on the way in which the anesthesiologist and the surgeon communicate with each other is an

important determinant of the anesthesiologist's behavior in the OR."

Xiao brings some important points to light. First, the surgeon's personality and style of communication often sets the tone for the work environment. Second is the importance of social relationships. In any job situation, work and social attitudes intermingle. Both surgeons and nurses told me horror stories about surgeons blowing up in the OR, leveling abuses at nurses and/or residents. Some surgeons spoke of trying to be a cheerleader in the operating room, to keep confidence up and attitudes relaxed. One surgeon spoke of the importance of the "theater" of the operating room; whether comfortable or not, the surgeon must *project* a strong sense of being in control, and of confidence in their decisions. It is the surgeon who is ultimately responsible for the patient, and who acts as the interface between the family and the patient. Whether the surgeon sets a tone of tension or relaxation in the operating room is likely to have an effect on the mood, and therefore the performance of the entire surgical team.

We asked the surgeons interviewed about teaching styles during a surgical procedure: for instance, which styles do they prefer, and whether preferred teaching styles change with situations. Not surprisingly, residents all felt they learned better and performed better when the attending did not adopt an accusing, degrading style of teaching. Many of the attendings also felt that raising one's voice served little purpose, and indicated that they purposefully tried to adopt a different, more relaxed style than they had been trained under. In situations where patient safety is at risk, however, surgeons often told of speaking and acting in a more abrupt manner, with more concern in their voice. When the going gets rough, the urgency of the situation and the high stakes involved can be communicated to others in the room through the surgeon's tone of voice.

2.4.1.2 Preoperative Tasks.

Once the patient was anesthetized and prepared for surgery (washed, draped, and positioned), the surgeons insufflated the patient's abdomen, inserted the laparoscope for an initial look around, and then made incisions so that the remaining three ports could be placed.

The purpose of insufflation is to create an airspace for operating in the abdominal cavity; the airspace is called pneumoperitoneum.[4] The abdominal wall is thus lifted from underlying structures. Carbon dioxide gas is typically used; an insufflation machine indicates whether the pressure is appropriate. There are two insufflation techniques. With this acute patient, the surgeons are more likely to use the "open" technique, where an incision is made at the umbilicus (bellybutton) so that the surgeon can use his or her finger to verify that the insufflation point is free from any obstructions. The "open" technique is considered by some to be generally safer than its alternative, inserting a Veress needle into the peritoneum and inflating the abdominal cavity, since it provides more feedback as to whether the proper cavity is being insufflated.

Insufflation placed our 80 year old's organs under pressure; venous return, respiration, and blood flow may have been affected, and even more so for an elderly patient than for a younger one. Along with anesthesia, insufflation is another factor which would cause a surgeon to move this procedure along as rapidly as possible, to minimize time the patient is exposed to this pressure.

Next the surgeon inserted the laparoscope in the umbilical port to survey the anatomy in the operative area. A port comes equipped with a sharp, spring-loaded trocar (pointed shaft) which is inserted through a cannula, or tube-like sheath. The trocar is removed after it punctures the exterior abdominal wall, and the laparoscope is inserted in its place. The surgeons secured the port to the incision with sutures, creating a seal to prevent carbon dioxide from escaping. Three other ports were also placed and secured in the same manner, located roughly in a diagonal line from above the bellybutton port towards the right hip. In general, placement of these incisions and ports depends upon where the surgeon feels a particular individual's biliary anatomy is, and how it can be best accessed. As we will see later, port placement is quite important, since it may or may not afford proper visualization of the back side of an instrument when structures are clipped or cut.

2.4.2 First View

When the laparoscope brought the patient's gallbladder into view, it was immediately clear that this gallbladder was a sick one. The gallbladder was purple, with

[4] *Pneumo* is a Greek word element meaning air or gas; *peritoneum* is the membrane lining the walls of the abdominal and pelvic cavities.

splotches of green and black which could be seen at it's base. The greenish color was referred to as "classic dead tissue." The distension which was apparent in the gallbladder's swollen appearance presented a problem: grasping the gallbladder and retracting it would be impossible without relieving the pressure somehow. An accepted method for dealing with this distension is decompression of the gallbladder, which involves draining the fluid out with a needle. A representative comment:

> "I think that picture should tell someone that the gallbladder doesn't have the same appearance of a smooth clear robin egg blue gallbladder with blood vessels you can see on the wall. Seeing that generates that whole set of information that says this is acute, if I can't decompress it, I can't grab it and I have to open because there is no way to manipulate the gallbladder." (staff surgeon)

The other major concern expressed at this point was concerning the dead tissue on the wall of the gallbladder, and the associated fear that this gallbladder would not afford manipulation, but would break apart, spilling infected bile in the abdomen. Four of ten residents and seven of ten staff surgeons interviewed predicted that the gallbladder wall would tear at this point, but two of these surgeons (one resident, one staff) specifically associated the tearing with spilling of contaminated material which may lead to abscesses in the abdomen. The risk of gallbladder tearing was treated as an acceptable one by some (but not all) surgeons:[5]

> "I know this is going to be very friable tissue, it's going to fall apart very easily in my forceps and it may be very difficult to complete laparoscopically. But this is still one that I would give a fighting chance to, because I know her recovery will be that much more quick, and I can diminish her mortality from things like post-operative lung problems and so on." (staff surgeon)

The alternative, but minority viewpoint:

> "It's going to shred. The gallbladder wall is dying. You're going to find yourself flailing. You're going to pull on the gallbladder to give yourself exposure to the cystic duct, and it's going to tear . . . you have torn the gallbladder, you've exposed their belly to everything the gallbladder has in it, you increase their risk of abdominal infection, increase their risk of a wound infection. The gallbladder is gangrenous, it's probably so adherent to the surrounding tissue that you can easily just cut through something and not even know it, because the surrounding tissues are going to be just that inflamed. And again, the laparoscopic procedure is done to shorten the person's hospital stay. But this person has a sick gallbladder, their concern is not just getting back to work in 6 days, this person could DIE from this

[5] Clearly, this association may have been considered but not verbalized.

disease. Your concern is doing what's best for the patient, not what leaves a minimal scar." (5th year resident surgeon)

Even at this early point in the operation, the conflict as to which approach would inflict less harm on the patient is apparent. The first quote demonstrates that that surgeon feels laparoscopy is best for the patient; the second surgeon feels the potential harm of laparoscopy for this patient outweighs the issue of scarring, which is treated as a cosmetic issue.

2.4.3 Decompressing the Gallbladder

The surgical team introduced a needle to decompress the gallbladder, draining fluid so that it could be more easily grasped and retracted. Watching the gallbladder deform and soften during the decompression provided information about whether the gallbladder was full of stones and about the thickness of the gallbladder wall. Watching this on videotape, surgeons said they would look at the color of the bile as it came out through the clear tube; white bile would indicate that a stone was blocking the cystic duct. Surgeons disagreed on the amount of decompression needed. One opinion was that decompressing all the way would lessen the amount of bile spillage if the gallbladder were to tear later. The opposing view maintained that leaving a bit of bile permitted clearer definition of the gallbladder wall during dissection; a totally floppy bag would be harder to work with. One surgeon indicated that the latter concern only is relevant for an elective (non-acute) case, where spilling infected bile is not a concern.

2.4.4 Initial Dissection and Clipping/Cutting First Structure

Once the gallbladder was drained, the surgeons were able to grasp it and put it on traction; two graspers were used, one pulling on the fundus, or top dome of the gallbladder, and the other providing traction near the neck of the gallbladder. This retraction is necessary to allow exposure to dissect out and identify the two critical structures for this procedure, the cystic duct and the cystic artery. Retraction puts the tissues on tension, so that extraneous tissues may be picked away and promising, tubular-looking structures can be isolated.

When the surgeons began dissecting this area, they found that inflammation of tissues surrounding the neck of the gallbladder made it difficult to tell what might be just fat and what might be a duct or artery. In one observing surgeon's words, "It's a swollen, bloody mess. They can't see anything in there." The inability to define planes between important and unimportant tissue makes for a dangerous situation; a wrong move could injure the common bile duct. Not only did the inflammation create a swollen, uncertain area for dissection, it caused blood to ooze continually, which further obscured visualization. Surgeons observing this situation on videotape cited operative techniques they would use to deal with the uncertainty; the two most common were (1) to begin dissecting closer to the gallbladder, so that work progresses from a known to an unknown area, and (2) to irrigate the area more to wash the blood off.

Another strategy which could have been considered at this point is use of an intraoperative x-ray, called a cholangiogram, to aid in identifying anatomy and help avoid injuries. This is done by injecting contrast (dye) into the biliary system and positioning an x-ray machine over the patient to take the pictures. A nearby monitor would display the image, and the surgical team could then discuss what is revealed by the cholangiogram. Cholangiogram appears to be an accepted method of dealing with uncertainty. Eight of the twenty surgeons who observed this case on videotape indicated they would do a cholangiogram to better identify the anatomy. Unfortunately, when the anatomy is severely inflamed, surgeons may be unable to find the cystic duct, or to insert the catheter tightly enough into the tiny, slippery duct so that the dye can be injected:

> "The other problem with acutes is that it's very difficult to do cholangiograms in this situation because everything is so friable that you can't get a catheter in, and so you eliminate one of your fallback mechanisms to better delineate the anatomy." (staff surgeon)

2.4.5 Isolating and dividing the first structure

The surgeons picked away at tissue for a time, grasping and stripping away bloody clots and strands, and eventually two structures were delineated. One was fairly thick and ran along the top of the operative area; the other was smaller and was located in the foreground. The surgeons turned their attention to the smaller vessel for a time, opening the dissector behind this vessel to separate it from underlying tissue, and very quickly introduced a clip applier. Two clips were applied; it was difficult to make out exactly which structures were included in the clip.

It is common practice to visualize the back tips of clip appliers and scissors when using them, since laparoscopy robs the surgeon of a three-dimensional view, and visualizing the back tip provides a check that the clip (or cut) does not include unintended structures. A few surgeons who observed the first clip being applied not only noted the difficulty of visualizing the tips, but traced the source of this difficulty to the original placement of incisions in the patient's abdomen:

> "See now, this suboptimal visualization of the staple as they are applying it. You can't see the tips, you need to see both tips. So you know exactly where your staple is going. One problem is the angle at which the scope is being held, . . . and perhaps the location of the upper gastric port was inappropriate." (staff surgeon)

Scissors were introduced after the clip appliers were removed: the small structure was then cut. What was this structure? Surgeons viewing the videotape varied in their assessment. The fact that only one clip was applied to the end of the structure which would remain in the patient's body led some observers to conclude that the operating surgeons felt this structure was unimportant, but had clipped and cut it just to be safe. An accepted method, or common practice, is to apply two clips on the patient's side of the cystic duct and cystic artery, for insurance against clips slipping off or otherwise failing. Five surgeons interviewed said they would have used an additional clip in this situation. The identity of this first structure never actually became clear. In light of later events in this case, we have assumed that it was probably a lymphatic vessel (part of the lymphatic system), which if cut unintentionally would have no harmful result.

Next a dissector was introduced again, and the surgeon worked to pull away extraneous tissue behind where the first structure had been cut. The area near the larger structure was dissected for awhile; the dissector was placed into the tissues at the proximal end of this structure (away from the gallbladder wall being retracted), and tissues were stripped away. These movements caused concern for several observing surgeons, who felt this area was too close for comfort to where the common bile duct should be.

2.4.6 The Gallbladder Tears Open

Off to the left side of the picture, the gallbladder suddenly burst open and bile flowed out; the camera quickly centered on this rupture. The camera also showed a grasper holding a chunk of tissue, but unattached to any structure; it is likely that the gallbladder's tear occurred where this grasper was retracting the gallbladder. Surgeons typically reacted as though the gallbladder tearing was an expected event, requiring thorough irrigation and suction but eliciting little change in overall approach. This spillage of bile provided an opportunity for the surgeons observing the videotape to evaluate the bile: a wide range of comments were made about its color (golden vs. white or purulent) and its consistency (fluid vs. mucoid gobs), as they assessed whether the bile was infected. Most surgeons concluded that this bile was likely to be infected. A suction/irrigator was brought into the abdomen to rinse and clean out the spilled material.

2.4.7 Isolating and Dividing the Second Structure

The second structure, the large one earlier mentioned at the top of the operative area, was isolated next, and clip appliers were brought in to apply three clips. One clip was used on the gallbladder side of the vessel, and two were applied on the proximal side (the side which remains in the patient's body, therefore proximal to the patient). The surgeons introduced scissors and severed this structure.

2.4.8 Isolating and Dividing the Last Structure

Dissectors were brought back in, and the tissue just behind the previous structure cut was stripped away; the field was very bloody at this point. Just beside where the dissectors were working, the double-clipped stump of the previous structure could be seen. After a few seconds, this structure began to pulsate, indicating that this was a blood vessel, probably the cystic artery. This pulsating stump remained in the visual field for 30 seconds or so; about half of the surgeons (six staff and three residents) who watched this case on videotape noted the pulsation. Some more material was then stripped away so that a single strand of tissue, of unknown significance, was all that remained connecting the gallbladder and the biliary tree.

The operating surgeons washed the last strand off with the irrigator, and then pulled at different parts of the strand with a dissector, trying to see what it was. They poked into the tissue a little bit more, and then brought the clip applier in, apparently satisfied that this structure did need to be clipped and cut. The first clip was applied. The surgeons then poked around a bit with the clip applier; although it was not often noticed, one portion of the gallbladder end of the structure now looked like opaque tissue.

At this point, the videotape skips over the remaining dissection of the gallbladder out of the liver bed; the next event shown is a drain being placed in the operative area. A drain is a means for monitoring whether there is any post-operative leakage of blood or bile, a temporary passageway from the abdomen to outside bandages.

2.4.8.1 Cognitive Aside: Identification with Certainty

Earlier I mentioned that surgeons need to identify the cystic duct and artery with 100% certainty. Although identification is an action-oriented, exploratory perceptual process, there is also a strong decision element; surgeons vary widely as to when they would state that a duct has been identified with 100% certainty. Surgeons recognize the subjectiveness of this judgment: three different surgeons we talked to offered this same general wisdom: "You need to believe what you see, and not see what you believe." Identification is complicated by the fact that the biliary system has a high incidence of unusual anatomy. Often structures have additional branches or loops which can be mistakenly identified. When structures are not accurately identified, the common bile duct may be clipped and cut rather than the cystic duct. This is probably the most severe injury which can result from a laparoscopic cholecystectomy, since this ancillary damage requires further surgical interventions (normally with open procedures) and the damage can have long ranging negative effects on the patient's health and well-being. Since the cystic duct flows into the common bile duct, surgeons take great pains to dissect as close to the gallbladder and as far from the common bile duct area as possible.

At this point in the procedure, two structures had been clipped and cut; now a third structure became evident. The surgeon faced uncertainty as to what was cut and what this last structure was. If the surgeon hasn't seen the pulsation of the artery, even more uncertainty was present. It was at this point in the operation that the greatest number of "I would just open..." statements were generated by surgeons thinking aloud while watching the videotape. Added to the uncertainty over identification and the possibility of unusual anatomy was concern that the actions taken previously had accidentally injured the common bile duct, since the tissue was inflamed and because it had been difficult to see the tips of the clip appliers and scissors.

2.4.9 Separating the Gallbladder from the Liver and Removing It

The videotape of our 80 year old's laparoscopic cholecystectomy ended with the clipping of the third and last structure, since we were primarily interested in identification processes. The remaining actions taken to remove a gallbladder will be described generically. The gallbladder is typically attached to the liver via avascular tissue (avascular means without blood vessels). While traction is applied by pulling the gallbladder up and away from the interface plane, the surgeon teases the gallbladder out of its liver bed with scissors or a spatula, often employing electrocautery. As this separation proceeds, the grasping instruments are repositioned to keep the gallbladder on optimal traction. If a hole is made in the gallbladder during this procedure, one of the graspers can be placed on the hole to prevent bile leakage into the abdomen. The surgeons are also careful not to damage the liver, since it is highly vascular and bleeding can result.

Once the gallbladder is separated from the patient's body, it is grasped and pulled into the largest port (typically the umbilical, or camera port) until resistance is met. If the camera port is used for removal, the laparoscope will be removed and inserted into another port, and the surgeons now view the abdomen from a different perspective.[6] When the gallbladder cannot be pulled any further into the port, the entire port is pulled from the body, and the gallbladder slips through the incision after the sheath holding it. If large stones make the gallbladder too large to fit, the incision may need to be widened (Cooperman, 1992). The abdominal area is then irrigated with saline and surveyed to make sure no problematic bleeding or bile leakage is left. A drain may be placed, as it was in this patient, if future leakage is anticipated. The incisions may be injected with a local anesthetic, such as bupivacaine, and are then closed with sutures (Cooperman, 1992).

[6] The new camera view results in a break in the coupling between the view and the space; Holden & Flach (1996) have studied the implications of such breaks in coupling.

2.5 Summary

Laparoscopic surgery may be viewed as a process by which surgeons act to remedy the patient's problem with as little collateral damage as possible; staying within a field of safe operation is one way to view the interaction between surgeon and the constraints of the system. As the surgeons we interviewed demonstrated, there is no one right way to accomplish a given operation; there are many trajectories which may be taken within a field of safe operation, and a surgeon proceeds according to individual experience and comfort level. It therefore may be more important to understand whether a surgeon's actions are well calibrated to their level of experience than to assess whether an action is 'correct.' This idea of calibration was expressed in the oft-repeated saying mentioned earlier, "if you're not comfortable, you should open." In other words, listen to your own assessment of risk, and know your own abilities.

Although residents are clearly taught these words, the culture of surgeons may not necessarily encourage acting upon them. Our interview transcripts suggested that there is a psychological pull towards trying to complete a procedure laparoscopically once it is begun. Also, it takes time for a surgeon to learn to recognize a dangerous situation, and to associate feelings of discomfort with such a situation. Another way to look at the problem is as a conflict between wanting to learn to handle dangerous situations one the one hand, and the responsibility to ask for help on the other. This conflict is akin to the dilemma Bosk (1978) discusses, whereby residents in surgery are told that under no circumstances should an attending be surprised when they come in to check on their patients. "The covering law for all behavior is, simply stated, 'no surprises.' Superordinates expect their subordinates to inform them of all changes, however small, in the service's status." (Bosk, 1978, p. 51) This conflicts with internal pressure to handle situations and learn from them:

> "The way you learn as an intern is by being put on the spot and coming through it. You develop a self-awareness that you can handle a lot of situations. The problem is learning what situations you can't handle. There's a lot of pressure not to ask, a lot of fear of appearing foolish." (Intern; Bosk, 1978, p. 53)

This quote gets at the heart of the dilemma. Surgeons are indoctrinated as residents to learn to make decisions and take action. Although Bosk's example refers to managing patients on a ward, the same difficulty of learning what you can't handle, in a culture where you are trying to learn to handle things, exists at the operating table, and not just for residents, but for all surgeons struggling with the decision to open a case.

The conflicting goals considered when a surgeon must decide whether laparoscopy or open surgery is best for the patient are undoubtedly influenced by psychological and cultural factors. An editorial by Greene (1995, p. 11) captures how surgeons see this dilemma:

> "The urge to follow through with an endoscopic approach may be so strong that judgment becomes clouded and the timing of the conversion process is, therefore, delayed until an untoward event has occurred (knowingly or unknowingly!). We all recognize that the oft-used phrase "to convert is not a complication, but represents good judgment" is indeed our standard, but in the "heat" of the OR, some forget this admonition because of ego, machismo, or some other inherent intangible in the psyche."

Thus, the desire to complete a procedure laparoscopically may cloud a surgeon's judgment. Some surgeons we interviewed referred to the stereotype of a "laparoscopic cowboy," who would persist laparoscopically when opening is indicated. However, the range of factors which determines a surgeon's proclivity to opening a case includes not only ego but experience, success with previous difficult cases, and perceived ability to proceed safely. The variability in what is thought to be a safe course of action for twenty different surgeons reviewing this same tough case clearly indicated that deciding to open is not a simple issue at all.

3 Theoretical Considerations: How to Approach the Scientific Study of a Real-World Domain

I have presented an example case to illustrate that laparoscopic surgery is a domain in which we can study cognition in all its complexity. It is important to ask at this point, why should we study laparoscopic surgery in a particular way? In this chapter, I will review theoretical considerations which have influenced the conduct of this research. These considerations are akin to the "Formal Concepts" which Sanderson & Fisher (1994) present as the driving force in their model of the exploratory sequential data analysis process. Formal concepts determine what issues are of interest, along with the level of abstraction which is acceptable when deciding how to collect and analyze data. In other words, here I will make explicit the psychological theory which has defined the questions of interest for this research. I will address three basic questions with respect to research in laparoscopic surgery:

1. What is a stimulus?
2. What is a decision?
3. Where does cognition take place?

3.1 What is a Stimulus?

> *We should try to discover what an organism is responding* to, *not what excites all the little receptors. (Gibson, 1960, p. 344)*

I would ask this question in two different types of settings. First, what is a stimulus in a laboratory experiment? Second, what is a stimulus in everyday experience? In a laboratory experiment, the key element is control. An investigator controls factors which might influence behavior, varies a stimulus of interest, and measures the behavior, or response, in an appropriate way. Hence we are able to make associations or even sometimes infer cause-effect relationships between stimuli and responses. John B. Watson's *Psychology from the Standpoint of a Behaviorist,* written in 1919, presents the entire goal of Psychology as predicting a response, given a stimulus, and specifying the stimulus, given the response. Watson hypothesized that all behavior could be reduced to stimulus-response cause and effect relationships, and he made a lucrative career in the advertising business with this belief in hand (Hergenhahn, 1986). Watson obviously did not confine the concept of the stimulus to the laboratory.

Did Watson have a basis for believing that stimulus and response are coupled as cause and effect in everyday experience? Certainly it is. We feel thirsty, and get up to get ourselves some water. An infant cries in the night, and we get up to feed it. A special on Christmas lights is advertised to our liking, and we buy them. However, this is only a part of everyday experience. Our lives do not consist of reactions alone. We set goals for the day (as Miller, Galanter, & Pribram, 1960 describe); we intentionally plan to acquire information and write a paper with it, we seek out people who can help us, we make prioritized lists of things which must be accomplished. The same is true for surgery. What might be called a stimulus-response coupling, such as a surgeon responding to a distended and gangrenous gallbladder by aspirating bile from it to release tension, is only a small part of the picture. Perception and action are tightly coupled. A surgeon might see a structure which looks like the cystic artery. He or she will tease away at the surrounding tissues, and will observe the structure while rotating it back and forth. What is seen and felt during this activity either supports or disconfirms an identification of the cystic artery, or compels the surgeon to continue dissecting to get a better look. These structures could not be identified merely by observing them, motionless, through a laparoscope; the active nature of information acquisition is integral to the surgeon's work.

I recently considered the second question, what is a stimulus in everyday experience, while taking a run around campus. I first turned my attention outwards and looked to see what stimuli might be around (and within) me. I could see and hear and feel a multitude of things: bugs, grass, trees, cars driving past, the pavement under my feet, the sunshine, a distant horizon, a low-flying cargo jet, birds singing, and on and on. The number of perceivable details seemed only limited by the time I had to attend to them all. As William James (1898, Vol I, p. 402) wrote, concerning the active nature of attention, "My experience is what I agree to attend to. Only those items which I *notice* shape my mind--without selective interest, experience is an utter chaos." When running, very few of these "stimuli" around me required a response; however, on rough gravel, it was necessary to seek out places to plant my feet to avoid twisting an ankle. In order to meet my goal of running without injury, I needed to attend to the gravel.

On a smooth stretch of pavement, I then turned my attention inwards, to my thoughts. It was very easy to tune out all of the objects and events around me and function in an "alert" status, merely watching and listening for cars and loosely monitoring for bodily fatigue or pain which might crop up. I could run for five minutes with very little recollection of where I had just been. Through this exercise, I learned that I could actively perceive my surroundings or tune them out to focus on thoughts: the driving force behind my behavior was intentionality. I could reach out and embrace all of the information available in my surroundings, or could simply turn inward and react to threats.

Stimulation which is present in laparoscopic surgery *is* the stimulation present in the surgeon's everyday experience, and hence has characteristics more in common with running outdoors than with a controlled laboratory experiment. Identifying cause-effect relationships in surgery would thus be inadequate to characterize cognition on (at least) three counts. First, as already discussed, the relationship between perception and action in surgery is far more often circular than linear; as rough gravel required active attention to avoid injury, so do surgeons also actively seek out a "field of safe travel" to fulfill their goals (Gibson & Crooks, 1938). Gibson (1966) has repeatedly emphasized this active nature of obtaining stimulation, as has Neisser (1976) in his model of the perceptual cycle. Second, intentionality and goals of the surgeon determine what information is sought; a stimulus-response portrayal of an operative procedure would exclude intentionality and goals, because it assumes we only react to stimuli, rather than anticipate. Third, information exists in an operative space which is not always perceived or understood, and a surgeon can compensate for lessened perceptual information by adopting a conservative policy (such as converting to an open procedure). Thus, many acceptable, safe paths may be taken to achieve the same goal in surgery, and often there is no "correct" link between stimulus and response.

Consider the possibility that a "field of safe travel" within an operative space actually *is* the relevant "stimulus" which surgeons seek. This idea blends together the three points above which reject a stimulus-response thought process for surgery. Surgeons apply their goals and intentions to seek out information regarding the identification of structures, while applying techniques for keeping to a path which is comfortably safe, given their individual experience and training. Constructing an abstraction hierarchy for a system of surgery (see Rasmussen, 1986) led to identifying the highest level goals for surgery as (1) to fix the patient's problem, and (2) minimize collateral injury (i.e., first do no harm). The invasiveness of surgery and the risks involved, as well as evidence from our research, suggest that surgeons consider these goals and actively work to stay within a field of safe travel in surgical practice.

3.1.1 The Field of Safe Travel

The concept of a field of safe travel originates from research on automobile driving by Gibson & Crooks (1938). Gibson & Crooks suggested that at any moment, there is a space before the driver in which the car may move without hitting anything. The driver *may or may not be aware of this field*; the field exists regardless. Likewise, a surgeon needs to know what course of action would have dangerous consequences, and what course would be safe. A surgeon must learn the particular safe areas of each patient's operative space. The safe area for surgery might be defined by, and constrained by, dimensions of (1) physical location, (2) affordances of the structures and tissues, and (3) hidden dangers.

Physical location boundaries are important in a laparoscopic cholecystectomy procedure in that the surgeon wants to operate only on the gallbladder and its connective tissues and structures. Great pains are taken to avoid physical contact with the nearby common bile duct and the hepatic ducts, as well as any nearby loops of bowel, since injury to these seriously impacts the patient's health, and since repairing these injuries may require conversion to an open procedure. Thus, the surgeon wants to dissect and operate only in a limited physical area. Keeping to this safe area may be complicated by anomalous anatomy, which is fairly common in the biliary tree, and by the fact that inflammation of the gallbladder can cause bowel or hepatic ducts to become adherent to the gallbladder area and distort the appearance of structures. Careful dissection is done to ensure that the structures are what they seem to be. Surgeons learn techniques for determining whether their location is within the field of safe operating. Some of these techniques involve rules, like following a structure all along its length to where it meets another structure, or beginning dissection as close to the gallbladder as possible, or knowing that green spots on tissue mean that it is dead. Some involve methods of manipulating the tissue so that three dimensions can be perceived. Some involve merely consulting another surgeon, and making sure both agree that a structure is what it seems to be.

Affordances of tissues must be sensed and understood as another critical component of a safe field of operating. Affordances refer to action constraints, whether something in the environment would support or afford a desired action, for example whether the gallbladder wall affords retraction without falling apart.[7] These boundaries involve an interaction between choice of instrument and degree of force the surgeon exerts. A surgeon tears and manipulates tissue in the operative area in many parts of a laparoscopic cholecystectomy: adhesions are cut or torn away, the gallbladder is grasped for retraction, peritoneal tissue is stripped away so that the vital structures may be seen and identified, and the tissue connecting the gallbladder to the liver must be cut or cauterized apart. To remove the tissue which covers the area where the cystic duct and cystic artery join the gallbladder, tension is placed on that tissue by another instrument grasping and pulling the gallbladder in the opposite direction. The surgeon then may take "bites" at the covering tissue, grasping and ripping it away. Alternatively, a closed grasper may be inserted into the tissue and then opened to widen an opening in the connective tissue.

This tissue can require varying degrees of force and precision. If the area is extremely inflamed, as it was with our 80-year-old patient, the duct and artery are vulnerable to being torn apart with the surrounding tissue. The thickness of the gallbladder wall may require a larger, perhaps toothed grasper for effective grasping. Surgeons use what the tissue looks like and how the tissue responds to exploratory manipulation to perceive the actions required to achieve their goal. As they gain experience, implications of visual and tactile cues become more apparent, and a wider working knowledge of tools available is gained. Thus, a surgeon learns over time to assess the boundaries and to utilize tools that work within the boundaries of tissue affordances.

A third dimension of the field of safe operating is appreciation of hidden dangers.

[7] Affordance was suggested by Gibson (1979) as a construct to show how the coupling of an individual actor and a physical system results in certain potential for action. A frozen lake might afford walking for a child, but not for an adult. The affordance exists in relation to the actor, whether the actor is aware of it or not.

This appreciation comes from being burned by these hidden dangers in the past, or from learning vicariously through someone else's mistakes. An example is blood vessels inside an adhesion, which may rupture and bleed when the adhesion is grasped and pulled down. An adhesed loop of bowel is another hidden danger which may be injured when an adhesion is torn down. Hidden dangers often would be made explicit if the operation were an open, large-incision procedure, affording direct 3-D vision and tactile feedback. We hypothesize that surgeons who have had extensive experience with open procedures, before laparoscopy became the standard mode of removing gallbladders, are more cognizant of the hidden dangers, since they have more frequently seen and appreciated the fully exposed space which can only be constructed piecemeal through a laparoscope.

Staying within the safe physical boundaries, applying force through appropriate instruments so as to minimize injury to healthy tissue, and appreciating hidden dangers all involve prediction of what injury might result from straying outside of the field of safe operation. This knowledge is weighed carefully when a surgeon evaluates whether to convert a laparoscopic procedure to an open one. What might occur if a particular action is taken? Sometimes the implications are immediate, as when a torn artery bleeds massively, and sometimes the implications are only seen when the patient returns five days after surgery with an injured common bile duct.

The field of safe travel is consistent with a concept of stimulus *information* for surgery. The stimulus information concept was Gibson's way of expressing that there is meaning inherent in the environmental invariants which convey affordances, or potential for action. This concept is distinguished from stimulus energy, which is reserved for the one-stimulus-to-one-receptor concept underlying many basic perception studies (Gibson, 1960; 1972). As Gibson stated, "What is useful is the conception of a structured *array* of ambient light (or an array of contacts, vibrations, or substances), [which] is entirely different from the notion of stimuli that impinge on receptors. Information about the environment consists of the invariants of structure in a continuous flow. . . The array *consists* of contrasts and transitions, not of stimuli, and not of groups, patterns, or series of stimuli." (Gibson, 1972, p. 349) Thus, the field of safe travel in surgery *is* an array of information which has meaning derived from the context of the procedure and the surgeons' own experiences.

3.2 What is a Decision?

There are many varieties of decisions, as there are varieties of research paradigms which have been developed to study decision making, judgment, choice, and problem solving. I will briefly discuss some of these paradigms as well as the characteristics which distinguish different types of decisions, and then present a definition of a decision to guide the reader in understanding how decisions are treated in this research.

3.2.1 An Evolution of Paradigms

Decision theory has evolved in many ways over the past half-century. A large body of research, sometimes referred to as classical decision theory (Beach & Lipshitz, 1993), originated with economic game theory (von Neumann & Morgenstern, 1947). Utility theory, subjective expected utility theory (Savage, 1954), and multi-attribute utility theory (Raiffa, 1968) all contributed to an expectation that a rational being should ideally make decisions according to values (or utilities) placed on outcomes, and according to statistical properties inherent in situations (such as prior probabilities of occurrence, as with Bayes' Theorem). This classical decision theory is often referred to as normative, or prescriptive decision theory, since it prescribes methods, or 'norms' for rational thought. The field of Decision Analysis (von Winterfeldt & Edwards, 1986; Weinstein & Fineberg, 1980) has evolved to provide tools which help humans (managers, physicians, and others) make decisions which conform to the normative calculations of utility theory. Under another large paradigm, Behavioral Decision Research, researchers have tested whether normative theories of judgment and choice are adequate to describe human decision behavior (see Payne, Bettman, & Johnson, 1992).

Researchers from economics, operations research, management, and psychology have struggled to make sense out of a consensus from behavioral decision research that there is a disconnect between how people make decisions and how the theories prescribe they should. Beach & Lipshitz (1993) describe four different responses scientists have made to this disconnect. First, some continue to embrace the normative theory, rejecting human behavior as flawed and irrational. The second response, exemplified by decision analysis and decision aids, is to continue to embrace the theory while attempting to teach humans to think as the theory prescribes. Third, some authors "retain the general logic and structure of classical theory but ... make modifications of some of the theory's components and operations in light of the research findings" (Beach & Lipshitz, 1993, p. 23). A fourth and final response is to get beyond classical theory and take a look at how people, both individually and as teams, make decisions in real-world contexts. Beach & Lipshitz (1993, p. 29) present a convincing argument that striving to understand why subjects in decision making studies fail to "live up to" behavior specified in normative theories is heading down the wrong path: "The strong suspicion is that classical theory does not provide the conceptual depth that is needed to deal with real-world complexity; in some ways people seem far more capable than the theory." Complex, dynamic work environments are typical of those studied under a naturalistic decision making paradigm, which this fourth response has been called. A key feature is that the complexity of problems and time stresses often lead decision makers in these work settings to select the first option considered which will accomplish the goals, rather than engaging in a utility-based search for the very best option. This is the 'satisficing' concept introduced by Herbert Simon (1955).

3.2.2 The Naturalistic Decision Making Paradigm

There are some important distinctions to be made concerning how research under the naturalistic decision making paradigm is conducted. One is whether the question studied in the research is defined by the investigator or by the domain (Orasanu & Connolly, 1993). This question carries with it the implication of expertise, since if the researcher defines a question about which participants have no prior knowledge or tools for understanding, the research is unlikely to find out anything about how people make decisions in a working environment with which they are familiar. Rather than testing whether ordinary people find problems of Bayesian inference to be intuitive, a decision which is relevant to understanding cognitive processes in a complex work setting can be defined and studied.

A second important question is what temporal assumptions are made about decision making in a research investigation: is decision making considered to be an event or a process? Medical diagnosis research often uses a methodology of presenting cases on paper for physicians of varying backgrounds or experience level to diagnose (cf. Patel & Groen, 1991). Patient management, however, is typically extended in time, with several exploratory and collaborative steps taken before diagnosis is reached, if it is at all (Rasmussen, Pejtersen, & Goodstein, 1994; Shalin & Bertram, in press). As Rasmussen et al. (1994, p. 113) state, "in normal work contexts, decision making is not usually an effort to resolve separate conflicts, but is more like a continuous activity to control a continuously changing state of affairs in the work environment."

In fact, Orasanu & Connolly (1993) discuss how a focus on decision making as a *decision event* in the hundreds of articles and books which have been published on the subject is the reason why I can find little generalizable, helpful guidance there when attempting to understand decisions in laparoscopic surgery and other complex environments.[8] They also contend that "decision performance in everyday situations is a joint function of two factors: (1) *features of the task,* and (2) the subject's *knowledge and experience* related to the task" (Orasanu & Connolly, 1993, p. 7). In surgery, task features change as new procedures are developed and new tools are introduced, so that physicians' knowledge must be constantly updated. Expertise in general surgery has become a moving target.

Regardless of how features of the task change with new procedures introduced in surgery, the characteristics of *any* surgical procedure are by definition far different than those of an "event-oriented" research investigation. The eight factors which Orasanu & Connolly (1993) discuss as characteristic of decision making in naturalistic settings are all relevant to laparoscopic surgery. **First**, problems are ill-structured. In other words, nobody presents a surgeon with a well-organized package defining the options and their potential outcomes. **Second**, the environment is uncertain and dynamic, or changing. The surgeon attempts to add as much certainty to the identification of structures as he or she

[8] Many authors acknowledge the importance of task context, and sometimes decision maker characteristics (cf. Kleinmuntz, 1985; Beach & Mitchell, 1978; Payne, Bettman, & Johnson, 1988 & 1992). However, these characteristics are operationalized in terms which fit the investigator's classification of their chosen tasks and non-expert subjects. Hammond, Hamm, Grassia & Pearson (1987) provide an example of how task and decision maker characteristics can be studied within a context in which subjects are experienced.

can, but often uncertainty remains. A gallbladder may or may not tear open in response to the tension placed on it. **Third**, there are shifting, ill-defined, or competing goals. This concept has been discussed at length in the decision to open, namely whether the goal of minimizing damage to abdominal muscles or the goal of doing no harm to structures near the biliary tree takes precedence. **Fourth**, action/feedback loops characterize decision making. Again, the decision to open is not a single event, but a series of purposeful actions which are taken to pick up relevant information, as Gibson describes (1979/1986). **Fifth**, there is time stress. Will this elderly patient be able to withstand anesthesia and insufflation stresses on her systems for the time it will take to laparoscopically remove her gallbladder? **Sixth**, the stakes are high, involving life and death. **Seventh**, there are multiple players involved. Capabilities of the assisting surgeon, the anesthesiologist's input, and whether the radiology group can provide support for an intraoperative cholangiogram all may impact decisions. Finally, the **eighth** characteristic is that organizational goals and norms must be considered, on several hierarchical levels. The surgical service, the hospital or corporation, and the culture of surgeons dictate policies which must be heeded. For instance, a hospital may schedule procedures with a particular lag time, and may impose time pressures over and above those involved with patient health.

I have reviewed these eight characteristics to show how the decision to open, as well as other decisions in laparoscopic surgery require methodological and conceptual tools which are best found under a naturalistic decision making paradigm. Methodological tools will be discussed in the next chapter. Next I will discuss conceptual tools which are appropriate for this type of research.

3.2.3 Tools for Representing Many Forms of Decisions

A common theme which emerges from a review of naturalistic decision making models, as well as from reviewing past literature on judgment and decision making, is that there are many forms of decision (Lipshitz, 1993). I have reviewed some of them briefly: there are gambles, choices between two or more alternatives, judgment calls, statistical assessments, preferences, diagnoses, and combinations of these. Some are singular events, some are embedded in a process of understanding a situation.[9] Rasmussen and his colleagues (Rasmussen, 1983, 1986; Rasmussen et al, 1994) have developed conceptual tools and representations upon which many types of decision processes can be overlaid. This research has been conducted to understand decision processes of humans who are controlling complex, sometimes automated processes such as nuclear power plants, electronic troubleshooting, and ferryboat operation.

In particular, the combination of Rasmussen's (1976) decision ladder representation and skills-rules-knowledge framework for understanding cognitive control (Rasmussen, 1983) can illustrate both the diversity of decision tasks and the ways in which people respond given their familiarity with the situation (i.e., the two factors which Orasanu & Connolly (1993, p. 7) cite as determining everyday decision performance, features of the task, and the person's knowledge and experience related to the task).

Rasmussen originally described the decision ladder in 1976, as he was trying to make sense out of verbal protocols collected from process control (power plant) operators. This decision ladder is shown in Figure 3.1. The most intuitive description of this model is to consider it as an information processing model with the two ends folded together. Rasmussen's (1976) verbal protocols did not reveal his domain experts' underlying mental processes; he conjectured that these processes probably could not be verbalized. They did, however, reveal "knowledge states," and distinctly different modes of operation when the domain experts were performing unfamiliar tasks. The decision ladder intersperses these 'knowledge states,' (shown as circles on the ladder figure) which represent what the operator knows as a result of previous and currently perceived information, with normative information processing stages: detection, observation/perception, identification, interpretation, evaluation, selection of action, planning action, and execution. These stages represented the process only when the domain expert faced an unfamiliar, ambiguous situation where 'conscious processing' (rational problem solving) was required. A more frequent state of affairs for the power station operators is represented by the ladder rungs, shortcuts to the full process, which Rasmussen calls 'shunting' processes. Shunts not only move forward across the ladder, but may move from right to left as well, to illustrate

[9] The importance of situation assessment, or developing a mental picture of the current and perhaps future situation, is another common trend evident in several naturalistic decision making models (Lipshitz, 1993).

how feedback loops enter a decision process.

These shunting processes show how humans with expertise take shortcuts, or use recognitional processes to simplify their tasks. When we have knowledge about how to handle a situation, we do not have to start from scratch and use an elaborate, laborious process for turning perceived information into an appropriate response. Rather, our prior experience suggests heuristics. Rasmussen (1976) suggests that perception may occur in a holistic way, leading

directly to knowledge of system state or to the appropriate action to be taken; in addition, "associations based on experience [lead] to leaps directly from one state of knowledge to another." (p. 376) This recognitional type of process is also the emphasis of Klein's (1989, 1993) recognition-primed decision (RPD) model.

The decision ladder has been used in different ways. Rasmussen originally proposed it as a map, upon which power station operators' activities could be overlaid. Hollnagel, Pedersen, & Rasmussen (1981) used it as a note-taking device, to directly sketch observed activity sequences. Xiao (1994) has used it as a planning model, for illustrating planning sequences that anesthesiologists employ in the operating room. These uses of the ladder emphasize that decisions are made in diverse ways; the ladder provides flexibility for describing how a particular decision is approached.

Rasmussen (1983) has discussed these perceptual activities in terms of a "cognitive control" structure, proposing that humans may operate under control of skill-based, rule-based, or knowledge-based mechanisms, depending upon the situation and their familiarity with it. A skill-based process is one in which the operator performs without conscious attention, and is difficult to verbalize, since it is based on tacit knowledge. It thus represents the lowest level of processing, meaning the involvement of the fewest processing stages on the decision ladder, but indicates the highest level of expertise. According to Rasmussen et al., "this formulation of heuristic decision making as a continuous control of action cued by signs from the environment relates closely to Gibson's direct perception of affordances." (Rasmussen et al., 1994, p. 70) How an experienced laparoscopic surgeon might prepare and insert the trocars (ports for providing instrument access), using fluid, smooth movements and little conscious thought, is an example. The subconscious control of movements allows the mind to think ahead to upcoming activities which will require attention. Rasmussen et al. (1994, p. 108) state, "performance at this level is typical of the master, the expert, whose smoothness and harmony have fascinated philosophers and artists throughout the ages."

Stored rules which have been learned from previous situations comprise rule-based behavior. Frequently, while operating at a skill-based level, the operator will generate and anticipate rules which will be needed in the near future. If a rule is not available, the operator may remember a similar situation in the past and transfer that successful action to the present. Surgeons apply rules in many situations. Some were cited by virtually every surgeon we interviewed (i.e., you must decompress this gallbladder in order to grasp it and retract it), and others were more idiosyncratic.[10] Rule-based control on the decision ladder might involve observation and identification of system state, and then a leap across to execution of appropriate action as defined by the rule.

Finally, knowledge-based control is put into action when an operator faces an unusual or unfamiliar situation for which new procedures must be sought. On the decision ladder, this knowledge-based behavior is represented by a process which moves up the left side of the ladder and then down the right side, without shortcuts. At this level, Rasmussen et al. (1994, p. 109) find "the goal is explicitly formulated and based on an analysis of the environment and the overall aims of the person. Then a useful plan is developed--by selection. Different plans are considered and their effects tested against the goal." An example is the process of identifying structures in an inflamed operative area, whereby understanding the anatomy may require several exploratory action sequences, and the surgeon considers the alternative of opening or doing diagnostic tests such as a cholangiogram. This process encompasses the entire sequence of the decision ladder, perhaps more than once.

Another way to explain the skills-rules-knowledge cognitive control framework is along a continuum from intuitive to analytical thought. Decisions which people attribute to their intuition correspond with the skill-based control, while those which require explicit, conscious analysis are akin to the knowledge-based control. Hammond & Brehmer (1973) first introduced the cognitive continuum concept, and later research with highway engineers

[10] Rules in surgery will be addressed in detail in Chapter 6.

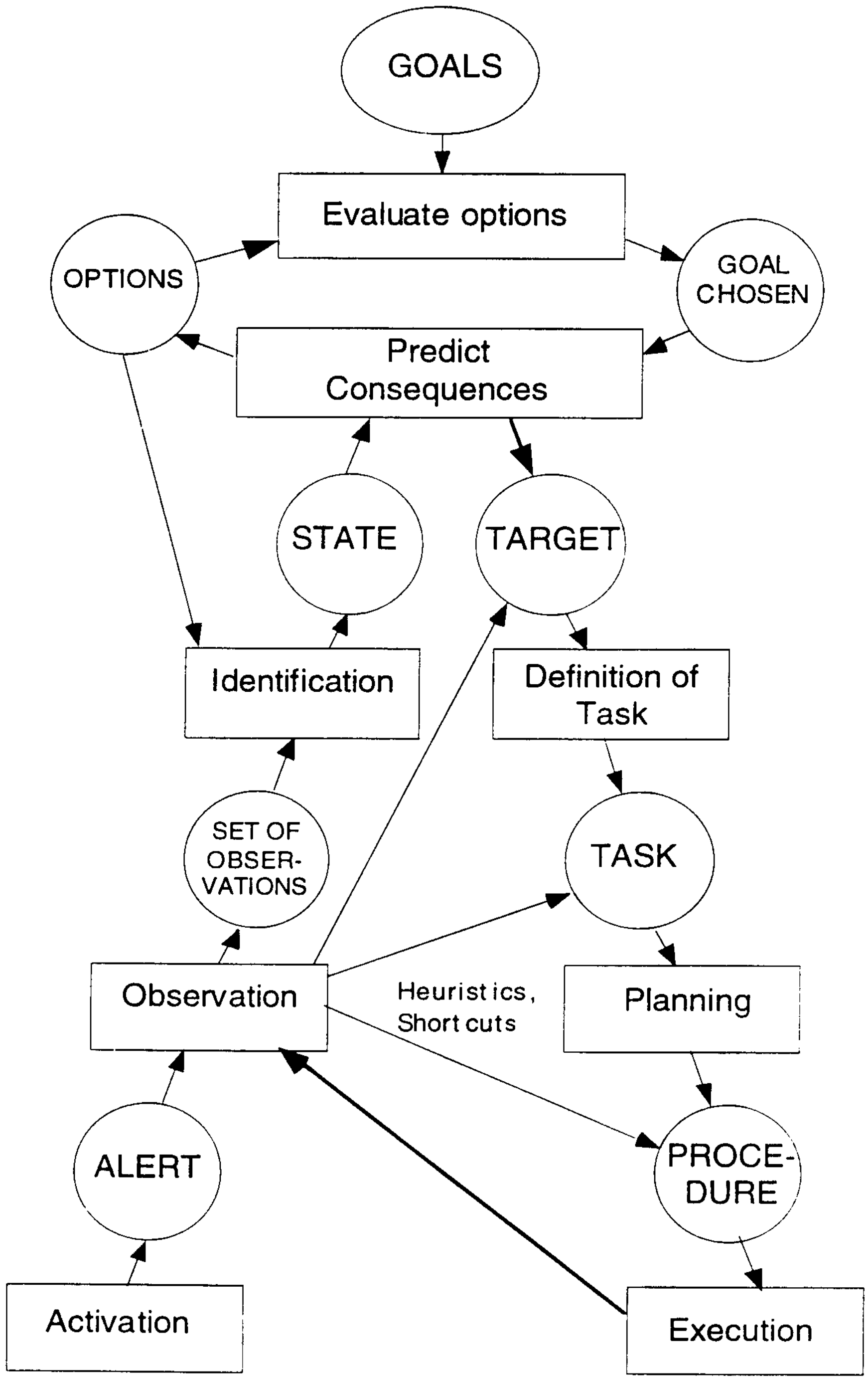


Figure 3.1 The Decision Ladder, as slightly modified from Rasmussen et al., 1994. Information processing activities are represented by rectangles, and states of knowledge are represented by circles. Reprinted by permission, © 1994, John Wiley & Sons, Inc.

demonstrated that some tasks are more likely to induce an intuitive approach, while others tend to induce analysis. Quasi-rational thought combines the two in the center of the continuum (Hammond, Hamm, Grassia, & Pearson, 1987). Furthermore, the idea that in complex work settings, people change fluidly and continuously between skill-based, rule-based, and knowlege-based control, depending upon the task and their familiarity with it, is consistent with Hammond et al.'s (1987) cognitive continuum theory.

To return to the original question of this section, what is a decision, I have explained how decisions take many forms. Rasmussen's decision ladder and skills-rules-knowledge framework are useful tools for specifying these diverse forms in psychological terms, and for showing how perception and action are coupled in a circular manner in work settings such as laparoscopic surgery. These representations help us see that decision making is far more than just simple choice or a gamble, but involves factors such as the eight influences Orasanu & Connolly (1993) discuss as characteristic of decision making in naturalistic settings.

There are two additional benefits of the decision ladder/cognitive control framework which will be developed further in this research. First, the concept of "cognitive control" connotes purpose on the part of the human actor in deciding what level of analysis is required in a given situation. If a problem is detected in surgery, the surgeon will begin to devote more attention to the situation, transitioning from a skill-based to rule- or knowledge-based control. This purposeful transitioning, I believe, is dependent upon metacognitive processes, which will be discussed in detail later. Second, moving between the levels of cognitive control sheds important light on the concept of expertise which is especially relevant in surgery (Olsen & Rasmussen, 1989). Rather than simply progress through five stages of skill acquisition from novice to expert (Dreyfus & Dreyfus, 1986), surgeons are continually required to learn new procedures and operate new equipment with updated technology. As stated before, expertise has become a moving target. An experienced surgeon's "dynamic world model" (Rasmussen et al., 1994) permits smooth adaptation to some new skills, but not all. The advent of laparoscopy in general surgery, as described earlier, has required significant perceptual motor learning. Again, with active metacognitive skills, surgeons can transition between the levels of cognitive control as they recognize that new situations require a more extensive thought process.

3.3 Where does cognition take place?

> *The properties of groups of minds in interaction with each other, or the properties of the interaction between individual minds and artifacts in the world, are frequently at the heart of intelligent human performance. But attributing them to individual minds hides them from analytic view and distorts our understanding of the processes that do belong to individual minds. As long as the nature of the shaping of thought by context is not seen, the organization of mental function that must be attributed to individual minds to account for observed performances will not be of the right sort. (Hutchins, 1993, pp. 62-63)*

3.3.1 Distributed cognition

Hutchins (1993; 1995) has conceived of the idea of distributed cognition. The distribution of our thought processes across other individuals and objects in a complex work setting dictates that naturalistic observation, or ethnography, must be a part of a research approach if these settings are to be understood. Other studies have shown how humans physically modify their workspace so that it augments memory and provides a means for prompting action (i.e., Scribner's (1984) work with food delivery pre-loaders). Kirlik's (1995) observations of short-order cooks illustrate this point well: "the cook not only uses the structure already present in the environment, he or she can dynamically create structure in order to make perception-action solutions available and thereby reduce cognitive burdens. For example, the cook may organize the placement of meats in order of doneness... " (p. 84) Thus, there is an interaction that occurs between an actor and a work environment which leads to behavior which would not be observed outside of that work environment. As Rasmussen et al. (1994) state, "humans do not have stable input-output characteristics that can be studied in isolation...When the system is put to work, the human elements change their characteristics; they adapt to the functional characteristics of the working system, and they modify system characteristics to serve their particular needs and preferences" (p. 6).

In laparoscopic surgery, the physical workspace is not the only dimension over which cognition is distributed. The four "developmental arenas" which Hutchins (1993) describes for navigation acknowledge the importance of (1) long-term histories of navigation tasks and (2) individual navigator careers. Hutchins also emphasizes that development occurs in (3) the minute-to-minute accomplishment of the task through human interaction, and that (4) further learning and innovation for the future is generated in this interaction as well. These four areas have close correspondents in surgery. Goals such as "first, do no harm" as well as names of procedures, anatomy and instruments are steeped in the history of medicine.[11] In addition, the specific training and experience of an attending surgeon, resident(s), and other team members, combined with the synergy of their interaction over a particular case all characterize the context in which this team will think and act.

If cognition is so context-related, how can we characterize it? This is similar to asking, if decisions are so diverse, how can we understand them? The key, as with decisions, is to adopt a broad perspective of what the influences might be, and attempt to define the factors which constrain thought in successful pursuit of the system's goals. For decisions, the decision ladder and skills-rules-knowledge framework provide the broad representation of possible trajectories. To understand an activity system (Engeström, 1993) which encompasses history, many actors, and physical artifacts of the work environment, we should as a minimum attempt to map this system with respect to its goals and means. This mapping does not represent historical development of a system, but it can depict the system on many other levels.

3.3.2 The Systems Approach

A system may be analyzed by decomposition into parts, as well as by functional abstraction; each of these approaches has its merits (Rasmussen et al., 1994). I found it useful to roughly sketch all of the players and influences in an operating room, and to think about the relationships between them (See Figure 3.2). This sketch provided a feel for the scope of a surgical operation and the various skills needed by the surgeon to coordinate the team members, to understand and manipulate the equipment and the tools, to remain within the organizational constraints imposed by the hospital administration, and to operate on the patient. However, this representation is lacking in functional description. (i.e., what are the goals and tasks?)

An alternative means for understanding the physical and functional nature of a system is to represent the system at different levels of abstraction. This approach is

[11] Engeström (1993) also stresses how the history of an activity system contributes to its development.

exemplified by Rasmussen's (1983) abstraction, or means-end, hierarchy. Rather than trying to capture one best way for doing a task, as many traditional (behavioral) task analysis methods do, an abstraction hierarchy lays out physical configuration and objectives of a system at levels ranging from global to local, so that the constraints inherent in accomplishing the task may be understood at these different levels. Rather than tracing a procedural, step-wise form of the task, the abstraction hierarchy shows the relationship between the physical configuration (at the lower levels of the hierarchy) and the goals of a system (at the higher levels), accounting for complexity in behavior in a way which sequential representations cannot.

Figure 3.3 shows an abstraction hierarchy for surgery. The system is depicted as a series of nested constraints, wherein "the functional and material features of the work system dominate the representation at the lower levels, while the intentional features, that is, the objectives that govern the control of the system functions, dominate at the higher levels." (Rasmussen et al., 1994, p. 38) In other words, material detail is added as you move down the hierarchy, and global context is added as you move up. At the uppermost, global level, the overall system goals are shown. For surgery, these goals are to fix the patient's complaint via the planned surgical procedure and to minimize injury of other tissue (first do no harm). The second level is for physical laws which constrain system operation, such as basic principles of anatomy. The third level depicts the functions of the system; it answers the question, "what really happens in this system?" There is continual diagnosis, visualization and manipulation of the operative area, and so on. The fourth level, physical function, represents the important constraints which are imposed during minimally invasive, or endoscopic surgery as opposed to an open, large-incision procedure. The very lowest, local level shows the constraints imposed by the physical form of the system, which for surgery details relevant elements of the patient and the surgical equipment.

As Bisantz and Vicente (1994) point out, each of these levels is a different model of the same system. It was developed by marrying domain knowledge, which I derived from direct observation, conversations with surgeons, books, and videos, with Rasmussen's descriptions of the levels. It is important to note that the abstraction hierarchy does not contain any information about the operator's knowledge, nor does it represent events or

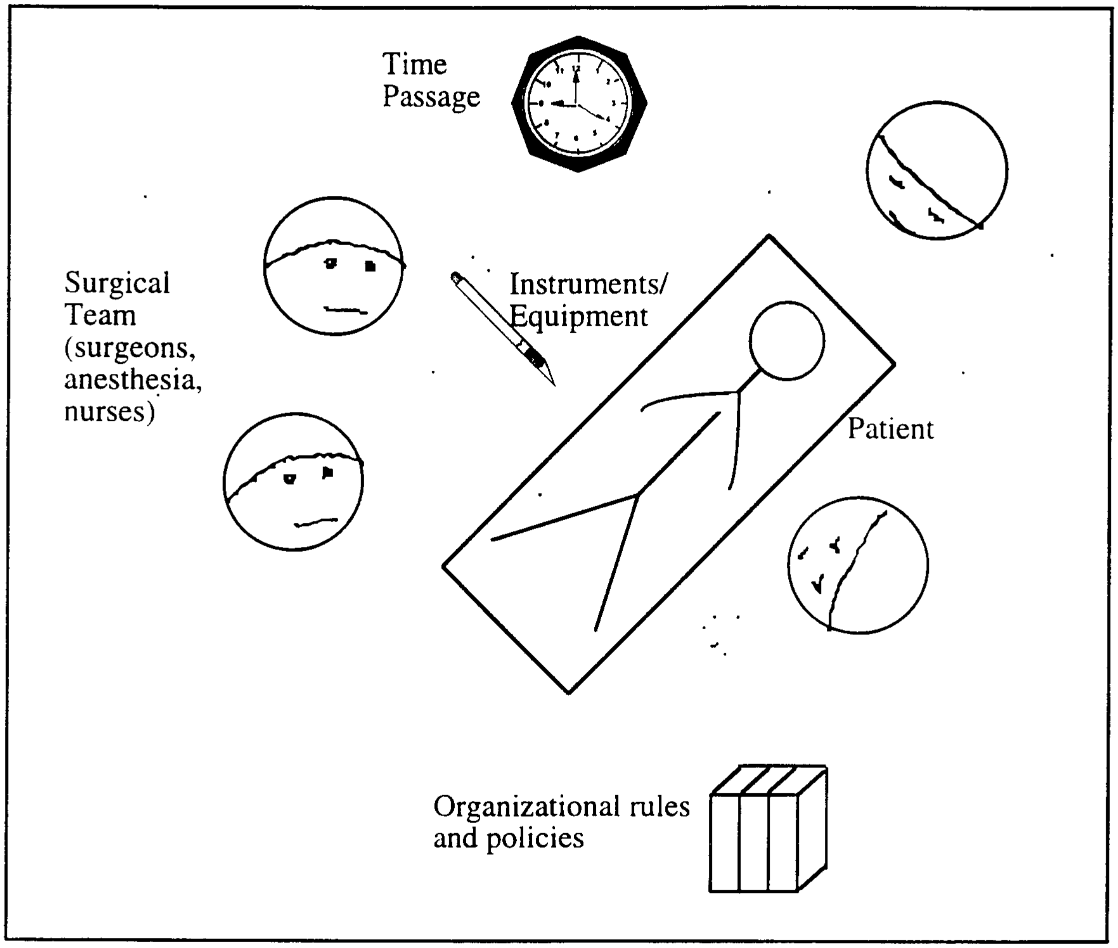


Figure 3.2 Players and influences in an operating room include the surgical team, instruments and equipment, the patient, organizational rules and policies, and time.

specific tasks inherent in the domain (Bisantz & Vicente, 1994). It is a representation of the system alone.

Representing a system in such a way helps define that system, but does not necessarily provide the entire picture of how successful performance is bounded and constrained. The abstraction hierarchy shown encompasses a so-called system of surgery. However, there are other influences on safe performance in surgery which are embedded in levels of professional culture, corporate policy, industry regulation, and legislation (Rasmussen, 1996). For example, the culture mandates that surgeons engage in what Bosk (1979) calls a "putting on the hairshirt" ritual known as a morbidity and mortality (or M&M) conference. This is comparable to other professions' analyses of accidents and

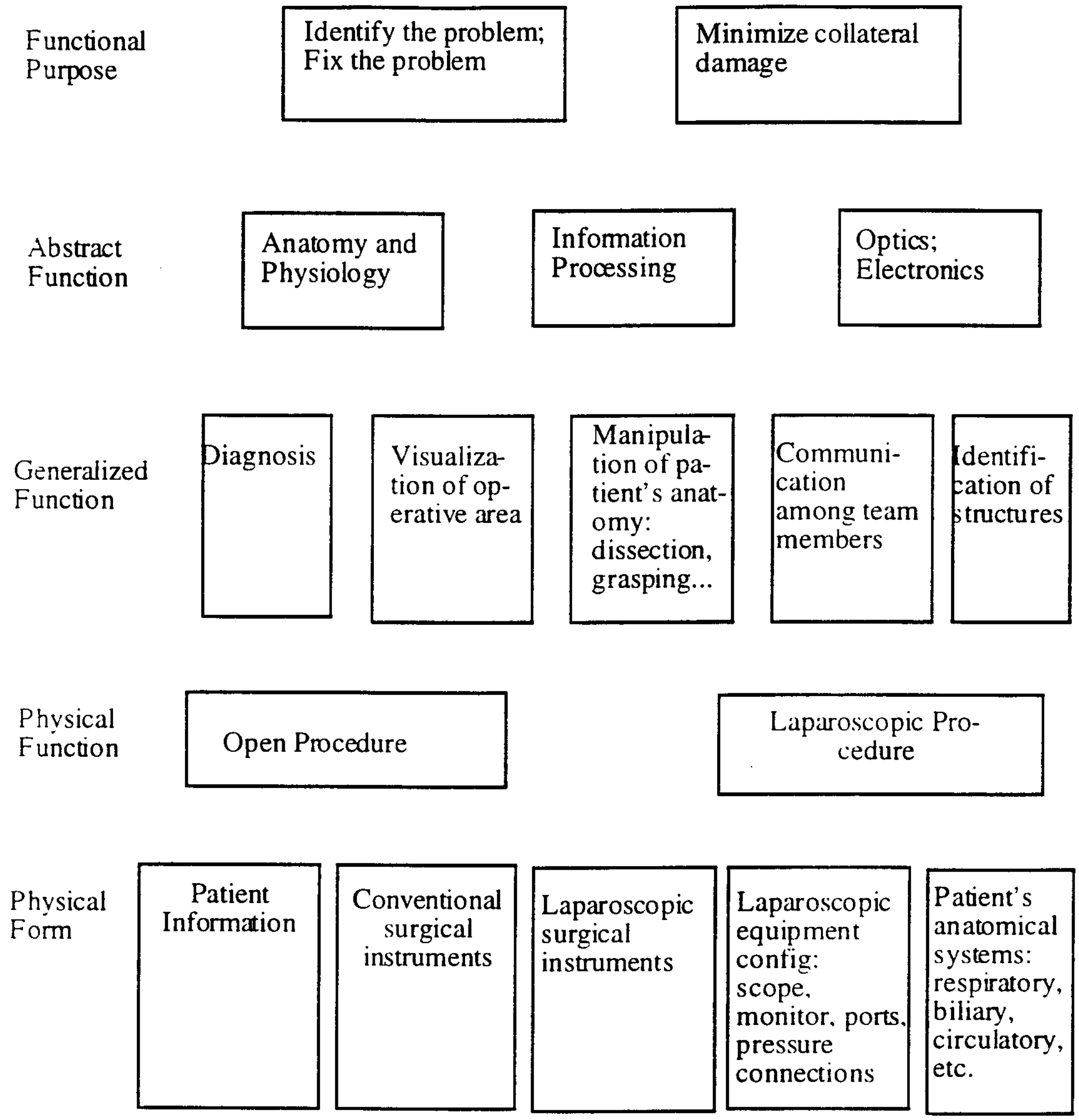


Figure 3.3 Means-End Abstraction Hierarchy for Surgery, both conventional and laparoscopic.

errors, such as airplane crashes; however, it is a more local and private exercise. When a patient dies or has a complication, the case is placed on the morbidity and mortality agenda, and the surgeons involved explain to their peers the circumstances and what can be learned from them. I have not observed a morbidity and mortality conference, but it seems to have many purposes. Bosk (1979) found that surgeons feel "policing their own," or keeping rates of morbidity and mortality low by using internal sanction and control mechanisms, both improves the quality of patient care and lessens the likelihood that a regulatory agency will step in to externally police them. This and other means of internal control interact with external controls levied by hospitals and corporate health care organizations, such as credentialling practices for performing new procedures independently. At the outermost level, legislation and current trends towards "managed care" are generating changes in the overall health care structure of this country which impact surgery as it is practiced. Often the metrics chosen and used to assess the success of a health care organization (such as throughput and waiting time) do not reflect how well an individual 'customer' to that organization is served, as Engeström (1993) found in research within the Finnish health care system.

There are some important implications to the study of surgery which evolve from the many-tiered influences described above. Often human performance in dynamic systems is examined in terms of tasks and the "acts" or behaviors which are used to accomplish them, the decisions which are made, and errors which are likely to occur. Rasmussen (1996) calls this modeling by structural decomposition, and explains the difficulties inherent in this approach. Rasmussen (1996, p. 5) argues that task and act analyses are difficult because in dynamic systems, there are "many degrees of freedom for choice by the actors even when the objectives of work is fulfilled." This fits with the 'many ways to skin a cat' principle which is demonstrated by military pilots who, even when many tasks are completely specified by a checklist interaction, find preferred, idiosyncratic ways of approaching their overall organization of tasks. This is certainly true for surgeons as well: twenty different surgeons led us through twenty trajectories of perception and reaction to the cases we showed them.

Because there are so many degrees of freedom in operating systems such as nuclear power plants, jet aircraft, and in the performance of surgery, humans often create 'workarounds' and procedures which become accepted in practice but which are not in accordance with rules, laws, and instructions. For instance, I once knew a strategic missile crewmember who told of taping an old pizza box over a section of the control interface in order to have space for placing his technical manuals. As Rasmussen (1996, p. 6) states, "one implication . . . is that following an accident it will be easy to find someone involved in the dynamic flow of events that has violated a formal rule by following established practice, and who is, therefore, likely to be exposed to punishment. Consequently, accidents are typically judged to be caused by 'human error.'" A surgeon does not refer to checklists or technical publications during a procedure. In this sense, there are few rules, laws, and instructions available during surgery; the attending surgeon has to have all the knowledge needed, or may call in a colleague for help if necessary. Error, or deviation from standards, is less well-defined. Either way, labeling a surgical mishap (or any kind of mishap) as human error does not reveal anything special, unless the particular circumstances and underlying factors are then identified (as they are in a morbidity and mortality conference). Rasmussen makes the point that "a task description or instruction is an unreliable model for judging behavior in actual work" (p. 6). Norms of behavior often depart significantly from written guidelines.

The many influences and developing nature of situations in surgery mandate that we understand, as Rasmussen suggests, the factors which provide a boundary to safe performance, and the pressures which act within and upon a system to push performance towards breaking these boundaries. As opposed to the decompositional approach of modeling decisions, tasks, acts, and errors which are made, this approach is called modeling by functional abstraction (Rasmussen, 1996).

Rasmussen et al. (1994) present the space of possible action and its boundaries in a model which is shown in Figure 3.4. The upper right boundary is that of economic failure; management policy typically exerts pressure for the human operator to move away from that boundary. The lower right boundary, of unacceptable workload, results in internally generated pressure towards efficiency of time and effort (i.e., why take two trips with a ferryboat if all of the cargo can be loaded on at one time). These pressures both tend to cause a system to migrate within the space of possible paths towards the left boundaries, which are separated by a margin of safety as defined by the domain. The migratory movements are likened to the 'Brownian movements' of the molecules of a gas (Rasmussen et al., 1994).

Financial and work load pressures shown in Figure 3.4 apply to the domain of laparoscopic surgery, and surgery in general. Hypothetically, economic pressure from a hospital or health care corporation might encourage the scheduling of several cases in a row to use operating room staff most efficiently. For example, Woods et al. (1994) describe

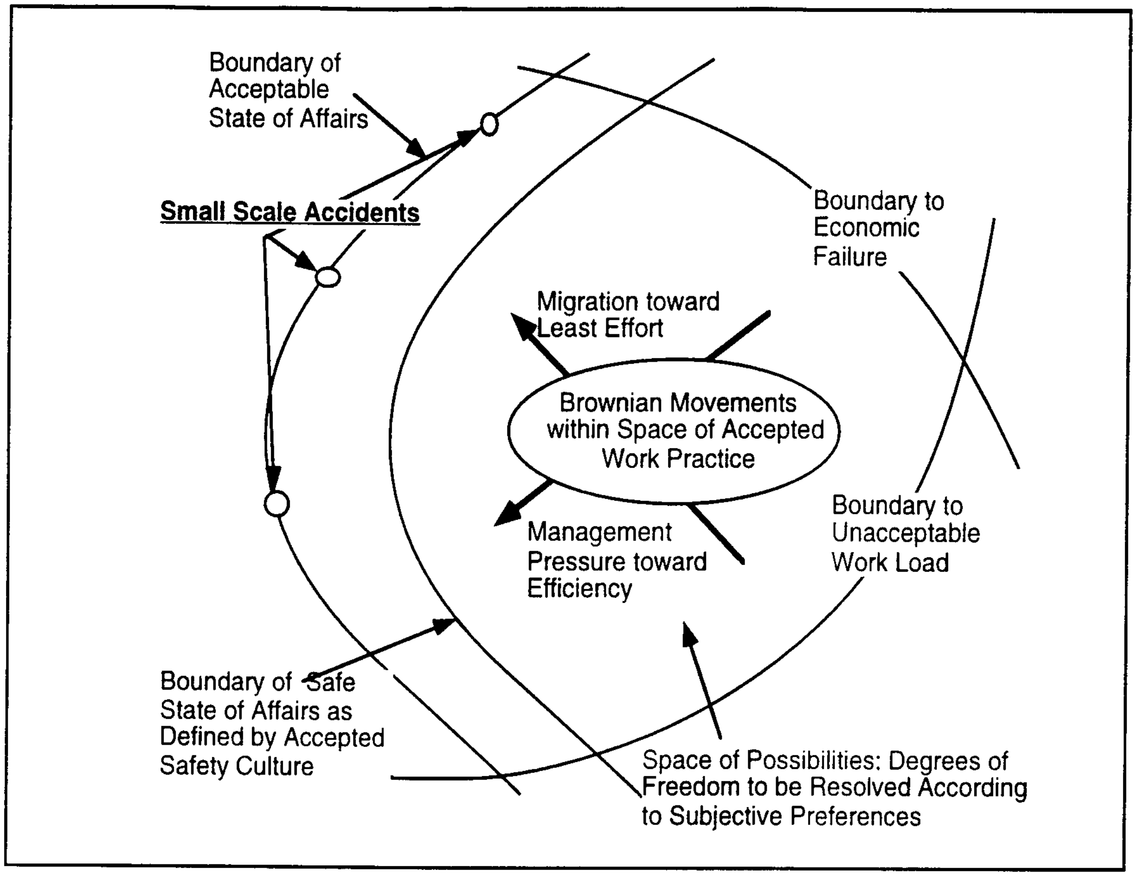


Figure 3.4 Rasmussen et al.'s (1994) figure showing the migration of human behavior towards boundaries of safety, due to pressures such as the reduction of work load and maximizing profits. (Reprinted with permission, © John Wiley & Sons, Inc.)

anesthesia scheduling in a large hospital during one weekend when case demands caused the anesthetist-in-charge to commit all resources to current cases. Having no one available to begin a major emergency trauma case was contrary to the requirements of this hospital, which was a major trauma center, but was accepted as a common occurrence. In this research, we have not explored the pressures existing in the higher levels such as legislation, regulation, and hospital policy.

From the lower right, rather than exerting pressure towards least effort, unacceptable work load is considered the norm for resident surgeons. The boundary of functionally acceptable behavior would tend to be approached due to fatigue and excessive work load rather than from minimal effort. However, pressure to migrate towards safety boundaries in laparoscopic surgery is influenced by other factors which may be unique to the domain.

First, pushing performance toward the boundary is what Greene (1995) calls the urge to follow through with an endoscopic approach. He writes, "We all recognize that the oft-used phrase 'to convert is not a complication, but represents good judgment' is indeed our standard, but in the 'heat' of the O.R., some forget this admonition because of ego, machismo, or some other inherent intangible in the psyche." Greene (1995, p. 11) This attitude was recognized by surgeons we interviewed. For example, the following excerpt is from a staff surgeon's response to the question, "If the surgeon decided to begin this case laparoscopically, would you think that was a reasonable decision?" at the first decision point:

> "Depending on the surgeon. I know many surgeons, I don't trust their judgment, other surgeons, I think their judgment's good, I would assume they've made the appropriate insight into the patient's care, if they started it. I would be VERY concerned if the physician had no, I would say almost in an arrogant way, say "I can do this case laparoscopically!" I call those guys the laparoscopic cowboys. Bad judgment, a LOT of bad judgment out there. To have no concerns, and not be prepared to open a case like this, that physician should not be operating....The ability to go out and talk to a family and say how wonderful I am, I've got this very difficult gallbladder I've dragged out in 3 hours, is often there. Ah, I think there's a lot in surgery in which physicians make an effort in what they can get away with."

The urge to follow through with a laparoscopic approach is no doubt complicated by the currently dynamic state of the domain, where newly pioneered minimally invasive procedures are continually taught to experienced and inexperienced surgeons alike, and confidence in familiar procedures must be tempered by inexperience in the new procedures.

Second, pushing performance away from the boundary and into safe territory is what I will call the professional culture of surgeons. Physicians take the Hippocratic Oath very seriously, and feel a strong sense of duty towards their patients (Leape, 1994). Moreover, the aforementioned morbidity and mortality conferences, where surgeons discuss negative outcomes amongst themselves, are a rare internal control process in complex systems operation. Perhaps the reason for this sense of responsibility and stringent internal control lies in the fact that more than in other fields, there is a more personal and devastating toll when mistakes are made. Significantly impacting the health of another human being through purposeful actions is heavy responsibility. One surgeon interviewed told the following story about a case involving injury, and its impact:

> "I would be trying to shoot an intraoperative cholangiogram before I'd go ahead and clip that but then again that's just my own bias from my own previous experience from having a ductile injury. In that girl, [she] had fairly acute disease, wasn't quite as bad looking as this but everything was fine until 5 days post-op when she came back to the office just still puking her guts out. And I'd just destroyed her hepatic duct, her common hepatic duct, because I hadn't realized where we were and that was an error on my part and I had been fooled by the size of her cystic duct, the stone. It had been a good size stone, it had worked it's way down chronically to the cystic duct enlarging it so it looked like the infundibulum of the GB and then at the common duct junction I thought the common duct was the cystic duct so I went ahead and clipped it, divided and then started cauterizing. Well when you cauterize up through there you've got the hepatic duct line right behind it and I eventually burned that part. If you talk to any other surgeons who've had that kind of an injury, I mean I lost sleep for several nights over that. It's one of those things that haunts you and you hate it, you just hate it."

The power of personal experiences, like the one described above, can change behavior in the operating room significantly. Performing a cholangiogram to better identify structures became standard rather than optional practice for this surgeon after this experience. It is the purpose of the morbidity and mortality conference to allow other surgeons to learn vicariously through the mistakes that inevitably occur.

These opposing pressures, the unchecked urge to continue laparoscopically and the professional responsibility of the surgeon to the patient, were acknowledged by surgeons we interviewed. These are pressures a surgeon exerts on his or her own performance. The first can be countered and the second can be brought to bear on a situation through the use of self-monitoring and self-regulation skills. Although neither the economic pressures nor the work load pressures shown in Figure 3.4 were the subject of this research, the data from this study yielded strong evidence for the function and importance of self-monitoring and regulation, referred to as metacognition.

3.4 Conceptual Synthesis

I have attempted to answer three very difficult questions with respect to approaching research in the domain of laparoscopic surgery. A field of safe travel, or safe operating, is considered to be the stimulus of interest in this domain. Decisions come in diverse types and forms, many of which can be captured on a generic mapping representation such as Rasmussen's decision ladder (1976) and appreciated in terms of skill-, rule-, and knowledge-based cognitive control (Rasmussen, 1983). And finally, cognition does not merely take place in the head; rather, it can be seen as distributed among team members and hardware configurations as well as influenced by administrative and professional/cultural factors. A key factor which ties these points together is the importance of interaction. A field of safe travel is not simply perceived, it is defined by the surgeon's interaction with the patient in a joint expedition with perception and action. Decisions are ongoing rather than singular events; whether to convert to an open case exemplifies this process. The interaction with the patient and team members which builds a situation assessment and drives the decision is key. And finally, boundaries of safe performance sometimes must be approached (tested?) in order to be appreciated and understood, as shown by the incident describing a patient's injury.

4 Cognitive Engineering Methodologies: A Rose by any other name . . .

4.1 Overview: A Proliferation of Methods and Goals

Research which seeks to understand cognition and learning in the context of people's work settings has proliferated in recent years. This research has grown in the separate but overlapping literature areas of knowledge engineering, naturalistic decision making, cognitive engineering, and in human-computer interaction (HCI) research in the form of exploratory sequential data analysis (ESDA; Sanderson & Fisher, 1994). I will discuss each of these areas briefly.

The knowledge engineering approach, which seeks to elicit knowledge from expert practitioners so that expert systems and decision support systems may be developed, often focuses on rules and facts. First generation expert systems relied on production system architecture, which specified if-then (antecedent-consequent) rules and their combinations (Hoffman, Shadbolt, Burton, & Klein, 1995). A study by Fox, Myers, Greaves, and Pegram (1987) is an example of this methodology. One expert physician was asked to think aloud while evaluating the clinical and laboratory records of patients who were to be diagnosed for leukemia; transcripts were made and analyzed for facts and rules. Fox et al. felt that they may not have extracted certain types of knowledge, such as common sense knowledge, "deep" knowledge,[12] and general problem-solving strategies from the transcripts, since their focus was to extract knowledge suitable for use in the EMYCIN expert system framework used. A great deal of research has been conducted to identify rule-based expertise. It is an important part of knowledge, but as expert systems developers have discovered, it is only a part of the picture. Rule-based knowledge in laparoscopic surgery will be discussed in chapter 6.

There has been a recent shift in decision research towards studying decision making in naturalistic environments. Several different cognitive task analysis (CTA) and process tracing methodologies have been developed and used in naturalistic decision making research (see Woods, 1993). Interviewing experts about how they would handle

[12] "Deep" knowledge is that which provides an underlying theoretical basis for taking action; an example is knowledge of biological foundations for diagnosis. It can be likened to knowledge-based behavior in Rasmussen's (1986) skills-rules-knowledge framework.

and reason through tough cases (i.e., the critical decision method of Klein, Calderwood, & MacGregor, 1989) is a method common to both knowledge engineering and naturalistic decision making work, and which has been employed in this research as well. Gordon (1992; 1995) has argued that in order to access different types of cognitive processing, such as the skill-based, rule-based, and knowledge-based processing described by Rasmussen (1986), several different types of elicitation methods are needed. For instance, combining document analysis, interviews, and recorded observation together may allow access to all three types of processing. This makes sense: if you are trying to characterize expertise, an extensive understanding of the domain is important. I will show how we have attempted to incorporate this multi-approach spirit in the following sections.

A third approach, which shares some methods with the naturalistic decision making approach, is cognitive engineering. Cognitive engineering is a term which can create confusion, so I will define what I mean by it here. Rasmussen (1986) indicates that Donald Norman first appealed for a profession of cognitive engineering back in 1981. Norman's (1986) book chapter entitled "Cognitive Engineering" described two goals of cognitive engineering (p. 32):

> (1) To understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design.
> (2) To devise systems that are pleasant to use--the goal is neither efficiency nor ease nor power, although these are all to be desired, but rather systems that are pleasant, even fun.

Norman indicates that cognitive engineering is a kind of applied cognitive science. Similarly, and taking the concept one step further, Rasmussen et al. (1994) present their recent book, *Cognitive Systems Engineering*, as a multidisciplinary approach which spans engineering, psychology, and the cognitive, management, information, and computer sciences to form a "cross-disciplinary market place" (Rasmussen et al., 1994, p. xv) as opposed to a singular research discipline. Thus, cognitive engineering is more directly geared towards the design of complex systems than the previous two approaches discussed, knowledge engineering and naturalistic decision making. The methodologies for eliciting data in cognitive engineering as well as in naturalistic decision making research are often termed cognitive task analysis.[13] Cognitive engineering resources such as Rasmussen et al. (1994) have been extremely useful in suggesting ways of representing, analyzing, and interpreting data which has been collected in this research.

Finally, Sanderson & Fisher (1994) have coined the umbrella term 'exploratory sequential data analysis' for research in which the data collection does not interrupt a natural sequence of events. They define exploratory sequential data analysis as:

> "Any empirical undertaking seeking to analyze systems, environmental, and/or observational data (usually recorded) in which the sequential integrity of events has been preserved. The analysis of such data represents a quest for their meaning in relation to some research or design question, is guided methodologically by one or more traditions of practice, and is approached (at least at the outset) in an exploratory mode." (Sanderson & Fisher, 1994, p. 255)

Exploratory sequential data analysis research has been performed within different theoretical approaches. Sanderson & Fisher present descriptions and examples of how this research has been done within behavioral, cognitive, and social intellectual traditions. Sanderson & Fisher present a generic model to illustrate how researchers undertake the exploratory sequential data analysis process; this model is useful for describing and explaining many varieties of field work.

All of these approaches to understanding human behavior in context *somehow extract information about a work domain with respect to particular research goals.* Rather than elaborate on the vast literature describing specific ways in which this research is accomplished, in this chapter I will present the goals and methods of this research in laparoscopic surgery, along with their roots in these different approaches. Conducting this research has been a trial and error process during which different methods have been attempted; all have contributed to the background domain knowledge, and have provided experience towards developing an approach which is well suited to my goals. I will discuss goals first, as well as mention how they have changed and evolved in response to exploration in this domain.

[13] Vicente (1995) uses the term "cognitive work analysis" to extend cognitive task analysis beyond the study and understanding of required tasks and into a level of system analysis in which events which are not anticipated by system designers, and are thus unfamiliar to system operators, can be dealt with.

4.2 Goals

This research began as a project in a 10-week course on Cognitive Task Analysis. The assignment was to find a "customer" in a real-world domain, apply some of the techniques learned in class, and provide a report which would be helpful to the customer in some way. Our customer was a surgeon in the local area, who thought about our questions for a few days and concluded that the decision to open (or not open) during a laparoscopic cholecystectomy procedure was an important issue to examine. From the beginning, then, and throughout this research, understanding the decision to open has both been a primary goal and has provided the context for our efforts.

Understanding expertise in laparoscopic surgery has also been a goal; we have sought to understand differences in perceptual skills, knowledge, and decision making between resident and staff surgeons so as to identify relevant areas for training. This goal has evolved towards gaining a richer understanding of the situations and type of experience which might lead to expertise, as well as how surgeons with different levels of expertise might maintain a field of safe travel or operation. Perceptual expertise in a perceptually degraded system such as laparoscopy is of particular interest (I will elaborate on these concepts of expertise in Chapter 7).

The third goal of this research was to take an exploratory look at surgeons' verbal protocols. In Chapter 2, I introduced the idea that surgeons learn to assess their comfort level as an important aspect of risk assessment. Based on the emphasis surgeons placed on comfort level during our interviews, I began to look into research on self-regulation and metacognition. As a result, a third goal has evolved: to understand how metacognition interacts with expertise in the context of laparoscopic surgery.

I will next discuss the path taken towards developing and implementing these methods.

4.3 Beginning with Ethnography

Regardless of what kind of data collection and analysis will follow, a strong argument can be made for beginning the study of a domain by simply observing people at work in it. Xiao (1994) supports this approach, and suggests that direct observation can give an investigator an initial feel for general patterns of behavior which are important in a domain. There are products which can be gained from direct observation of a complex work environment that are not available with other approaches to understanding that environment, such as an understanding of the stream of behavior as it occurs naturally. In addition, directly observing behavior reduces concern about veridicality or reactivity of the data, since no intermediate explanation of what and how a task is being performed is required (Russo, Johnson, & Stephens, 1989) when it is directly observed. However, it may be difficult to understand what is observed without commentary from the operator. The downside of observation, in terms of reactivity, is that domain experts such as surgeons may act differently when they know they are being watched (Xiao, 1994). Even so, it would be impossible, as well as meaningless, to do research in laparoscopic surgery without an understanding of the domain. Many authors emphasize the need for beginning a research effort in a complex domain with an ethnographic approach (Sanderson & Fisher, 1994; Woods, 1993). Hutchins' (1995) work on ship navigation in the U.S. Navy is a classic example of how anthropological and cognitive approaches can be woven together.

On my first day in an operating room, I observed a local specialist in joint (arthroscopic) surgery as he conducted three cases, one shoulder and two knee operations. Surgery had always in my mind been considered a delicate undertaking, requiring precise, small movements and intense concentration. Watching this surgical team get behind a 10 millimeter "reamer," as it was called, I was amazed by the gross force being applied. The other surprise of this day was that it was far more difficult to watch a small procedure in which the patient's thumb was cut open than it was to watch the arthroscopic surgery, since in the latter all of the 'blood and guts' could only be seen on the television monitor, disconnected from the patient on the table. I began my exposure to laparoscopic surgery slowly, by watching videotapes available from the library and from cable television documentaries on laparoscopic cholecystectomy. Textbooks on laparoscopic cholecystectomy delineated the specific steps of the procedure, along with issues and problems that might be encountered. Medical journal articles recommended by collaborating surgeons gave me a perspective of how surgeons formally write about the issues and complications of gallstone disease and laparoscopic cholecystectomy, as well as a feel for how surgeons viewed the burgeoning influx of technology into their field.

The most direct and compelling way to understand surgery, however, has been watching surgical procedures in the operating room. Observation has been essential to understanding the activity system of surgery throughout the entire conduct of this research. Books and videos are controlled, and well-edited: in the operating room, anything can (and does) happen, and I could see first-hand how problems are dealt with. In one procedure, the laparoscope's light source failed, and the surgeons could not move until it had been restored. In another, the surgeon needed a particular suturing device in order to make a repair laparoscopically; without this device, the surgeons felt they would have to open. When the circulating nurses searched for, but could not find this device, the attending surgeon asked for some other material which *was* available and fashioned an approximation to the desired device, thus enabling a successful repair without opening. In another laparoscopic cholecystectomy I observed, the attending surgeon decided to open. The sequence of events leading up to the conversion and the role of the cholangiogram (x-ray) taken during the operation illustrated the uncertainty of identification, and how it can be recognized and respected through conversion. The equipment changeover and instruments involved in converting, added to the previous procedures I had seen, underscored the importance of tool use in surgery. Both awareness of the appropriate application of tools as well as motor learning for tool manipulation are crucial in surgery. Observing surgery led to appreciation of the constraints inherent in certain surgical equipment, and how various tools and techniques are combined to keep the surgeon within a field of safe travel.

Observation also fosters understanding of how all of the players interact: scrub nurses, circulating nurses, anesthesiologists and nurse anesthetists, radiology technicians, and of course, the team of surgeons. A bored circulating nurse would stop and make a few comments to me, providing a far different perspective on patient care from that of the surgeon. The team perspective and other observational experiences were deepened by our direct participation in laparoscopy in a training laboratory, arranged by surgeons collaborating on this research. As our team of three psychologists attempted to retract tissues, operate the laparoscope, and dissect structures, challenges such as instrument manipulation under indirect vision and team communication became painfully obvious. On the whole, observation of laparoscopic procedures has been a continuing process which has provided a rich framing for cognitive questions such as how surgeons decide to open and how they operate safely. Each experience has revealed something new, adding to the technical, procedural, cultural, and social picture.

4.4 Trial and Error: First Interview Study

4.4.1 Approach

Having a general question to work with, 'how is the decision to open made,' and armed with general background knowledge on laparoscopic cholecystectomy from textbooks and videotapes, our cognitive task analysis class group (of 3) set out to conduct a series of interviews using various techniques.

We did a total of seven interviews. Three were done with a 'knowledge audit' technique, two were based on a procedural timeline, and in the last two, we used the critical decision method (Klein, Calderwood, & MacGregor, 1989).

A knowledge audit is designed to reveal how some basic characteristics of expertise might be manifested in a domain. The three knowledge audit interviews were conducted in order to gain a general understanding of the issues and factors involved in making the decision to convert to an open procedure. There are six areas generally covered in a knowledge audit interview; these areas and a general question used for probing each area are listed below (Klein, 1994):

1. **Mental Models**: Most of the time, experts have a sense of the big picture that novices don't have. Can you tell me an example of what might be happening when someone doesn't have the big picture?
2. **Declarative knowledge**: Have you ever learned any shortcuts or simplified ways of completing the task? Have you developed "rules of thumb" you go by?
3. **Perceptual skills**: In many cases, experts can see things novices cannot, they can notice cues or patterns that novices just miss. Does this ever happen in your job? Can you give me examples?
4. **Typicality/anomalies**: In many cases, experts notice when something unusual happens. They have such a good sense of what to expect that they can quickly catch the deviations. Does this ever happen in this domain?
5. **Metacognition**: Experts are often more aware of their own limitations, of where they might get confused, and they can avoid or work around these problems. Is that ever true in your job? What are some examples?
6. **Analogues**: If you were going to construct a scenario to teach someone that this isn't such an easy job, what would you put in that scenario?

The knowledge audit technique proved very useful in terms of gaining an overall impression of the information considered by the surgeon in a laparoscopic cholecystectomy procedure. It also helped us to elicit some useful examples, in story form, of incidents when a procedure was converted, or when converting was considered seriously. After the first three interviews, we felt that we needed a better structure with which to focus the interviews on the issue of converting. These general questions about expertise and our reminders to focus on the decision to open yielded too much variability in responses. We found it difficult to coherently tie the information gained in these interviews together in a meaningful way. It was at this point that we considered how the knowledge elicited would be represented, and realized that we could structure subsequent interviews in a way that would streamline our data representation scheme if the interview approach were tied to the representation.

We decided to construct a timeline which summarized steps in a laparoscopic cholecystectomy procedure. These steps were derived from a training video on laparoscopic cholecystectomy, from the previous interviews, and from a textbook (Cooperman, 1992). We started with a detailed, 13-step procedure, and condensed this down to 10 steps with feedback from the surgeons interviewed (see Table 4.1). In these interviews, we asked the surgeons to describe what they might encounter during each step which might make them consider converting to an open procedure. Some factors were based on preoperative conditions, such as patient health factors. Some factors were particular to a stage of the operation, such as observing a malignancy upon first entering the abdomen. Some factors were cumulative: time the patient spends under insufflation and under anesthesia are examples which interact with patient health factors to cause concern.

The primary difficulty found with parsing the operation into a step-wise format was that most factors were not specific to one step. The other danger in representing information in this manner is that when a procedure is converted, there is not typically one catalyst. Rather, a complex set of information including patient factors, condition of the tissue in the operative area, and other situational constraints combine with the attending surgeon's predisposition for opening to result in a decision for or against opening at a particular time. Our interviews mainly yielded rule-based knowledge (if ___, then open, or perhaps open), which is only a part of the picture.

1. Insufflation
2. Survey anatomy
3. Establish 3 other ports
4. Grasping gallbladder and retracting it
5. Identify cystic duct and cystic artery
6. Cholangiogram decision if clarification of anatomy needed
7. Clip and transect cystic duct and cystic artery
8. Separate gallbladder from tissue connecting it to liver bed
9. Remove gallbladder
10. Final survey

Table 4.1 Ten step procedure for Laparoscopic Cholecystectomy

Because of the number of steps covered in each of the 'timeline' interviews, combined with limited availability time of the surgeons interviewed, we were not able to delve deeply into any stories the surgeons might relate with this approach. It became clear that stories would be a key element to lend understanding to the contextual combination of events leading to a conversion. Therefore, we decided to conduct subsequent interviews with a critical decision method approach.

In the critical decision method, which is a critical incident technique (Flanagan, 1954) modified to focus on critical decisions (Klein, Calderwood, and MacGregor, 1989), the interviewer asks the interviewee to relate stories of incidents where his or her expertise was challenged to a high degree. One incident is then selected which both parties agree is a good candidate to explore further. A timeline of the incident is constructed, and then each step on the timeline is examined in minute detail to determine the information, considerations, and actions involved as the domain expert handled the incident. In this approach, the goal is to understand how decisions are made through the use of the incident. The investigator may infer a model of decision making from the context-specific description of the domain expert, thus avoiding asking the domain expert to directly analyze his or her thoughts.

We asked surgeons to think of a story where they either opened, or carefully considered opening, a laparoscopic cholecystectomy procedure. The surgeon gave a synopsis of the story, and then we explored different aspects of that case in detail. Since the entire interview (about an hour in length, in most cases) involved discussion of only one or two cases, enough time was available to explore the background information considered in each case. However, the two surgeons interviewed with this technique were not willing to delve into their cases in detail. This was perfectly understandable, in retrospect. A surgeon is not likely to want to expose his or her uncertainties about a case with an unknown researcher. We were not able to get beyond a surface level description of events for these interviews. We couldn't help but conclude that in order to get a deeper description of what a surgeon might be thinking during an incident, it was important to present a challenging case which someone else had performed, and encourage role-playing. This scenario would remove any personal discomfort and reluctance about patient disclosure which might be present in an interview based on cases from experience. It would also form a common ground for comparing perceptions and thought trajectories across different surgeons.

4.1.2 Findings

The data from this study were condensed and represented in a series of six tables; these are shown in Appendix A. The first two tables list the integrating factors which influence the perception of specific findings in the patient. Preoperative considerations are patient, equipment, and team factors which the surgeon knows about before the operation begins, and intraoperative considerations are patient, equipment, and team factors which develop over the course of the procedure. These two tables list the relevant factors as well as the potential impact each might have. The impact of a significant number of these factors involves *time*; this will be discussed shortly.

The next four tables list perceptual cues encountered during a laparoscopic cholecystectomy which surgeons identified as impacting their decision to open. There is one table for each of four primary stages of the operation; the ten steps in Table 1 have been condensed here into four stages because many of the cues appeared in several different steps. To paraphrase, the stages essentially involve (1) accessing the operative area, (2) dissecting and identifying, to include clipping and transecting the cystic duct and artery, (3) operative removal of the gallbladder, and (4) surveying, cleaning the operative area, and closing. In each table, the perceptual cues are associated with related expectations, and with alternatives to opening. The perceptual cues alone do not represent what these cues *mean* to the surgeon; the related expectations show the causal factor surgeons expect are behind each cue. The alternative to opening presents a "workaround," a different way to safely proceed rather than simply converting to an open procedure. In addition, notes are made at the bottom of each table to add relevant information about the cues.

These six tables are limited in that they present a disjointed, itemized feel for situation awareness in surgery. Constructing the tables was an enlightening process, but as stated before, they are limited in their ability to show how combinations of events interact. Two general findings from the entire effort will be discussed here.

(1) Temporal constraints. Our first finding was that an awareness of time passage is important to the decision to open. When a complication leads to time delays early in a procedure, for example when bleeding is encountered and excessive time is spent finding and stopping the source, the time available to deal with other complications becomes constrained. In essence, there is a time window available to complete the procedure. The time window depends on the patient's condition and on what injuries or complications arise in the procedure. Although a time window per se was never mentioned by the surgeons we interviewed, the *pace* of the operation combined with the patient's condition were mentioned as important factors influencing the decision to open. For instance, if it becomes evident that a laparoscopic procedure would require hours of struggle, and the patient's condition is poor, opening is seen as a safer and more reasonable course of action.

(2) Integration of many pieces of information is critical. Each surgical procedure is a unique event, with a particular history and an evolving story line which bears upon the surgeon's decision to open. This ongoing story contains elements such as those represented in the first two tables of Appendix A, the patient, equipment, and team factors which are discovered both before and during a procedure. In addition, those elements are not simply present or absent; they occur to some *extent*, or to some level of seriousness. For instance, it would be inadequate to say a team of surgeons encountered bleeding; the location, the nature, and the rate of flow are all important dimensions which influence an assessment of the bleeding, and which have bearing on the appropriate response. Thus, realizing that surgical decision making is an ongoing process which incorporates many pieces of information and nuances of those pieces of information led to the theoretical position that perception action coupling in surgery is a circular process, and is well described by Neisser's perceptual cycle (1976).

In Neisser's perceptual cycle, the integration of information takes the form of a schema, a knowledge structure encompassing both case-independent and case-dependent information. This schema serves as the framework for acquiring and assimilating new information, and thus acts as a basis for perceptual recognition. Similarly, Schmidt, Norman, & Boshuizen (1990) have extensively studied knowledge structures physicians use for diagnosis, calling them illness scripts; similar structures may be utilized in surgery. In novice surgeons, the framework is less extensive, since the experience base which forms the framework is small. Thus, because all new information must be considered in light of the situational context, citing a single event as a primary catalyst for converting to an open procedure is an unrealistic conclusion.[14] As we came to appreciate the complexity of the developing situation in surgery, it became clear that a program for training new surgeons should strive to teach an appreciation for an evolving situation.

Understanding the importance of the time factor and the varying ways which information can be configured to influence a decision to open was an important result of this preliminary interview study. We gained a higher level of background knowledge with which to understand the domain of surgery, and furthered the trial and error process of what techniques were likely to work well in future work. However, more questions were generated than were answered, and the research provoked a strong feeling of being perched atop the tip of an iceberg.

4.5 Where to Proceed Next? Work Analysis

With only a cursory understanding of the decision to open, new approaches were needed. Suggestions made by Rasmussen et al. (1994) made it clear that an understanding of the *system* and *activities* of surgery were needed in order to meet the goal of characterizing competent courses of thought and action in laparoscopic surgery. Toward

[14] Wherry, Rob, Marohn, & Rich (1994) present archival data indicating that most cases are opened for more than one reason.

that end, the next step was to analyze the system of surgery by constructing a means-ends hierarchy and understanding the influences on safe performance in surgery (this analysis is discussed in section 3.3.2).

4.6 Cognitive Task Analysis Through Video-based Interviews: Issues

In this section, I will describe some issues which must be dealt with in attempting to gather data about how practitioners in a field think as they perform. First of all, how do you provide the mapping between the work situation and the data collection setting in a representative way? The field of laparoscopic surgery provided us with a means which was representative in many ways. This aspect of my methods will be discussed in the first subsection following. Second, in light of evidence which suggests that humans are incapable of accurately telling you how they think, how should we try understand the cognitive processes involved without directly asking people how they think? There has been much work discussing how this can be done as well, which I will review along with presenting my approach to the problem in the second subsection.

4.6.1 Videotape: Linking the Research with the Domain

> *The eye* developed *to register change and transformation. The retinal image is seldom an arrested image in life. Accordingly, we ought to treat the motion picture as the basic form of depiction and the painting or photograph as a special form of it. What a strange idea! It goes counter to all we have been told about optics. But it follows directly from ecological optics. Moviemakers are closer to life than picture makers.* (Gibson, 1979/1986, p. 293)

Using videotaped cases to elicit knowledge for this research was an easy decision to make. Other approaches taken, in our first study, had been only slightly successful in furthering our understanding of the decision to open. The goal was to get as close to the operating room environment as possible without presenting the unacceptable risks of asking surgeons to talk aloud while operating. My budget was low, and not only was the video available, it provided veridical representation of the inside of a patient. In other words, the surgeon's view of a patient in surgery would be identical to the view we provided in the research setting.

There are some strong theoretical reasons for using videotaped cases as well. I will discuss the ideas of representative design of research (Brunswik, 1956) and capturing the complexity of surgery next.

Representative design. Studies of medical problem-solving, diagnosis, and expert-novice differences are plentiful. A large portion of this research employs pencil and paper cases for the physician to assess and attempt to diagnose, often requesting that the physician think aloud about the information given (cf., Patel & Groen, 1986; Bordage, 1994). The percentage of experts and novices who reach an accurate diagnosis is assessed in these studies; also, the verbal protocols may be coded, in terms appropriate to the researchers' hypotheses, and analyzed for differences in use of knowledge, structure of knowledge, and strategy. These studies are open to criticism on the grounds that physicians view the physical examination[15] as an important part of information gathering; in addition, diagnosis is often extended in time as the physician requests and reviews test results, and the paper case approach treats diagnosis as a one-time decision. These studies therefore violate Brunswik's principle of representative design, which holds that when a researcher intends his or her work to generalize to a situation or set of conditions (i.e. medical diagnosis), these conditions must be represented within the research situation (Hammond, 1993). As Woods (1993, p. 230) describes it,

> ". . instead of focusing on the elemental, spartan strategy of throwing away complexity to achieve tractability, the appropriate criterion for creating tractable study situations is establishing a mapping between the test behavioral situation (where one is observing and measuring behavior) and the target behavioral situation one wishes to understand or generalize to."

Asking surgeons to role-play their thoughts and actions while watching videotaped cases provided such a mapping for this research. The target situation is laparoscopic surgery; the video provided a test situation which included a large subset of the perceptual information available during this kind of surgery. Again, the decision to convert is of primary interest, and it has been treated here as one which is made over a course of time, influenced by various factors and constraints which can be seen unfolding on the video.

Capturing the complexity of surgery. Using cases on video had the

[15] Seeing, talking with, and examining a patient is far different from seeing a description of such an interaction on paper. A few surgeons we interviewed would have liked more information of this nature about the 80 year old patient on the videotape. An important distinction was whether she was a 'young 80 year old,' active and alert, or an 'old 80 year old,' perhaps a nursing home patient, who was relatively inactive.

additional benefit of depicting diseased tissues, complex relationships among them, and natural human movements which would be virtually impossible to depict in other forms such as still slides, or in verbal or written descriptions. The superiority of using video to capture complex movements and situations is supported in a variety of research domains. For instance, it is advantageous to record videotape of users in studies of human-computer interaction because, unlike other forms of data capture, it records gestures, it gives a complete picture of the work environment, and it may be viewed repeatedly (Laws & Barber, 1989).

Further, in studying how best to facilitate cued stimulated recall, Omodei & McLennan (1994) placed video cameras on the heads of orienteers during a race. They found that orienteers in the video assisted recall condition felt more immersed (emotionally and intellectually) in the experience of the race as they recounted it than those in the free recall condition. The level of involvement surgeons display with the videotaped cases has been surprising to us as well. We interviewed more than one resident who professed they had been up for 24 hours, yet who remained alert, curious, and interested in the patient throughout the interview. This interest in the cases presented is probably due to the fact that the videos depict surgery on real patients. In most instances when surgeons interviewed said they would convert to an open procedure, it was a voluntary, rather than solicited statement. Another indicator of involvement were the statements we coded as "change in comfort level," which marked when a surgeon responded to events on the video with a statement such as, "I'm really worried now," or "my heart rate just went up; he's up to his neck in alligators." Fourteen out of 20 surgeons made at least one such comment. This level of emotional involvement indicates both that the surgeons found it easy to role-play as surgeon while watching the video, and that the reason for this likely was the strong mapping between the operating room and the research interview situation.

4.6.2 The Trouble with Verbal Protocols

When verbal protocols are used as data, as they are in this and other naturalistic research, there are two primary concerns affecting validity (Russo, Johnson, & Stephens, 1989). First, does verbalization of the information change the primary thought process which occurs naturally? If a person under study changes their behavior as a result of thinking aloud for an observer, then the process is *reactive*. For instance, a surgeon who verbalizes a course of action which is more conservative (ie, a quicker threshold for opening) than their typical course of action would be displaying reactive changes. Second, does the verbal protocol accurately capture the thought process which would occur during performance of the task studied? Russo et al. (1989) call this factor *veridicality* (see also Nisbett & Wilson, 1977, and Hoc & LePlat, 1983) A major disturbance to the data can result if a subject reports thought processes which do not actually occur. This last concern is one which is a recurring criticism of research which elicits verbal reports in which observers attempt to describe their own thought processes.

Nisbett & Wilson's (1977) landmark article on verbal reports as data is referred to again and again when the issue of veridicality arises, and their view is worth describing here. These authors focus on a subject's ability to report about higher-order, inferential processes rather than lower-order perception and memory processes which are assumed to be inaccessible. In most of the studies reviewed by Nisbett & Wilson, subjects are exposed to different stimuli, asked to solve a problem or give a rating of some sort, and then asked what sources of information impacted their responses. Often the experimenter gives a final debrief of the hypothesis, and asks the subject to indicate whether their judgments were in fact influenced by the different conditions. The studies reviewed by Nisbett & Wilson all revealed that subjects are extremely poor at reporting the factors that influence behavior; in addition, even when subsequently presented with a hypothesis which describes that subject's behavior, the subject often adamantly denies being influenced by implausible sources. Nisbett & Wilson liken the behavior observed in these studies to the representative heuristic described by Tversky & Kahneman (1974), since subjects seem to make a judgment as to whether a stimulus is representative of one which *should* be affecting their cognitive processes. Thus, Nisbett & Wilson (p. 234) conclude:

> "When people attempt to report on their cognitive processes, that is, on the processes mediating the effects of a stimulus on a response, they do not do so on the basis of any true introspection. Instead, their reports are based on a priori, implicit causal theories, or judgments about the extent to which a particular stimulus is a plausible cause of a given response."

Although none of the studies described in Nisbett & Wilson involve subjects performing tasks in a real-world job, their conclusions are often presented as a blanket truth, indicating the inability of humans to accurately describe what information is influencing their higher-order processes. Authors who report verbal protocol data generally acknowledge the ideas presented by Nisbett & Wilson, yet many take a more moderate view, one that proposes a relationship between how a subject describes his or her thoughts and the actual thought processes themselves (cf., LePlat & Hoc, 1981). Ericsson & Simon (1980, p. 247) state that "verbal reports, elicited with care and interpreted with full understanding of the circumstances under which they were obtained, are a valuable and thoroughly reliable source of information about cognitive processes." Likewise, Bainbridge (1990) argues that Nisbett & Wilson provide important cautions, but there are techniques of understanding cognition which do not require subjects to speculate on what their thought processes are, instead focusing on the *content* of a domain expert's thoughts. She also hypothesizes that "people in working situations may have more accurate information about their behaviour, both because more detailed and accurate information is available to them about the state of the working environment and the results of behaviour, and because people are explicitly, and usually verbally, trained to respond to particular aspects of the environment" (Bainbridge, 1990, p. 162).

Bainbridge's latter comment is particularly relevant to assessing whether surgeons can be expected to accurately verbalize their thought processes. Surgeons *are* trained to verbalize what they see and what they would do. The methodology of video-prompted interviewing adopted in this research has features in common with the Certifying Exam of the American Board of Surgery, which 5th-year residents practice for and take to become independent, board-certified surgeons. In this exam, residents are judged on their ability to verbally present their thought processes in a logical, coherent manner. A verbal description of a case situation is presented, and examinees must explain and justify what actions they would take. The similarity of our approach to the exam was unintended, and I believe it has both positive and negative repercussions.

On the positive side, the very fact that surgeons become board-certified in this way indicates they must be able to verbally express and justify what they are thinking (not necessarily *how*) with regard to patient care. If they fail, as some do, they cannot succeed in this profession. This provides hope that surgeons are likely to be relatively good at verbalizing their thoughts.[16] On the negative side, it is possible that surgeons we interviewed modified their responses and judgments to conform to a careful, defensible textbook course of action, if there is one. We had no way of knowing if surgeons responded in a manner consistent with their behavior in surgery. However, a surgeon on our team did alert us to potential reactivity while reviewing pilot interview transcripts. We then modified our opening instructions to emphasize this point, asking: "Please tell us how you personally would act or think in these cases; we're not looking for a textbook or "approved solution" answer. In fact, we're looking for insights that experienced surgeons might have that are not typically presented in standard texts or training materials." The wide variation in courses of action surgeons described indicate they are probably not relying on an "approved solution."

Returning to Bainbridge's (1990) earlier proposition that there are techniques for eliciting knowledge which avoid asking subjects to speculate on what their thought processes are, one often used method is to provide a challenging case and ask practitioners how they would handle it. In section 4.4, I discussed how the critical decision method (Klein et al., 1989) was employed early in this research effort to ask practitioners how they had dealt with a difficult case they had experienced, along with the (understandable) lack of willingness to discuss these cases on the part of surgeons. The methods described in the next chapter are a modification of the critical decision method, but remain true to the goal of asking surgeons *what* they think, rather than *how*.

[16] Another reason why surgeons are likely to be good at verbalizing, at least in a training community, is the fact that attending surgeons continually teach during surgical procedures. Although there are several styles of teaching, this apprenticeship type of learning environment requires some level of verbalization at the operating table.

5 Methodology for Video-based Interview Study

We have conducted a series of 20 interviews with general surgeons. In this chapter, I will describe the surgeons, the interview methods, and how the resulting verbal protocols were coded and analyzed.

5.1 The Surgeons

Ten interviewees were senior residents; five of those were in their fourth post-graduate year and five were in their fifth post-graduate year[17]. Since the surgeons in this group have eight or nine years of medical training, we consider them to be a "journeyman" group, rather than a "novice" group. The other ten surgeons are on the staff at local hospitals, and have a range of 2 to 28 years since completing residency. The mean number of years since residency was 10.1 (with a five-year residency, this translates into a mean number of years since medical school of 15.1). We were not able to get a evenly distributed range for years of experience, however. Three of the surgeons had more than twenty years since residency, and the other seven surgeons had six or less years. Of the latter group, five surgeons had between 4 and 6 years since residency.

When asked how many years ago they had done their first laparoscopic cholecystectomy, the resident group's mean was 2.77 years, while the staff group's mean was 5.3 years.[18] Both groups estimated how many they had done: the mean for the resident group was 70; the mean for the staff group was 255. However, many residents had never done any laparoscopic gallbladder removals without an attending (supervising) surgeon present, so the ultimate responsibility for these cases was in another surgeon's hands. Three residents estimated the number of cases done on their own as 10, 4, and 2 respectively; others had done none. Of the staff group, with only one exception, surgeons had done all or all but 10 on their own. Descriptive data are shown in Table 5.1.

[17] Post-graduate year reflects number of years since graduating from a four-year medical school. The general surgery residency is a five year program; fifth year residents are called "Chief Residents."

[18] These numbers should be read while keeping in mind that this surgical procedure only became widespread in the US about 5 or 6 years ago.

	Resident	Staff
Years since medical school	4 or 5 (five of each)	7-33 mean=15.1 SD=9.81
Number of Lap Choles done	35-113 mean=70.2 SD=22.1	75-1,000 mean=255 SD=288.05
Number done without help	0-10 mean=2.28 SD=3.73	75-1000 mean=237.77 SD=293.55
Number of years ago first Lap Chole was done	2-4 mean=2.77 SD=0.66	4-6 mean=5.3 SD=.70

Table 5.1 Descriptive data for surgeons interviewed. The first number in each cell is the range spanned, the second number is the mean, the third number is the standard deviation.

5.2 The Interviews

A surgeon who collaborated on this research had been collecting videotapes of laparoscopic cholecystectomies, and had cataloged these cases by noting information such as the age of the patient, the difficulty of the case, whether the gallbladder broke open during the operation, and other unusual problems or events. This surgeon chose three of these cases which were challenging over a range of variables for our interviews, and noted the specific points on the video which would be natural ones for stopping and asking questions. The interviews were structured around these three laparoscopic cholecystectomy cases. Our aim was to present tough cases for the surgeons to watch and comment on, with the rationale that only by presenting a challenge would we find out how surgeons think and propose to act in risky situations, where the largest propensity for injury would exist.

We interviewed surgeons in the hospitals where they worked, typically in a library, conference room, or any convenient room where a TV and VCR were available. All interviews were conducted by the author; during most interviews, a research assistant also was present to take notes and help with equipment. At the beginning of each interview, a script was read to the surgeon to explain the purpose of the research, and to let them know what to expect over the course of the interview. The interviews involved a combination of structured and unstructured elicitation. In the structured portions of each interview, at the predetermined points chosen by our collaborating surgeon, we stopped the video and asked several pre-defined questions, such as "what do you think is going on here," "what are your concerns," and "what errors might be made in this situation?" Surgeons were also asked for a comfort level rating, on a 7-point anchored scale ranging from having no concerns (1) to indicating they would open right now (7), at each decision point. The set of questions was tailored so that only relevant ones were asked at each decision point. The questions and anchored scales are shown in Appendix B. Unstructured elicitation occurred as videotape was being watched; surgeons were asked to think aloud and provide continuous commentary on events seen on the videotape. We requested that the surgeons role-play, to try to imagine they were actually doing the case.[19]

Videotape cases were used rather than asking surgeons for their own critical incidents for reasons discussed earlier; we found surgeons understandably reluctant to divulge information about their own challenging cases. Using another surgeon's case on videotape solved this problem and eliminated any personal bias inherent in eliciting individual stories. In addition, using the videotaped cases allowed us to compare surgeons' reactions to the same situation, in the same context, thus providing a common frame for evaluating whether and how staff and residents differ in their assessments.

The interviews were audiotaped and later transcribed, in their entirety, directly into a MacSHAPA software file (Sanderson, Scott, Johnston, Mainzer, Watanabe, & James, 1994). MacSHAPA provided a spreadsheet format for the verbal protocol data. For our purposes, we organized the interviews in column format, with salient videotape events noted in the first column, pre-defined interview questions in the second column, surgeons' dialogue in the third column, and follow-up, spontaneous questions in the fourth. We

[19] Getting into this role was difficult in the few cases when the interviewee stated they would not be in the situation which was shown on the tape. We handled this for residents by having them imagine their attending directed this action, and for staff surgeons by having them imagine they had been called in to help on this case in progress.

created our own time stamps for each cell to indicate temporal order and events which coincide in time; the interview process sufficiently interrupted the case video so as to render its time stamps too quick.

Three cases were chosen for the interviews, but only two were used during each interview due to time limitations. Timing of decision points and number of decision points varied for each case, depending on its context. Each case videotape was edited down to relevant scenes by the surgeon who chose placement of the decision points. Case 2, the case which was seen by all 20 surgeons, is the focus of this dissertation. This case, which involved an eighty year old woman with an acutely inflamed gallbladder, has been described in detail in Chapter 2.

5.3 Coding and Transforming the Data

Once the interviews were conducted, it was necessary to define an approach which would permit us to analyze them in terms of the "formal concepts," or theoretical assumptions of this research. The most salient aspect of the coding scheme used in this research is its iterative nature: many different approaches (and codes) were conceived of and tried. Once we settled on a working approach, the specific codes and alternatives for each code were modified right up to the time the last transcript was coded. There was no way around it. The data kept showing us new ideas, or making old ones obsolete.

Originally, we decided to code four different variables which were indicative of metacognition. They were (1) looking for disconfirmatory evidence, (2) deciding to open, (3) antecedents and consequents, and (4) boundaries, such as physical location, affordances of tissues, and hidden dangers. In addition, with an eye towards understanding how goals are expressed as surgeons role-play through a case, we planned to map out "information-goal-action" summaries at each decision point, and to map antecedents and consequents onto a decision ladder representation.

The four metacognition variables proved to be too ambiguous to identify reliably in the transcripts. A clearer operationalization of metacognition was needed. Looking for disconfirmatory evidence and antecedent/consequent pairs in the written transcripts could not be defined well enough: if you "read into" the transcript, everything seemed like an

Dec. Point 1: Discomfort Level Ratings, Questions
Predictions when GB first seen
Dec. Point 2: Discomfort Level Ratings, Questions
Aspiration of Tense GB
Beginning dissection: Cholangiogram decision
1st structure: Lymphatic Identification
GB bursts open, spills bile
2nd structure: Artery Identification
Satisfaction with identification
Dec. Point 3: Discomfort Level Ratings, Questions
3rd structure: Duct Identification

Figure 5.1 Storyboard showing events which occur in the Case 2 videotape.

antecedent/consequent pair. Furthermore, surgeons often did not verbalize what information they were attending to on the video, and only occasionally mentioned something that could be construed as a goal. Thus, the information-goal-action codings were not representative of what surgeons said. The decision ladder mapping of antecedents and consequents was not tried, due to the difficulty of identifying antecedent/consequent pairs; this mapping was more meaningful with if/then rules which were coded (see Chapter 6).

Other paths were suggested or tried. We were searching for an approach that would provide traceability between the protocols and our analysis and interpretation. As Woods (1993, p. 240) has stated concerning research in field settings, "there tends to be a great leap from data collected to interpretative conclusions, with a vast wasteland in between." We did not want to make such a leap.

5.3.1 Storyboard-based, or Event-Dependent Codes

After watching the interview video twenty times, and meeting intermittently to discuss how these data could be analyzed, we began to see more regularity in the surgeons' range of responses to salient or cognitive events (such as identifying structures) in the videotape. A clearer vision of the sequence of events began to emerge. Identifying these events which permit comparison across surgeons led to making a storyboard (see Figure 5.1) of the case, a time-ordered sequence of perceptual events which occur on the videotape.

Creating the storyboard helped us to think about the videotape-based interview as a kind of research simulation, wherein surgeons were exposed to the same events and were asked to respond in the same manner, either by answering interview questions or describing what they saw and what they would do. Thinking in terms of a research simulation was a liberating concept. Instead of trying to piece together an individual story twenty times, we could directly examine and note what every single surgeon said (or did not say) about, for instance, the gallbladder bursting open. This research by nature has many aspects which would make an experimental-control advocate cringe (no standard setting for the interviews, nor time of day; questions added ad lib). Even so, the research simulation concept, with its implicit standardized exposure to the same perceptual information and questioning, fostered a feeling of experimental control and ability to compare across individuals. It is important to note that we recognize surgeons each experienced a slightly different interview, since follow-up questions varied, and since half of those interviewed (5 residents and 5 staff surgeons) saw Case 2 after being interviewed on Case 1, which may have had an influence. In fact, two residents entered the interview after having been working for 24 hours. Inter- and intra-subject reliability would therefore be expected to be poor. These facts are an accepted part of the bargain when one's research goal is to understand surgery as close to the operating room as possible without being there, hence requiring us to catch busy doctors where ever and whenever they could be found.

By reviewing the transcripts repeatedly to compare how surgeons talked about the different events they were exposed to, we began to develop a coding strategy. A range of responses was identified which specifically related to each event of interest, and these responses were documented as ranges of a variable[20] for that event. (These were the event-specific variables.) I will next list the nine variables applied to each transcript which were event-specific, how they were defined, and what the range of responses were.

(1) COMF1. This was the comfort level rating for the first decision point, on a Likert scale of 1 to 7 where 7 is extremely uncomfortable with proceeding laparoscopically. This was a question asked directly to the surgeon, and the surgeon's response was noted; nothing needed to be translated or inferred for the comfort level variables. The question and anchored scale the surgeons used to make their rating looked like this:

Comfort level at continuing (or beginning) this case laparoscopically:

1. No concerns whatsoever	(0)*
2. Little concern.	(5%)
3. Increased concerns	(25%)
4. Moderate concerns; 50/50 chance this will need to be converted	(50%)
5. Many concerns	(75%)
6. Very seriously considering converting/beginning as open	(95%)
7. Would convert/begin as open *now*	(100%)

*Percentage indicates level of concern and probability that this case will have to be done open.

(2) PRED1. When the gallbladder was first seen in this case, surgeons tended to pass a judgment on how sick they believed it to be (how inflamed, or whether it was gangrenous), and to make predictions about how the state of the gallbladder would influence conduct of the laparoscopic cholecystectomy. We wanted to document whether and what type of predictions were made here. To differentiate these predictions from those made later, when the gallbladder burst open, and from predictions made at other times in the interview, this variable was called PRED1. The range of responses was as follows:

[1] Prediction that the gallbladder wall will tear
[2] Prediction that it will be hard to grasp and get traction on the gallbladder
[3] Prediction that infected material will be spilled in the abdominal cavity
[4] Prediction that spilling of infected material may lead to development of abscesses in the abdominal cavity
[5] Other prediction from seeing sick gallbladder
[0] No predictions made

On virtually all of the variables, we included a null condition [0] to note that that variable was not invoked at all in the transcript, and a catch-all, "other" category such as number [5] above, since there were usually instances we did not anticipate which we wanted to document.

[20] The word "variable" will be used to denote the label we applied to concepts we wished to identify and analyze in the transcripts, and the word "code" will be used to denote the choice from the range of responses for that variable which reflects the verbal data. We entered these variables into a MacSHAPA predicate variable column in each transcript, and thus we could generate reports on their frequency and location from MacSHAPA.

(3) COMF2. Comfort level rating at the second decision point, see COMF1.

(4) LYM. We have labeled the first structure dissected out, clipped, and severed as a "lymphatic" (it may or may not have been one). What was of interest was how the surgeon interviewed labeled this structure, if they did at all, and what information, or cues they used to make this identification. This variable, like some others, has two "arguments," or data points which are assigned codes. The template for the variable is thus expressed in MacSHAPA as LYM(<cue>, <insign>), where the first argument, <cue>, had the following range of responses:

[1] lumen
[2] twang
[3] bile
[4] size
[5] location
[6] other
[7] pulsation
[0] null, no cues given.

This range is also employed for the variables which indicate identification of the other two structures, the artery (ART) and the last structure (LAST). "Lumen" is a tubular structure which. if seen as a cut cross-section, indicates that something important, like a duct or artery, was cut. Some surgeons said they looked to see if a structure retracted in a "Twang" fashion, like a cut guitar string might. Bile remnants inside the cross-section, size of the structure, and its location were three other commonly mentioned cues surgeons mentioned when talking about information they would use for identification. No surgeons mentioned the pulsation cue for identifying this structure, but it is an important one for the artery, and we developed one standard list of identification cues for use with all three structures.

The second LYM argument, <insign>, was used to document whether the surgeon indicated that this structure was insignificant. Because the video showed only one clip being placed on this structure, some surgeons assumed that this structure was being clipped and cut just to be safe, but not because it was either the cystic duct or the cystic artery. This argument was not used at all if no such comments were made. When the argument was used, it was replaced by either a yes or a no, yes indicating the surgeon assumed insignificance, no meaning the surgeon ascribed importance to the structure.

(5) PRED2. The second prediction variable noted what predictions surgeons made when the gallbladder burst open. The range of responses was as follows:

[0] Acknowledging spill, but no mention of stones or infected material
[1] Simply noting that infected material or stones are being spilled into the abdominal cavity
[2] Prediction that spilling of stones & infected material may lead to development of abscesses in the abdominal cavity, or other problems

(6) ART. This variable documented cues and identification made as the videotape showed dissection of, clipping, and cutting the cystic artery. This variable also has two arguments, <cue> and <ID>. The cue argument has a range of responses identical to those listed in LYM above. ID was coded as either [D] for duct, [A] for artery, or [0] if no identification was made. The ART variable provided an important means for comparing perceptual expertise, since the artery was the only one of the three structures for which unambiguous information for identification was shown on the tape, that information being its pulsation after being clipped and cut.

(7) COMF3. This was the third and final comfort level rating, see COMF1 for an explanation.

(8) SAT. During decision point 3, we asked each surgeon if they were satisfied that all the structures have been identified at that point. The responses coded were either [yes] or [no].

(9) LAST. This variable was used to document what cues surgeons were looking at as the last structure was dissected, and whether they identified it in any way. We looked for this information before, during, and after the last decision point, since the dissection of this structure spanned those periods of time. The arguments and responses coded were identical to those in ART, number (8) above.

5.3.2 Event-Independent Variables

In addition to the event-specific variables, a set of event-independent variables were derived to examine key ideas which might occur at any time during the course of the case. As a general overview, there are five primary categories in which these event-independent variables fell:

(I) Conversion. A surgeon's decision to convert the case to an open, large-incision procedure is a primary event the coder noted, along with the point in time it occurred, the rationale for that decision, and the strength of the decision (would maybe open vs. would definitely open).

(II) Constraints. Constraints upon the procedure relating to use of equipment and techniques, other team members, passage of time, and the patient's age were noted in separate variables.

(III) Metacognition/self-monitoring. In-depth discussions about (1) general comfort level, (2) risk assessment, (3) acknowledging hidden dangers, (4) methods used to monitor own progress, and (5) other comments pertaining to judgment or experience level needed to do this case laparoscopically were coded with this metacognition variable.

(IV) Perceptual expertise. When the surgeon elaborated on a specific piece of information, either seen or felt or given in the patient's background, by making predictions or inferences about that cue, or stating an action they would take, the cue and nature of the inference/prediction/action were coded.

(V) Goals. This variable was invoked when the surgeon discussed top-level goals for the operation, how they might be conflicting, or how they impact decisions made in the procedure.

There were fifteen variables used to document event-independent information of interest. Unless the information was well-specified by the variable itself, we used text comments in a column beside the variable column to elaborate what the surgeons had said which led to using the variable. These variables are shown here as grouped into the above five general categories:

(I) Conversion:

(1) OPEN. Conversion to an open procedure was documented with this variable; it had three arguments, OPEN(<when>, <why>, <strength>). This variable was used when a surgeon stated that they would convert the case, or might be converting the case right now. The range of responses for the <When> argument were:[21]

[0] Before seeing any videotape
[1] After first look at gallbladder
[2] During initial dissection for duct & artery
[3] During or after lymphatic is clipped & cut
[4] After gallbladder opens
[5] After cystic artery is clipped & cut
[6] During last decision point
[7] After last decision point, last bits of dissection & drain placement
[no] END OF SCRIPT: NO OPEN

<why>:

[0] No rationale given
[1] Afraid of injury to the common bile duct or other unknown structures
[2] Feels like situation is just too risky, is in over his/her head: bloody, poor visualization, bad situation, worried about age/insufflation
[3] All the structures have not been identified (at last Decision Point)
[4] Other reason (such as doing the patient a disservice)

<strength>:

[m] = maybe open here.
[d] = definitely open here.

(2) IFOPEN. One follow-up question which was asked fairly consistently was "If someone did decide to open at this point, what do you think would be the most likely reason?" Responses to this question were documented via the IFOPEN variable, which had two arguments, <when> and <cue>. The <when> argument was coded with the same range of responses for the OPEN variable above. For the second argument, the coder summarized as succinctly as possible the reason for conversion, such as "gangr, swollen," indicating a gangrenous and swollen gallbladder would be grounds for opening. The explanation would be given in the adjacent comments column.

(II) Constraints:

(3) AGE. This variable was invoked and coded as a [y] for yes when the surgeon stated that an older person is or is not a good candidate for laparoscopic surgery, and why. Coded as '0' at end if never invoked. Text comments were used to indicate why.

[21] We later converted the 'when' to the more detailed time sequence structure shown at the end of this section, to make it consistent with the 'when' code used with other variables.

(4) EQUIPMENT. Equipment constraints were noted via this variable any time the surgeon made mention of surgical or laparoscopic equipment: for example, "I would want to have another instrument in," and "the video resolution is poor." The range of responses was as follows:

[1] Decompression needle takes too long to aspirate
[2] Resolution of the video is poor
[3] Would use a specific same/different instrument than the one shown
[4] Requests open surgical equipment
[5] Other equipment constraints (note in comments)
[0] Null: none in transcript, code at end.

(5) TECHNIQUES. This variable was used when the surgeon said they would use a different technique than the one shown on the video. The range of responses was continually developed as new techniques cropped up consistently.

[1] Would move up or down on anatomy (toward or away from gallbladder) when dissecting. (Often expressed as more proximal or more distal)
[2] Wouldn't decompress as much, leave some fluid in gallbladder for better traction (The coder will look for a mention of how the extent of the aspiration would affect subsequent traction on and manipulation of the gallbladder.)
[3] Would do trocar/incision placement different, it's constraining instrument movement
[4] Irrigate more/wash things off
[5] Dissect more, expose area better for visualization
[6] Use different number of clips
[7] Would not pull away from CBD area, pull away from gallbladder area instead
[8] Would be gentler on tissue, use less force
[9] Would flip gallbladder back and forth, or side to side
[10] Other creative or unique technique suggestions
[11] Other more commonly used technique (i.e., provide more retraction, dissect on back of gallbladder)
[0] Null, no techniques invoked

(6) TEAM. When other team members and how they contribute to or constrain the surgical procedure were mentioned, the TEAM variable was used. The range of responses was:

[1] Camera operator
[2] Anesthesiologist
[3] Assistant, i.e. comment about traction being given, *taking over operation*
[4] Other
[0] Null, no mention of team members.

(7) TIME. Time constraints surgeons discussed were coded with this variable. Comments indicated the nature of the statement. The range of responses was:

[p] time constraint focusing on patient
[s] focusing on surgeon
[g] general time constraint
[0] no time constraints are discussed.

(8) CHOLANGIOGRAM. Cholangiograms are typically performed during difficult laparoscopic cholecystectomies to aid in identification and reduce risk of mistaking another structure for the cystic duct or artery. The "cholangiogram decision" (whether to perform one) is often made early on in a dissection. At the beginning of the dissection of this

gallbladder, as well as later when a likely cystic duct is found, we were interested to see how many surgeons said they would or would not perform a cholangiogram. The range of responses was as follows:

[1] At beginning of dissection, after aspiration of gallbladder
[2] At a later time
[3] Surgeon states they would *not* do a cholangiogram, or it would be difficult
[0] Cholangiogram never discussed

(9) CLIP. This variable was used when the placement of clips or scissors over a structure was difficult to visualize, because the interviewee could not see the back tine of the instrument. We developed this variable because for this case, some surgeons asserted that where the incisions for instrument access were placed was constraining the range of motion available for manipulating and viewing the back side of clip appliers and scissors. We wanted to document which surgeons were thinking in terms of these constraints, and how the constraints influenced recommended techniques as well. The range of responses was:

[1] Positive comment made about clip/scissor placement
[2] Negative comment made about clip/scissor placement
[3] Negative comment made about clip/scissor placement *and* surgeon mentions constraints on angle of clipping due to placement of initial incisions.
[0] Null, no clip or scissor visualization comments.

(III) Metacognition/self-monitoring:

(10) META. This variable documented when the interviewee gave indications of or examples of metacognitive thinking. At first we simply invoked a META[yes] code, but later the types of statements began to fall into more clearly definable categories. Those categories were:

[1] General comfort level: whenever surgeons mentioned the interviewee's or the operating surgeons' comfort level. For instance, "If a surgeon doesn't feel comfortable doing acute gallbladders laparoscopically, then they should do what they feel comfortable with."
[2] Risk involved: whenever surgeons discussed qualitative or quantitative risk, such as "she's got an increased risk of developing an infection post-operatively," or "unrecognized duodenal injury has a 40-50% lethality rate."
[3] Knowing consequences of actions which could cause injury, hidden dangers which could 'bite you' right away or later on. For example, "you could poke through the gallbladder into the liver and aspirate blood if you are not aware of where you are," or "there's danger in trying to dissect the common bile duct too well, if you injure its blood supply you can injure it."
[4] Monitoring/controlling own actions or thoughts. For example, "I would try to be more careful, go slower and be more meticulous because of the inflammation," and "if there are stones in the common bile duct, I don't have any experience with choledocholithiasis, and in an older patient I would therefore begin open."
[5] Other: general discussion of judgment, or experience level, or other. Examples of statements coded in this catch-all category include "the biggest mistake an inexperienced surgeon can make is not realizing they should have opened," and "judgment is sometimes based on what a surgeon can get away with, not what is best for the patient."
[0] none in the entire transcript.

(11) CHANGE IN COMFORT LEVEL. This variable was used when comfort level changed significantly for the surgeon viewing the tape. Examples: "I'm really worried now," "my heart rate just went up," "I just went from a 5 to a 6." This variable was also

used if the surgeon became more comfortable, i.e., "This doesn't look nearly as bad as I thought it would." The 1st argument, <dir> for direction, was coded as [more] or [less], indicating more or less comfortable. If the surgeon voluntarily provided a new comfort level rating according to our scale in expressing the discomfort, then a second argument was added, with the rating from 1 to 7 becoming the code for that argument.

(IV) Perceptual expertise:

(12) PERC. This was the primary perceptual expertise variable. When surgeon provided a *substantial* description of a cue they saw or felt or *might* see or feel hypothetically, and either (1) made predictions based on that cue or (2) drew inferences about the patient's disease or (3) recommended an action based on that information, the PERC variable was used. The range of responses was:

[v] = visual;
[t] = tactile
[c] = other cues, hypothetical or those we provided, such as the patient's age
[v&t] = both visual & tactile cues, or v&c, etc.,
[0] none

We extracted the discussion into the comments column, summarizing the nature of the cues and what the surgeon interpreted from them.

(13) RULES. Looking through the transcripts early on, it seemed as if many surgeons invoked if/then rules during Decision Point 2 as to how they should handle the tense gallbladder which would be difficult to grasp. We realized later on that surgeons were making if/then statements throughout the interviews, and opened up this variable to document these statements wherever they occurred. The range of responses was as follows:

[1] If you put trocar in and see a gallbladder like that, you should open.
[2] Try to grasp gallbladder again; if can't, then decompress it.
[3] If can't grasp the gallbladder, even after decompressing it, then you have to open.
[4] Other general rule, if _____, then OPEN.
[0] No rules invoked in transcript

(14) UPRED. We eventually realized that predictions were being made throughout the interviews, not just where the PRED1 and PRED2 event-specific codes had been applied. When a general prediction was made during the interview, not associated with first seeing the sick gallbladder or with the gallbladder breaking open & spilling, this variable was invoked and coded with a [1].

(V) Goals:

(15) GOALS. We used this variable when the surgeon discussed top-level goals for the operation, how they might be conflicting, or how they impact decisions made in the procedure. An example of this: 'She's so sick, I'm not worried about giving her small scars, I'm worried whether she's going to live, and so I will keep that at the top of my priority list.'

The two highest-level goals for surgery are "fix the problem," i.e. take out the gallbladder, and "minimize collateral damage," i.e. the Hippocratic principle of first do no harm, don't make things worse when you fix the problem. We looked for references to these kinds of top-level goals here. This variable was coded with a [1], and the nature of the goal was explained in the comments column.

When an event-independent variable was used, it was also tagged with a time sequence code indicating the general block of the videotape it occurred in.[22] Eleven such blocks were parsed out:

(a) Decision Point 1: Pre-video (structured questions asked before surgeon saw any videotape)
(b) First watching (think-aloud session)
(c) Decision Point 2 (structured questions after first look at operative area)
(d) Draining gallbladder (think-aloud)
(e) Initial Dissection (think-aloud)
(f) During/after first structure is clipped & cut (think-aloud)
(g) gallbladder tears open (think-aloud)
(h) Artery dissection, clipping & cutting (think-aloud)
(i) Last Structure dissection (think-aloud)
(j) Decision Point 3 (structured questions)
(k) Post-DP3: clipping last structure, drain placed (think-aloud)

The time sequence codes helped us to see what event-independent variables were frequently employed during each segment of the case. They correspond closely to the storyboard events, as can be seen in Figure 5.1.

5.3.3 Reducing Experimenter Bias in Measurement

From the beginning of this research project, reliable and unbiased interpretation of verbal protocol data across coders was a concern. Several steps were taken to anticipate where bias might occur, and to ensure that all three individuals coding the transcripts (myself and two undergraduate research assistants who had both helped conduct the interviews) were consistent. First I will describe the process used to apply measures to transcripts, and then I will discuss how reliability/consistency and preventing bias were approached.

During the coding process, two people analyzed each transcript, and then met to reach consensus on how the transcript should be coded. For each disagreement on a variable, we instituted a negotiation process whereby the coder had to defend why the proposed variable and code was appropriate. This process helped refine and clarify our variable definitions, made the coders accountable for decisions, and provided a forum for

[22] We could have saved a great deal of time had we identified this time sequence partitioning before transcribing, and had incorporated it directly on the original MacSHAPA transcripts, in the space we allocated for "video events." Instead, we had to go back and divide up the transcripts into the sections post-hoc.

discussing what new variables might capture interesting points made. All three coders used a standardized reference sheet which defined the variables and their range of responses, similar to the descriptions given in the previous section. The variables and codes were hand-written directly on printed MacSHAPA transcripts. The measurement scheme changed frequently during the period of time transcripts were analyzed. New variables were added, and variables which seemed to be yielding nothing were taken away, so the standardized reference sheet was constantly in a state of flux. Thus, it was rare that two coders had used an identical set of variables when they sat down to compare transcripts. After all twenty transcripts had been coded and justified in a consensus meeting, we had a coding scheme which was fully applied on only the most recently coded transcripts. Therefore, we reexamined and updated the variables coded in each of the earlier transcripts to make them consistent with changes which had been made. At that point, we entered the variables and codes on the MacSHAPA transcript computer files, creating a variable column for the predicate codes and another text column for comments which noted the specific transcript text reflected by the variable.

Processes used to enhance consistency in how the variables were applied were:
(1) As already mentioned, two individuals coded each transcript, ensuring a more consistent application of the measures, as well as a more thorough analysis, since more codable statements were "caught" than one person could find alone.
(2) As evidenced by the above listing of variables, we attempted to evolve and define variables to a point where there was <u>no room for misinterpretation</u>; i.e., so that information was either present or absent in a transcript. For example, "if...then" statements were always rules, and comfort level ratings, open statements and identification of structures were directly available from the transcripts. Issues that the coders raised and discussed during the negotiation process were used to tighten definitions. For many of the coded variables the literal statements from the transcripts have been included in tables or appendices so the reader can directly judge the appropriateness of the code.

With some of the variables, however, there was room for misinterpretation, if only due to the natural ambiguities of language. Such ambiguity was predominantly found in applying the metacognition variable. This variable involved five different categories which were defined as clearly as possible, but statements which could be interpreted as falling under these categories were frequently missed in the initial coding. As an example, one staff surgeon said: ". . . if his anxiety levels aren't pretty high now, he shouldn't be out there. He's up to his neck in crocodiles." This statement reflects the interviewed surgeon's assessment of what the operating surgeon's comfort level should be, and therefore should be coded under the metacognition[1] variable, general comfort level. However, it was "missed" by the two coders in the initial coding process. Since several statements were found during individual transcript analyses to have been similarly "missed," a follow-up reading of all twenty transcripts was done specifically to identify these missed metacognitive statements.

Processes used to reduce experimenter bias were as follows:

(1) Experimenters were blind to identity of transcripts which were analyzed.

(2) Transcripts were assigned to avoid confounding of independent variables with coding; no individual analyzed only staff or resident transcripts. If there were errors, they were randomly distributed across groups

Further, a major independent variable, the opener/nonopener categorization, emerged post hoc. Experimenters were thus unaware of this variable and could not have applied any systematic bias towards coding.

5.3.4 Individual Transcript Analysis

Another, more individual approach to coding each transcript was derived after the transcripts were completely coded using the above-described scheme. The data yielded using the event-dependent and -independent variables provided global descriptions of number and type of statements made. It permitted aggregating, characterizing and comparing. Hypotheses on how several variables interacted with each other were developed, such as the relationship between surgeons who decided to open and metacognition (described in chapter 8). From these hypotheses, we were able to conceive of a preliminary model describing relationships between metacognition and perceptual expertise. However, these variables did not yield an understanding of how statements referring to constraints, or indicating metacognition and perceptual inferences were *interleaved in each transcript* to influence conclusions, assessments, or the decision to open. To understand whether our hypotheses were valid, we needed to represent each individual surgeon's flow of thoughts.[23]

The representation developed reflects the spectator nature of our data collection method. Our videotape interviews could not capture interaction whereby surgeons made decisions, took actions, and used the subsequent feedback. They frequently stated what they *would* have done, but could not implement it. Consequently, a large proportion of statements in the transcripts can be classified as surgeons expressing judgments and doubts about the process unfolding on the videotape. Sometimes specific visual cues were cited and courses of action or technique were recommended. In order to see how statements which reflected metacognitive processes and consideration of constraints bounded these cues, judgments, doubts, and actions, a table was devised which classified and recorded each statement the surgeons made in the 15-minute think-aloud period and the decision point following. (I constructed these tables myself, to maintain consistency in the process.) The think-aloud segment of the transcripts was selected because it encompassed the dissection and identification of the three structures, the time period when all but two of the decisions to open were made. Responses to interview questions following this period provide deeper information and summary statements. An example of a segment of one of these tables in which a resident recommended converting is shown in Figure 5.2. Cues are coded as follows:

HC - hypothetical cues (surgeons engaged in what-if scenarios often);
AC - actual given cues (those provided by us about the patient, such as age)
VC - visual cues, seen on the video
VC/A: visual cues derived from action taken by the surgeon on the tape
Q: interview question provided the impetus for the judgment, doubt, etc.
TC: tactile cues used

[23] Thanks are gratefully extended to Jens Rasmussen for providing helpful ideas about how this could be done.

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
G. GB opens	Q: have you reached the point where you would convert?	J: I probably would earlier, in the bloodstained area, because I couldn't really see what was going on		
	Q: is this patient more confusing than you expected from the history?	J: the disease process is a little more advanced than I would have expected		meta4: I think part of the decision making in doing any type of surgery is that you have to keep reevaluating what you are doing as you go along meta4: I definitely wouldn't say it's wrong to convert b/c you knew the rest of the procedure would be like this, difficult to see, a lot more difficult than your average inflamed gallbladder
H: Artery Dissec -tion	VC/A: clipping artery	J: it looks like they are clipping the cystic duct.		
		D: They don't put the edges of scissors around the structure first to make sure they've got it isolated. Looks like they tried to see back of clips, but wasn't clearly shown		meta3: they keep on pulling at things back there, you are not going to be able to delineate structures (cystic artery & cystic duct), and making sure you are not clipping or doing something to another structure that you don't want to
I: LAST DISS		D: I don't know what we're doing here. You can't see enough to identify structures.	C: If I hadn't converted earlier, and unless I could clean all the blood out of there, I would convert to open	meta1&3: You don't know if you're on the gallbladder or are too far down. You can kind of maybe see the common duct coming up towards whoever is grasping right now. I would be very uneasy at this point.

Figure 5.2 A portion of an individual transcript analysis from a resident who decided to convert to an open procedure. The time code on the far left shows what events were happening in the videotape.

In the second column, Judgment and Doubts are labeled with either a J or a D. Actions which would be taken were also given a classifying code, as follows:

C: change entire situation or approach
V: to get visual info.
T: to get tactile info.
ST: to stay within field of safe travel
D: do experiment to diagnose
O: operate, move procedure along
NO: would NOT take action which is shown
SA: to improve SA
LA: to prevent/head off later problems
I: avoid injury now

The table reads like a MacSHAPA transcript, from left to right and with time progressing down the page. With this representation, we can isolate how each metacognition statement or constraint mentioned relates to judgments and doubts and the decision to open. We can also lift out portions of the table from a particular time code, such as artery identification, and compare the thought processes of several surgeons as they respond to that segment. These tables were used to support the analyses of surgeons who said they would open (presented in Chapter 9). The individual analysis tables for surgeons who decided to open are shown in Appendix C.

6 Rules

In the first section of this chapter, I will review the literature on rule-based theories of cognition. In the next four sections (6.2 through 6.6) I will introduce and present the analysis of rules we elicited in this research. Finally, in section 6.7 I will summarize the findings and relate them back to the literature, as well as to the chapters on Expertise and Metacognition which will follow.

6.1 Rule-based Theories of Cognition

Rules are an important part of our thought processes. But are they the only part? One would intuitively tend to think they are not. And that very intuition could stem from a rule you may apply yourself, such as "any time someone presents one and only one mechanism of thought as making up the whole process, disagree." Here I will review two different viewpoints on rules and their place in our thought processes, and how these views might contribute to an understanding of rule-based thought in laparoscopic surgery. The two viewpoints are those of Anderson (1983) and Rasmussen (1986; 1993).

6.1.1 Production Systems and ACT* Theory

Understanding rule-based thought has been an important aspect of the information processing paradigm. This paradigm's view of the human mind as an instantiation of a general purpose machine (Lachman, Lachman, & Butterfield, 1979) has led to computer-analogous frameworks and theories of cognition. With the advent of computers, testable theories of cognition came to be seen as those which could be modeled with computer programs, and since computers function as a combination of rules and sequences of rules (algorithms), a production system framework for studying thought processes was developed. Theories proposed under the production system framework include those of Allen Newell (1973) at Carnegie-Mellon and the general ACT framework and set of theories of John Anderson (1976; 1983). In general, production systems theories hold that condition-action pairs known as productions, often instantiated as if/then rules, provide the underpinnings of cognition. Anderson (1983, p. 6) states, "one might conceive of production systems as 'cognitive S-R theories,' despite the contradiction in the connotations of those terms." They are "in part programming languages for computer science and in part psychological theories."

Anderson (1983, p. 6) gives the following example of a production system's condition-action pair: "If person 1 is the father of person 2, and person 2 is the father of person 3, then person 1 is the grandfather of person 3." Anderson's (1983) ACT* (pronounced ACT-star) theory proposes that if the first two statements, the conditions, are in working memory, they will activate a production rule in production memory which produces the action "then person 1 is the grandfather of person 3." The action is typically the depositing of the new information into working memory. The major components of the general ACT framework are working memory, production memory, and declarative memory. Declarative memory acts as a storage and retrieval depository, similar to long-term memory in other familiar theories. Working memory is the "desktop" which holds current working information available for use, in the typical sense. The production memory is unique to this theory. It is essentially a long-term store for procedural knowledge. Production memory is linked to working memory so that when conditions in working memory "match" a production rule in production memory, that production is transferred into working memory and executed. Production memory is sometimes referred to as "procedural memory," since it transforms the facts known from declarative memory into a procedure by which they can be used (via a process called knowledge compilation). This distinction between declarative, or factual knowledge (which Anderson calls *knowing that*) and procedural knowledge (called *knowing how*) is a fundamental characteristic unique to ACT theories. Anderson distinguishes between the learning involved in these two memories as well: procedures are only learned by doing, whereas declarative knowledge is added by simple encoding of facts.

The ACT theories have evolved to show how elemental procedures can be combined into more complex chunks of behaviors (through *composition)* which are learned through practice, and how procedures can become automatic (in terms of Schneider & Shiffrin's (1977) automaticity). Understanding the acquisition of skills has been a major theme in Anderson's work (see Neves & Anderson, 1981).

6.1.2 Can ACT* Help in Understanding Laparoscopic Surgery?

Research based on production systems has made a well-acknowledged contribution to our understanding of cognition, and provides a good illustration of the importance of rules in cognitive theory. It also shows how psychological theory and computer programming have become tightly coupled in the information processing paradigm. I have only provided a short and shallow description of Anderson's complex theory. How might it help us to understand rules in laparoscopic surgery? A great deal of the knowledge learned in medical school and in residency programs exists in the form of stored rules. Activities or tasks in surgery might be modeled as a production system according to the ACT* theory. As a rough start, we could say, "IF the goal is to remove the patient's gallbladder safely, THEN the subgoal is to provide access to the operative area." And then, "IF the goal is to provide access to the operative area, THEN ensure the patient is ready, and make an incision, and insufflate the abdomen to prepare it for surgery." There would be several if/then relationships which would need to be specified for each of these activities. If you could elaborate the if-then relationships which should underlie each action taken to do the surgical procedure, you could possibly help an intern or resident understand what information to consider when performing these activities. Such a listing of goals and steps would be a product of a behavioral task analysis. In this research, I have not elicited the kind of information from surgeons which might support such a model.

According to Rasmussen & Vicente (1990) humans working both in natural environments and complex man-machine systems have sensori-motor capabilities which are highly efficient and which probably defy capture as if-then rules, and which therefore cannot be captured by a production systems architecture such as Anderson's. The problem lies in Anderson's idea that a skilled performer has simply practiced procedures at what he would call knowledge-based level of control until they become automatic. Rasmussen (1993) takes issue with this idea. He proposes that a shift in level of task performance from knowledge-based towards an automated skill-based control involves a *deterioration of the rule system,* or the conscious declarative and procedural knowledge; in its place a new, holistic representation of the system evolves, and several other complex parameters change as well. This shift in level of expertise may lead to errors as the operator first becomes accustomed to functioning at the new level; Rasmussen et al. (1994) use the example of pilots who have about 100 hours of flying time being particularly error-prone, possibly due to making this transition between levels of control.

Dreyfus & Dreyfus (1986, p. 152) provide support for Rasmussen's view of skill development in the following example:

> "In the Air Force, instructor pilots teach beginning pilots how to scan their instruments. The instructor pilots teach the rule for instrument scanning that they themselves were taught and, as far as they know, still use. At one point, however, Air Force psychologists studied the eye movements of the instructors during simulated flight and found, to everyone's surprise, that the instructor pilots were not following the rule they were teaching.[1] In fact, as far as the psychologists could determine, they were not following any rule at all. The instructors, after years of experience, had learned to scan the instruments in flexible and situationally appropriate ways."

Assuming that these examples from aviation would transfer to the complex environment of surgery, Anderson's idea that new procedures compile into more automated ones may not be an accurate way to think about rules and procedures as they evolve with extensive experience.

In addition, both the scope of the declarative and procedural knowledge required and the elements of the situation which make it ideal for study under a naturalistic paradigm would cause problems for an ACT* modeler in the operating room. For instance, the problems are ill-structured, and goals are ill-defined and sometimes changing or conflicting. Rules often are dependent upon the skill level of the surgeon, since what one surgeon is comfortable with is outside the boundaries of experience of another. A set of productions could not be defined which would hold for all surgeons. It is possible that these difficulties are why ACT* has not been used to model behavior in complex systems. Solving geometry problems, simple pattern matching, and a lexical decision task are production systems Anderson (1983) uses to exemplify research on ACT*.

6.1.3 Rasmussen's Rule-based Level of Cognitive Control

Rasmussen's alternative view of the role of rules in cognition, which has already been briefly described in the context of the skills-rules-knowledge levels of cognitive control (see Section 3.2.3), will be discussed next. A rule according to this approach is

[1] See DeMaio et al., 1976.

quite different from an ACT* rule. ACT* production rules are ways to combine goals and facts into procedures, and they are the primary structure for relating a sequence of actions. Rasmussen's rules, on the other hand, are called into play when a situation is anticipated which skill-based control cannot handle, and for which the operator has knowledge from previous experience which can help him or her decide how to proceed. If a situation requiring rule-based knowledge is foreseen, stored rules can be remembered and pre-positioned to permit operation to continue smoothly (Rasmussen et al., 1994). Implementing these rules can allow an operator to avoid the time-consuming and effortful knowledge-based analysis needed if no rules are available. Rasmussen (1993, p. 166) states of rule-based behavior: "control of behavior at this level is goal oriented, but structured by 'feed-forward control' through a stored rule. In other words, the person is aware that alternative actions are possible and has to make a choice." The choice is made according to information in the environment which indicates that a certain course of action will work, similar to a recognitional process as described by Klein (1989). Only the cues which are needed to point clearly to one action alternative will be used; this concept has ties to Herbert Simon's (1955) concept of satisficing.

6.1.4 Rasmussen's Rules in Laparoscopic Surgery

The rules surgeons used in discussing how they would approach the gallbladder removal of our very sick 80 year old woman are more consistent with Rasmussen et al's (1994) approach than with production system-type rules. Cue-action associations were cited frequently. There were configurations of information and hypothetical cues which some surgeons stated would indicate they should convert to an open procedure. For example, if the gallbladder is gangrenous, if you can't decompress the gallbladder, if it is so edemetous[2] that it is plastered down into the liver and no neck region is identifiable, and if you are uncomfortable were all reasons different surgeons gave for converting. A frequently mentioned rule which fits Rasmussen's description of goal-oriented, feed-forward control was "if you can't grasp the gallbladder, then decompress it." This course of action would allow a surgeon to retract the gallbladder so that he or she could keep operating laparoscopically; without decompression the only alternative would probably be

[2] Edemetous means filled with edema and swelling; inflamed.

to open. The fact that the rules we found were heavily loaded towards the beginning of the interview indicates that surgeons' rule use may be more anticipatory than reactive, which is consistent with Rasmussen's description (26 of the 63 rules we found in all 20 transcripts were stated before surgeons saw any video; 50 of them were stated before any structures were dissected or identified).

6.1.5 Summary

There are three major points to be summarized here about rule-based cognition. The first is that expert performance is more than just combinations of procedures. We should be wary of the tendency to think experienced humans think and act in the same way as novices, only faster. Many aspects of performance change as expertise is gained, including the development of a more holistic "world model" and increased use of intuition. The second point is how we can rely on analogues from familiar situations which match with the present one, as Rasmussen et al. (1994) propose; a simple match recognition-primed decision model (Klein, 1993) characterizes this process. Thirdly, as analogues accumulate and are compiled, to borrow a term from Anderson (1983), pieces of information within a specific context can trigger an appropriate action. For instance, "if liver enzymes are markedly up and the patient is very sick, then there is probably a common bile duct stone, and you should remove the gallbladder with open laparoscopy." This type of rule depends on knowledge about the symptoms and progress of disease as well as preferences and experience.

6.2 Approach to Analysis of Rules

The rule variable was used any time an if-then statement was found in the interview transcripts. We never specifically asked a surgeon for any rule; they all were stated in response to other questions or as a part of the general think-aloud process. In analyzing these rules, we laid them out along a timeline, and looked for commonalities, clumpings/groupings, and trends. There were 64 rules coded in all. Of those 64, 43 were rules which pertained to opening. Upon close examination of these rules, a general "cue-action" trend surfaced again and again, and so I began to look at the decision ladder as a way to sketch out these rules. Once I had clearly defined the knowledge states and information processing activities on the decision ladder, it was fairly unambiguous to map these rules onto ladder nodes. Only one rule, "if you don't like what you see, then open," defied this mapping process; this fits into the "intuitive affect" type of decision rule described by Sage (1981).

Only one of the twenty surgeons interviewed did not state any if-then rules. The surgeons made about 3 rule statements each, on average; the range for each surgeon was from 0 to 8. Staff surgeons averaged just slightly more than residents in number of rules cited, 3.6 as opposed to 2.9 rules each (this difference was not found to be statistically significant). Those rules which were metacognitive in nature (there were fifteen) were formed into a separate category. Thirteen of these fifteen metacognition rules pertained to opening.

There are several ways that these data can be analyzed. I have chosen to focus on three specific aspects of the rules which will be discussed in the following three sections. First, I will present and discuss the rules relating to opening, as to their content, decision ladder mapping, and validity. Second, I will treat the non-opening rules in the same way. This organizational scheme categorizes the rules via their outcome (opening or not). Finally, I will delve into the rules which are metacognitive in nature, and discuss these rules in terms of Rasmussen's (1986) skills-rules-knowledge framework.

Agreement ratings. Before discussing the rules themselves, I will introduce the agreement ratings solicited for these rules. We interviewed twenty different surgeons, each of who may have had differing opinions as to how this difficult case should be approached. The danger inherent in this research is presenting a unique and seemingly innovative train of thought, only to find that other surgeons see it as inappropriate. And the fact that only one surgeon mentions a particular rule does not mean it is rarely considered or that few surgeons would invoke it. As an outside investigator, I have no way of knowing whether rules are well-accepted or agreed upon. In order to gain a measure of consensus for these rules, as well as for the perceptual expertise statements, predictions, and techniques, two staff surgeons involved in this research were asked to rate their agreement with the statements. The raters were not among the twenty surgeons interviewed in this research, but one provided an early pilot interview and the other helped in editing the case for the interviews, so both were familiar with the videotape and case context. The question was phrased, 'I agree with the inference, prediction, or recommended action shown to the following extent: 1, totally disagree; 2, mildly disagree; 3, I am neutral; 4, mildly agree; and 5, totally agree.' The average rating of the two surgeons for each opening rule is shown in Table 1, and the same is shown for those not involving opening in Table 3. In some cases, the context of a statement was not clear to the raters, and they were not able give a rating; these are labeled 'nr.' Metacognitive rules had some of the highest agreement ratings; those will be presented and discussed in section 6.5.

The ratings also permitted an examination of whether staff surgeons' rules have higher levels of agreement. There were 29 rules which residents cited; they averaged 3.55 on agreement. The 35 staff rules were rated 3.74 on average. A one-way analysis of variance on the ratings showed no difference in the agreement ratings of staff and resident rules.

6.3 Rules for Opening

The surgeons interviewed expressed a wide variety of rules with regard to opening. As we would expect, these rules also took the form of a variety of mappings on the decision ladder. The fact that virtually all of the rules coded could be mapped upon a decision ladder leads to the conclusion that surgeons are using if-then pairings as decision rules, which help them associate certain pieces or combinations of information with a course of action (or are using action to seek out needed information). Defining the nodes on the decision ladder was an important part of this process. Working definitions used to map each rule are shown in Figure 6.1, along with another view of the decision ladder. Deciding to open has been mapped onto the decision ladder as a "Definition of Task" activity, since it involves changing the overall approach to the task and because there are many subtasks and plans to be considered before actually executing the procedure of conversion (shown on the lower right of the decision ladder).

There are four primary categories of if-then statements which surgeons made about opening. (The fourth category spanned several types of initiating information, but were

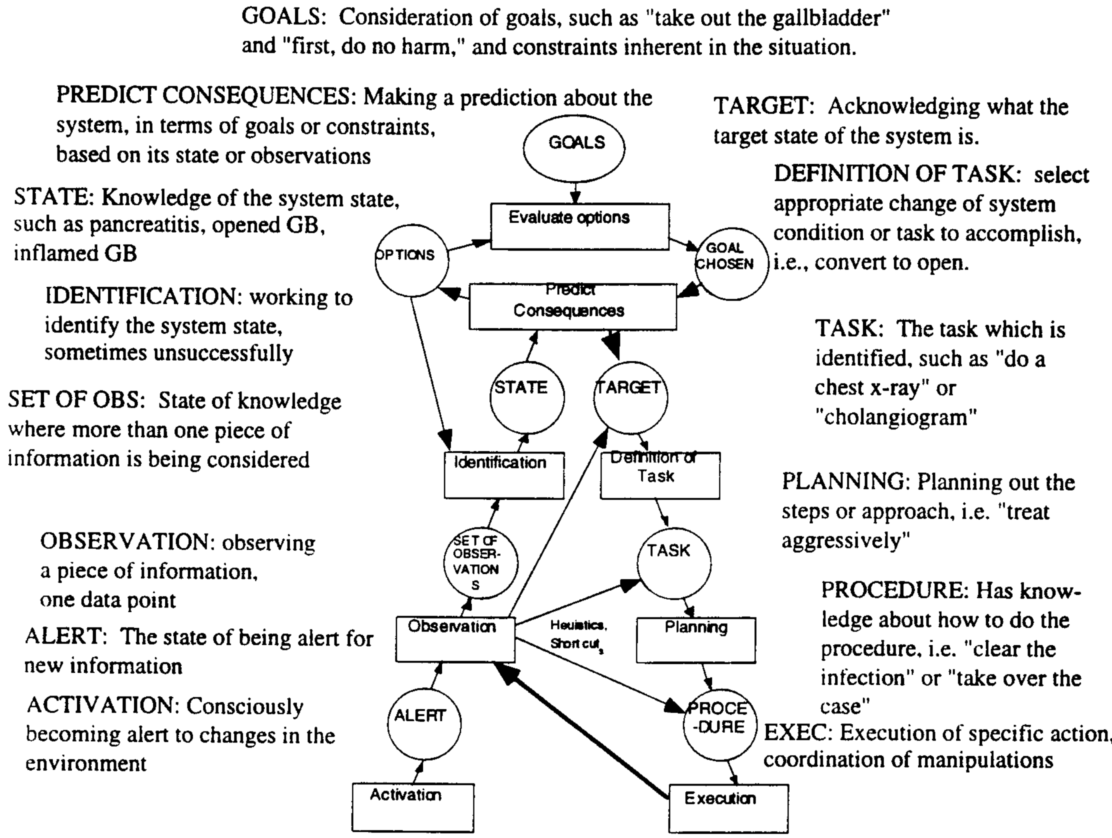


Figure 6.1. Rasmussen's decision ladder, annotated with definitions used to map decision rules from surgeons' transcripts onto ladder knowledge states (circles) and information processing activities (rectangles). From Rasmussen et al., 1994, Reprinted with permission, © John Wiley & Sons, Inc.

categorized as metacognitive rules; these will be discussed separately in section 6.6.) First are those in which the initiating information was stated as a sole *observation* or a *set of observations*, which can be seen on the left side of the decision ladder in Figure 6.1. Rules which directly linked an observation or set of observations with opening are shown in Table 6.1, rules 1-6 and 15-17. For instance, one sole observation was "if there is a lot of pericholecystic fluid,[3] then this is not a case that can be done laparoscopically." Other observations which might lead to opening were pus in the gallbladder, color of the gallbladder, discovering the gallbladder is filled with one huge stone, observing stones in the duct or a gallbladder 'plastered down' with adhesions, or a combination of laboratory values. Agreement ratings for the single observation rules were neutral at best, possibly because surgeons use a set of information rather than just one fact in the decision to open.

[3] Pericholecystic fluid is fluid around the gallbladder, indicating inflammation of tissues.

Second, surgeons noted a *state* of the system (usually the patient) which would lead them to open. These rules began at the "System State" knowledge state on the decision ladder and leaped to the Definition of Task activity. Eight of these rules which linked System State with Definition of Task are shown in Table 6.1. As an example, one surgeon stated "If the patient is hemodynamically unstable, then it is likely we will open this procedure."[4] Other patient states which surgeons felt would lead to conversion were a gangrenous gallbladder and a patient who is septic, or who has cholangitis (inflammation of the bile duct). In another three rules (18-20 in Table 6.1) the state of the patient was used to predict that the patient would not be able to undergo laparoscopic surgery, i.e. "if the patient is too sick for regular surgery, then will be much too sick for laparoscopic surgery." Many of the rules cited were hypothetical. In citing these rules, surgeons did not say what specific observations would lead to a judgment that the patient was in that state. To differentiate between the state-initiated rules and the observation-initiated rules, consider a rule which would include both observation and state. Suppose the following rule was stated by a surgeon: "if the gallbladder was green and black, I would know it was gangrenous, and would open." This rule would be mapped onto the decision ladder as Observation (green & black), State (gangrenous), Definition of Task (open).

Third, and least frequently, surgeons cited an *action* that was tried, or could be tried to gather information, such as "If you can't retract the GB, you have to open." These rules began at the "Execution" activity on the decision ladder, jumped to monitoring or observation of the results of the activity, and eventually ended at the Definition of Task activity. The four execution-initiated rules for opening are shown in Table 6.2, along with the decision ladder figure representing them. Three of these four rules are related to whether the surgeon would be able to retract the gallbladder to begin dissection. In addition, four of the five *non-opening* rules beginning with 'execution' also have to do with grasping the gallbladder, and how the inability to do so requires decompression of (aspirating the fluid out of) the gallbladder (see rules 15-19 in Table 6.3). For any patient, not being able to grasp the gallbladder is a potential stumbling block. One staff surgeon said three times, "if you can't retract the gallbladder, you have to open." Draining fluid out

[4] Hemodynamics is the study of how blood flows throughout our bodies, and the forces which guide that flow.

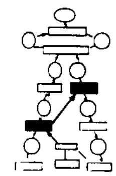
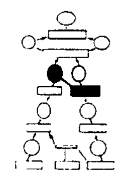
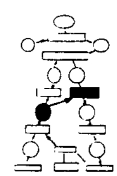
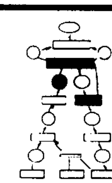
If...	Then...	rat.	Decision Ladder Mapping
1. If GB contains frank pus	then you should open (said 2x)	2	OBSERVATION-DEFINITION OF TASK 
2. If deep deep purple color GB, almost black	indicates you should open*	3	
3. If see creamy pus in bile	then open	1.5	
4. If lot of pericholecystic fluid	then this is not the kind of case that can be done lap*	nr	
5. If the surface were dull, almost a white opaque	you would have to open*	2	
6. If there's one great large stone	then probably will have to open*	2.5	
7. If Gb is mottled or gangrenous	then open*	3.5	STATE-DEFINITION OF TASK 
8. If GB is gangrenous	you have to do an open procedure	3.5	
9. If GB is gangrenous	then open	3.5	
10. If very ill from GB	start open*	4	
11. If there are signs of cholangitis (inflamm. of bile duct)	then open*	4.5	
12. If patient is septic	then you should do an open procedure	3.5	
13. If patient is hemodynamically unstable	then likely to open	4.5	
14. GB opening is indication	you should convert to open	1.5	
15. If had stones in duct	then would do an open cholecystectomy*	2.5	SET OF OBSERVATIONS-DEFINITION OF TASK 
16. If bilirubin is greater than 3 and there is a high amelase and alphatase	then start open *	3.5	
17. If gallbladder is too edemous or plastered down, no tissue will be seen, no neck region	then would open*	4.5	
18. If too sick for regular surgery	then much too sick for laparoscopic surgery*	4	STATE-PREDICT CONSEQUENCES-DEFINITION OF TASK 
19. If very sick (infer 'septic')	would not be safe for even an open procedure	2	
20. If pt comes in after 4-5 days of infection/fever	then could not do it laparo-scopically	3.5	

TABLE 6.1. Twenty rules for converting to an open procedure, along with surgeon ratings. Rules which were stated by staff surgeons are noted with an asterisk afterwards.

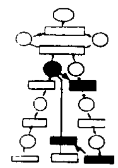
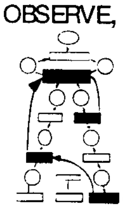
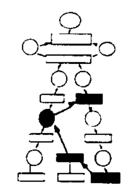
If...	Then...	Decision Ladder
1. If can't retract GB	then have to open (said 3 times)	EXECUTION, MONITOR, STATE, DEFINITION OF TASK 
2. If can't decompress the gallbladder	it can't be grabbed and have to open	
3. If GB rips to pieces when you pull up on it	then it won't be able to be done laparo-scopically	EXECUTION, OBSERVE, PREDICT CONS., DEF. OF TASK 
4. If put trocar in and see a gallbladder like that	you should open	EXECUTION, MONITOR, SET OF OBS., DEF. OF TASK 

Table 6.2 Rules for opening which were initiated by execution of action.

to provide a less taut, more graspable gallbladder was a well-accepted procedure for continuing laparoscopically (see agreement ratings in Table 6.3).

Rasmussen's (1986) rule-based cognitive control, discussed in the introduction to this chapter, submits that rules are called into play when a situation is anticipated which skill-based control cannot handle, and when the operator has knowledge from previous experience which can help him or her decide how to proceed. These rules can be pre-positioned and implemented to allow the operator to quickly access relevant knowledge when an anticipated situation arises. For instance, one staff surgeon said, "If the gallbladder is too edemetous or plastered down, no tissue will be seen, and no neck region, and I would open." This comment was made during the initial dissection, when the surgeon was anticipating how the tissue around the primary structures to be identified would look. It is a pre-positioned rule which allows the surgeon to make a decision to open based on a level of inflammation which would impede dissection or identification of structures. However, there is judgment involved as well, since "too edemetous" is likely to be a matter of experience and other factors. Stored rules which are pre-positioned to avoid a knowledge-based analysis can thus be subject to interpretation. A more clear-cut rule, which a staff surgeon stated during decision point 2, before any dissection, was "If the gallbladder rips to pieces when you pull up on it, then it won't be able to be done laparoscopically."

But there are very few rules which surgeons would agree stand alone in the decision to open. Situations in surgery are not that simple. The decision depends upon ability, team members, time pressure, perceived indications of the patient's state of disease, and whether this surgeon had a particularly bad experience in a similar situation recently. In addition, there is difficulty in interpreting these rules because often a great deal of information is left unsaid. For instance, "if you put a trocar in and see a gallbladder like that you should open" gives no information about what the surgeon saw which indicated opening, no assessment of the observations and resulting progression of disease or of the risks which are inherent in continuing laparoscopically. The surgeon's individual transcript provides the background and context of the reasons for this statement. What makes sense to one surgeon within a context may not be understood or agreed upon by others. Thus, although we noted many different rules for opening, whether these rules can "stand alone" as truth in any situation is questionable.

6.4 Rules Not Involving Opening

The 19 rules coded which did not relate to opening are shown in Table 6.3. Most fell into the same general decision ladder categories as the rules for opening: those rules

Rules (Not involving opening)	Decision Ladder	Ratings
1. If swollen gallbl., be more cautious on port entry*	OBSERVATION-PLANNING	3
2. If amelase elevation , it suggests pancreatitis, delay surgery until resolved or improved*	OBSERVATION-STATE-DEFINITION OF TASK	5
3. If see shadow of stones then the gallbladder is soft enough to grasp (stop draining)	OBSERVATION-STATE-EXECUTION	4
4. If resident is brushing structures, he is stalling and I may take over*	OBSERVATION-STATE-PROCEDURE	3.5
5. If white bile then complete obstruction, do a cholangiogram	OBSERVATION-STATE-TASK	3
6. If liver enzymes mildly elevated, do ERCP if you can do it within 24 hours*	OBSERVATION-TASK	2
7. If you can clear infection then inflammatory response won't be as much	PLANNING-PROCEDURE-PREDICT CONSEQUENCES	3.5
8. If dark, distended, bleeding, adhesions, indicates gangrenous GB that will have to be drained*	SET OF OBSERVATIONS-STATE-PLANNING	2.5
9. If over 40 and have symptoms then need chest x-ray*	SET OF OBSERVATIONS-TASK	4.5
10. If elevated bilirubin or alkphos do an ERCP pre-op to rule out common duct stones	SET OF OBSERVATIONS-TASK	3.5
11. If electrolytes are out of wack then give patient a potassium bolus	SET OF OBSERVATIONS-TASK	4.5
12. If pt. is active, then treat post-op pneumonia aggressively	STATE-PLANNING	2.5
13. If nursing home DNR (do not rescusitate) patient then wait for family's okay to treat	STATE-PLANNING	3.5
14. If it's really inflamed then you need a drain	STATE-TASK	2
15. If you can't grasp the gallbladder you have to decompress*	EXECUTION-MONITOR-STATE-TASK	5
16. If can't grasp GB then decompress	EXEC-MONITOR-STATE-TASK	4.5
17. If can't grasp GB then decompress	EXEC-MONITOR-STATE-TASK	5
18. If can't grasp GB then decompress (said 3x)	EXEC-MONITOR-STATE-TASK	5
19. If you decompress the GB the blood will come back and it won't look as blue	EXEC-PREDICT CONSEQUENCES-MONITOR-OBSERVATION	2

TABLE 6.3 If/then rules invoked which do not involve opening, and which were not metacognitive. The rules are grouped according to their decision ladder mapping initiation state. Ratings shown at right are an average of two surgeons' agreement ratings on a scale of 1 to 5 where 5 is "totally agree." Rules stated by a staff surgeon are followed by an asterisk.

which begin with (1) observations or a set of observations, (2) the state of the patient, (3) execution of a task or procedure. However, unlike the rules for opening, these rules have many different end states on the decision ladder, as characterized by the 'then...' portion of the rules. Many of these rules recommend a task be accomplished, such as decompressing the gallbladder, doing a cholangiogram, or placing a drain before closing up the abdomen.

These rules seem to fulfill different functions. Some serve as a warning, such as number 1, "if the gallbladder is swollen, be more cautious on port entry." (also see 2 and 8) Some are for moving the operation along, such as number 3, "if you see the shadow of stones then the gallbladder is soft enough to grasp, and you can stop draining." Most of these rules pertain to different procedures, diagnostic tests, or treatments which should be administered, such as number 9, "if over 40 and have symptoms then the patient needs a chest x-ray" (10-18 also fall into this category). Agreement ratings were fairly low for most of these rules, with the exception of the "if can't grasp the gallbladder then decompress," which was stated several times by different surgeons.

6.5 Metacognition Rules

Fifteen of the rules surgeons invoked were labeled "metacognitive." These were rules in which surgeons verbalized a pre-positioning of concern that either the structures will not be identified correctly, or there will be an injury to a nearby structure, or both. They are labeled metacognitive because the surgeons indicated how they would monitor themselves more closely, how lack of comfort or of clear identification, or possibility of injury are good reasons for opening (metacognition will be more extensively defined in chapter 8). These fifteen rules are shown in Table 6.4. Thirteen of these were rules for opening.

The metacognitive rules follow a definite trend over the course of the operation. The far left column of Table 6.4 shows when in the videotape interview each rule was elicited. Up through decision point 2 (which is just before the gallbladder is decompressed and the real dissection begins) surgeons seem to be warning themselves that this patient is at a high risk for injury. At this point, the rules which surgeons agreed strongly on (both surgeons rated these a 5) were quite general: "if you don't like what you see then open," "if you can't proceed without injury then open," "if can avoid duct injury by doing it open then open," and "if uncomfortable then open." Two of these rules were stated by one resident, and two by one staff surgeon, neither of whom indicated they would convert anytime during the procedure. Although these rules are probably reinforced heavily within the surgical community, they are not so clean-cut as observing a big mass at the head of the pancreas and opening as a result. No surgeon sets out to injure a common bile duct, and often they don't realize it when they do. If you are a resident, if is harder to define whether you like what you see, or you are uncomfortable, since there tend to be more situations you have not encountered. Surgeons are thus in agreement with the spirit of these metacognitive rules, but there is a large amount of leeway in applying them.

After decision point 2, when dissection of the three structures was shown on the videotape and during decision point 3, metacognitive rules illustrate doubts about the identity of structures. This is natural, since three structures are clipped and cut and this is one more than is necessary for a laparoscopic cholecystectomy. Again, the rules are subject to a great deal of individual interpretation. Self-knowledge as well as confidence is needed to announce to the rest of your operating team, "I have doubts about what I've cut here, and therefore we're going to open," or "I can't identify the cystic duct, so we're going to open."

Since these rules have been presented along with their decision ladder mappings, the assumption is that all of them represent rule-based cognitive control as defined by Rasmussen (1986). The metacognitive rules challenge this assumption. I have represented the rule, "If you are uncomfortable, then you should open" as STATE-DEFINITION OF TASK in decision ladder terms, using STATE to represent the state of the surgeon, which is uncomfortable. However, this rule seems to span all three levels of cognitive control. According to Rasmussen (1993), skill-based control is characterized by subconscious interaction, where a surgeon directly perceives the affordances of the environment. Feeling uncomfortable about being able to safely continue laparoscopically must occur partly on a subconscious level; if it could be defined rationally in terms of cues, then "feeling uncomfortable" wouldn't be given so much credence. In knowledge-based control, a surgeon keeps goals firmly in mind while working through a plan, and possible mental simulations for dealing with an unknown situation. Feeling uncomfortable is defined in relationship to accomplishing the goal of safe gallbladder removal, and surgeons often try various techniques or continue to dissect in hopes of mitigating their discomfort. To illustrate the ambiguity of discomfort, and how trial and error is used to mediate it, consider the following quote from a staff surgeon at the last decision point:

Time Segment	Rule	Decision Ladder	Rating
a. Decision Point 1: pre-video	If the gallbladder's been sitting more than 48 hours then more likely to have injury because it's thick and inflamed*	SET OF OBS-PREDICT CONSEQUENCES	4
b. Decision Point 1: pre-video	With this pt, if there is anything at all wrong (previous surgery) start open	ALERT-OBSERVE-SET OF OBS-DEF. OF TASK (DOT) (OPEN)	3.5
b. Decision Point 1: pre-video	If you don't like what you see then open	(NONE: INTUITIVE AFFECT) (OPEN)	5
c. Decision Point 2	If uncomfortable then open	STATE-DOT (OPEN)	5
c. Decision Point 2	If anything amiss (anesthesia, insufflation) then open*	ALERT-OBS-SETOBS-DOT (OPEN)	4.5
c. Decision Point 2	If can't proceed without injury then open*	GOAL-PREDICT CONS-DOT (OPEN)	5
c. Decision Point 2	If can avoid duct injury by doing it open then open*	GOAL-PREDICT CONS-DOT (OPEN)	5
c. Decision Point 2	If uncomfortable then open	STATE-DOT (OPEN)	5
e. Initial dissection	If doubts about identity then do a cholangiogram	GOAL-PREDICT CONS-TASK	4.5
f. Lymphcut	If can't id CD and the point where CD meets CBD then open	IDENTIFY-DOT (OPEN)	2.5
f. Lymphcut	If at point where just irrigating and not identifying anything then consider opening*	IDENTIFY-EXECUTE-DOT (OPEN)	3
i. Decision Point 3	If doubts about what clipped or cut then he should open*	EXEC-ID-DOT (OPEN)	4.5
i. Decision Point 3	If can't id cystic duct then open	IDENTIFY-DOT (OPEN)	5
i. Decision Point 3	If don't identify CD and CBD in 5-10 min then would open*	IDENTIFY-DOT (OPEN)	3
i. Last structure dissection	If can't id the duct next then open*	IDENTIFY-DOT (OPEN)	4.5

Table 6.4 Metacognitive Rules, their decision ladder mappings, and agreement ratings on a scale of 1 to 5 where 5 indicates total agreement. Staff surgeon rules are followed by an asterisk.

"I'm not comfortable with this dissection. I'm not sure, if I could feel it

> myself, if that would make a difference as to whether I'm going to open, but I'm still not comfortable at all with how this is going. At this point in the case, I want to know definitively where everything is, and I don't. So I would not be hard on myself right now if I said, let's just open, let's get out of here. But I also think, I've gotten this far, maybe I'll just take a few more minutes and I'll be able to successfully do this laparoscopically, maybe just a little more dissection and everything will become crystal clear."

Thus, one could make an argument that all three levels of cognitive control contribute to understanding of a metacognitive rule such as "if you are uncomfortable, then you should open." The intuitive side of decisions will be addressed more in the next section, and metacognition in general will be looked at in greater depth in the chapters 8 and 9.

6.6 To Sum Up: What About Intuition?

Dreyfus & Dreyfus (1986) feel that the rule-like production system aspects of human thought which can be modeled on a computer miss an important aspect of thought which is less analytical, and more intuitive. They suggest that there are risks inherent in a so-called "machine view of mind." Like Rasmussen, they have found that experts do not merely automatize the stepwise procedures they learn as novices, and they warn that computer-aided instruction should not try to force more experienced operators into procedures which are appropriate for early learners.

Dreyfus & Dreyfus (1986) begin their book by describing a historical debate between philosophers which is relevant to a rule-based view of cognition. Philosophers on one side of the debate, beginning with Socrates and Plato, held that there are logical relationships which define perception and understanding; this is the rationalist view. Dreyfus & Dreyfus write:

> "Plato . . . loved mathematics and thought that if one put aside cooks, craftsmen, poets, and all the others acting on mere skill and intuition, it would be possible to find a whole system of theoretical, objective principles, which like the truths of geometry, could be defended in rational argument and used to explain nature and justify actions. It was this claim that nurtured the main line of our Western philosophical tradition." (Dreyfus & Dreyfus, 1986, p. 2)

The opposition consisted of those who felt the skills of cooks, craftsmen, poets and the like are a large part of what should be accounted for, and excluding them puts a theory out of touch with everyday experience. Plato's student Aristotle took this view, and it was eventually taken up by the mathematician Pascal. "In deciding what to do, Pascal said, one had no choice but to trust one's emotions and intuitions. As he put it, 'The heart has its reasons that reason does not know.'" (Dreyfus & Dreyfus, 1986, p. 3) Dreyfus & Dreyfus trace this debate through to the present day. Like Anderson, they employ the terms "knowing how" and "knowing that," asserting that our everyday functioning in the world cannot be reduced to a hierarchy of rules for applying facts (knowing that), but is based on how flexibly we can adapt to current situations (knowing how).

Dreyfus & Dreyfus therefore have been vocal critics of modeling thought on computers, and of the optimistic claims of the artificial intelligence movement. They feel that rule-based processing is all a machine is capable of, and that this processing misses the "knowing how" element that many philosophers believe is an important part of our perception and understanding. There is no reference to Anderson's ACT framework in Dreyfus & Dreyfus' book, or commentary of how Anderson implements 'knowing how' under a production system framework. The two seem to adopt different views of 'knowing how.' Anderson's "knowing how" stems from procedures which have been 'compiled' or are currently being learned and are stored as such, awaiting a 'trigger' from a set of conditions in working memory. The 'knowing how' of Dreyfus & Dreyfus seems to defy storage as procedures, but rather to consist of a flexible adaptation to conditions which are encountered, based on an individual's cultural and experiential background.[5]

In conclusion, the literature on rule-based cognition and some empirical evidence about rules in surgery have been presented. There is a great deal of common ground between the two, in that most of the rules we have documented fit well within the framework of Rasmussen's decision ladder and skills-rules-knowledge framework. Often the rules surgeons cited could be interpreted in different ways, and required judgment for application (i.e., how is 'too sick for regular surgery' defined?) The rules, however, were only a small part of what surgeons expressed in relationship to the challenging case

[5] It is difficult to explain the Dreyfuses' position because of the difficulty in defining terms such as "intuition" and "common sense" as psychological concepts. To provide one viewpoint, Chaplin's (1985) *Dictionary of Psychology* defines intuition as "direct or immediate knowledge without consciousness of having engaged in preliminary thinking," and common sense as "the practical understanding and good judgment that folklore attributes to the common man."

presented to them, and many of the most well-supported rules, the metacognition rules, were so general that it would be impossible to define when they should be applied outside of a given context. In the following chapters, I will examine variables associated with perceptual expertise and metacognition, further emphasizing that rule-based knowledge is only a part of the cognitive picture in a complex environment such as surgery.

7 Expertise

> *Vague notions of "experience" and "practice" obscure what is undoubtedly the socially most significant issue in the study of expertise, the issue of why there are such great differences in competence among people with equivalent amounts of experience and practice. No one is disturbed by the fact that experienced physicians are better at diagnosis than interns. We are all disturbed by the possibility that our health may fall into the hands of physicians whose diagnostic expertise has not kept pace with their years of experience.* (Scardamalia & Bereiter, 1991, p. 191)

7.1 Introduction

In the last chapter, I presented a discussion of rule-based cognition and the rules surgeons invoked during our interview study. Rules play a large part in expertise. The artificial intelligence movement has been based on the idea that intelligence can be coded as production system rules, and expert systems are typically developed from rule-based instantiations of expertise, although the problem of incorporating common sense into these systems is well-recognized. What is it about expertise which goes beyond the capabilities of artificial intelligence and expert systems? Dreyfus and Dreyfus (1986) feel that intuition is left out. Shanteau (1992) questions whether expert characteristics such as highly developed perceptual and attention abilities, understanding what information is relevant and irrelevant to a problem, communications skills, adaptability to changing task conditions, and adaptability to exceptions can be incorporated into expert systems. Another view comes from Bereiter and Scardamalia (1993), who discuss informal knowledge, impressionistic knowledge, and self-regulatory knowledge as influences which are critical to everyday thought as well as to domain-specific expert performance, yet which could not be incorporated into a rule-based system.

The approach I will take to frame and discuss expertise in surgery departs from the view that expertise forms as a simple function of time and experience. As Scardamalia & Bereiter (1991) indicate in the quote beginning this chapter, there are far too many examples of "experienced nonexperts" who have put in the time, and developed an extensive knowledge base, but lack other characteristics which are necessary for the development of expertise over this time. Another reason for this departure is the revolutionary introduction of new surgical procedures and technologies in the current era of endoscopic surgery. Development of new tools and procedures levies massive requirements on a surgeon's time just to keep pace, and at a point in time when a new procedure is introduced, I would argue that there isn't anybody who is expert at that procedure. It is true that the knowledge base a surgeon brings to bear on learning a new procedure significantly impacts knowledge-based functions, but in terms of skill-based control, surgeons can only be more or less expert at a new task.

This departure from a time- and exposure-dependent formation of expertise leads to questioning a stage model of expertise in which the progression from novice to expert is described; the most well-known of these models seems to be Dreyfus & Dreyfus' (1986) five-stage model. The terminology, "expert-novice differences" also is seen in a new light when the expertise-experience correlation is questioned, since in the medical domain research examining these differences has typically compared diagnostic thought processes and knowledge between a group of individuals with experience in the area and those with less or no experience. An original intention of my research *was* to examine expert-novice differences in surgery. However, surgeons collaborating with us told anecdotes illustrating the non-linear relationship between years of experience and formation of what is known as good surgical judgment. Resident programs spend a lot of effort to "weed out" their residents who do not show promise of evolving towards an accepted way of thinking and acting.[1] An individual can be bright enough to gain acceptance into a surgery residency program, yet be asked to leave as a result of behavior in the program, based on cultural norms of expertise (Bosk, 1979). A stage model of expertise implies a time-dependent, steady progression towards development of skills and a knowledge base, and hence towards expertise. A more realistic view might be one which accepts that people do not necessarily become expert at all tasks in their domain; expertise is more aligned with being able to approach more of the required tasks with fluid, skill-based control (Rasmussen, 1986; Klein & Hoffman, 1993).

In this Chapter, I will focus on three aspects of expertise which, although not the focus of many of the mainstream research efforts on expertise,[2] have been shown to be

[1] This very evaluation of "promisingness" involves a process which is intuitive and hard to explicate into rules (Bereiter & Scardamalia, 1993).

[2] Here I am referring to what Ericsson & Smith (1991) call the original expertise approach, whereby laboratory tasks are designed to capture what is thought to be representative about expertise in a domain. Well-known examples of this approach include the chess work by Chase & Simon (1973) and deGroot (1965).

important in studies on simulated process control, combat aviation, nursing, firefighting, intensive care medicine, and other domains as well. These aspects are goals, predictions, and perceptual expertise.

7.2 Review of Studies Pertaining to Goals

Goals play a part in several different models of decision making and information processing which I have already discussed. Constructing and validating an abstraction hierarchy representation (Rasmussen, 1983) for surgery (shown in Figure 3.3, section 3.3.2) helped the process of identifying overall system goals. From this starting point, goal conflicts as well as lower-level goals and those which we might have overlooked could be identified in verbal protocols, and could be mapped onto a decision ladder representation. A link between expertise and goal-oriented thinking was made by Christofferson, Pereklita, & Vicente (1993), who studied subjects operating a simulated thermal-hydraulic process. Christofferson et al. (1993) mapped think-aloud verbal protocols onto an abstraction hierarchy problem space representation, and analyzed how observers with different types of expertise reasoned during fault analysis. Their results indicated a strong correlation between high level of experience with the simulated thermal-hydraulic process used and number of reasoning trajectories which began at the abstract function level (second level) of the problem space or higher. These data support the idea that experts impose a goal-oriented perspective upon their problem-solving. Recognizing plausible domain-specific goals is also an important aspect of situation assessment elaborated by Klein (1989) in his Recognition-Primed Decision model. In research on firefighter decision making, Klein, Calderwood, & Clinton-Cirocco (1986) found that goals may shift as a situation develops, causing redirection of efforts.

Finally, medical goals in an intensive care environment are directly addressed by Shalin & Bertram (in press), who found that one of three primary functions that physicians perform in that environment is pursuing ill-structured goals. Shalin & Bertram discuss how health care is often compared to machine repair, and how this is an inadequate analogy for patient care, in their view, since "correctness" of a solution cannot be judged independent of the situation. If a machine is not working, the goal is to find the fault (diagnosis) and repair or replace what is causing the problem so the machine can return to functionality. Often we think of medical care along these lines; however, some conditions are uncurable, and must only be managed according to goals which are determined by cultural values, such as quality of life. Shalin & Bertram (in press) describe the case of an aging, deteriorating patient who has no hope of return to functionality; the resident discussing the case suggests the appropriate goal is to reduce treatment so that discomfort and pain are minimized. Sometimes it is necessary to merely aim for patient stability, and other times expenditure of resources for patient care is an issue which must be traded off with these other goals (Shalin & Bertram). There are few easy answers or approved solutions to patient care when these goals conflict with each other, or when they may lead to inflicting harm on the patient. Likewise, removing the gallbladder from an 80-year old woman with laparoscopic techniques serves some goals but conflicts with others, as will be seen in the following discussion of findings related to goals.

To summarize this short review of literature linking goals with expertise, experts have been found to impose a goal-oriented perspective onto problem-solving processes (Christofferson et al., 1993); naturalistic decision making research has shown that the ability to recognize changing goals over the time course of a situation is an important skill for experts to develop (Klein et al., 1986); and understanding the cultural influences on competing goals is an important function of expertise (Shalin & Bertram, in press).

7.3 Goals Findings

The following description was used to recognize and code a "goal" statement in the transcripts of case 2:

> Code this when the surgeon discusses top-level goals for the operation, how they might be conflicting, or how they impact decisions made in the procedure. An example of this: 'She's so sick, I'm not worried about giving her small scars, I'm worried whether she's going to live, and so I will keep that at the top of my priority list.'
>
> The two highest-level goals for surgery are "fix the problem," i.e., take out the gallbladder, and "minimize collateral damage," i.e., the Hippocratic principle of first do no harm, don't make things worse when you fix the problem. Look for references to these kinds of top-level goals here.

Only 18 statements were coded as matching this description. In Table 7.1, these

No.	Time Period	Goal Statement	Category
1	a. pre-video	Goals for a DNR (do not rescuscitate) patient post-operatively are different, don't treat as aggressively, just the basics	Post-op. goals for patient(R)
2	a. pre-video	If patient was a smoker, I'd be concerned about pneumonia, secretions, and whether we can get her off the ventilator with an open procedure	Laparo-scopic (R)
3	a. pre-video	Doing it laparoscopically, the patient bounces back quicker and has less risk of pneumonia	Laparo-scopic (S)
4	a. pre-video	Think about what's appropriate for the patient not what's appropriate for the surgeon	Open (S)
5	a. pre-video	Would do laparoscopically because of the benefits- out of hospital sooner, less risk of pneumonia and blood clots	Laparo-scopic (S)
6	a. pre-video	You can struggle for 2 hours with a patient like this and then open, or just open and do it in 30 minutes; she hurts more, but it may be safer	Open (S)
7	a. pre-video	A lot of judgment is based on what I think I can get away with, not what's good for the patient	Open (S)
8	c. DP2	With laparoscopy the patient recovers sooner, has a lowered mortality for lung problems, breathes better, eats and is up sooner, less bladder problems	Laparo-scopic (S)
9	c. DP2	In a sick patient who could die from this, your goals change, concern should be what's best for the patient, not minimal scarring	Open (R)
10	c. DP2	There is a cost for trying to get it out laparo-scopically in a case like this, you're concerned post-operatively whether you injured something	Goal conflict (R)
11	c. DP2	There's a good chance you won't be able to do this **safely** laparoscopically	Open (R)
12	e. initial dissection	If can complete case laparoscopically, the patient will have less discomfort and will be up and around the next day	Laparo-scopic (S)
13	g. GB opens	The operating surgeon is playing catch-up, what they can get away with instead of what's best for the patient	Open (R)
14	j. DP3	Need to open because it's an issue of what's safe for the patient (also mentions what's good for your career)	Open (R)
15	j. DP3	Goal is to open the belly and get this gallbladder out safely without injuring CBD	Open (R)
16	j. DP3	Opening may prolong recovery, but would still be quicker than recovering from an injury	Open (R)
17	k. post DP3	In this kind of situation, you were just lucky and need to reconsider your goals and how you'd handle the situation; this procedure was unsafe	Open (R)
18	k. post DP3	Think about alternatives that have a higher likelihood of success (taking longer, longer hospital stay, converting to open)	Open (R)

Table 7.1 Goal statements, and whether they favor laparoscopic or open surgery for this patient. (S) = staff; (R) = resident.

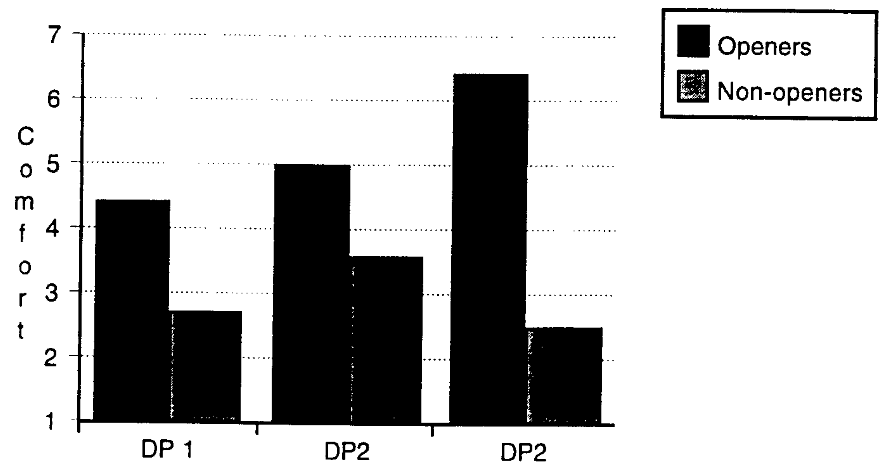


Figure 7.1 Resident Comfort Levels, Openers vs Nonopeners

statements are listed, along with the time period in the videotape in which they were elicited, whether they were from a resident (R) or a staff (S) surgeon, and a general category indicating whether the surgeon leaned towards opening this case or continuing laparoscopically in their goal statement. These statements will be analyzed here by highlighting trends and content in a mostly qualitative manner.

It is interesting that all of the comments favoring laparoscopy were made before any of the structures were identified. As the interviewed surgeons watched the dissection and severing of the structures, none of them made goal statements about the benefits of continuing laparoscopically. This is consistent with the overall lower comfort level surgeons expressed during the dissection and identification of structures in this case, even among those who did not indicate they would open.

What is best for this patient, an open or a laparoscopic procedure, is by no means a clear issue. Those who list benefits of removing this gallbladder laparoscopically do so because they foresee serious health consequences for conversion (typically pneumonia). Being able to get up and move about soon after surgery is viewed as important to the recovery of an older patient like this, since the longer she stays in bed, the more other bodily functions will likely suffer from the inactivity. None of the benefits listed for continuing laparoscopically are cosmetic, yet in number 9, the surgeon indicates the competing concern is that of minimal scarring. Most commonly, the comments favoring opening imply that a surgeon who continues laparoscopically is not considering what is best for the patient (statements 4, 7, 9, 13, and 14), which is clearly an overarching goal of surgery supported by the Hippocratic Oath. The statements favoring laparoscopy, however, tell a different story, defying the notion that those who continue are disregarding what is best for the patient; they focus on benefits which can be gained for the patient with regard to illness and health by continuing laparoscopically.

Of the ten residents we interviewed, five of them indicated at least once that they would convert this case to an open one; the other five did not. One of the most striking facts about the goal statements in Table 7.1 is that all eleven of those which were made by residents were made by the five residents who decided to convert this procedure to an open one. I cannot conclude that the other five non-opening residents weren't thinking about goals simply because they did not make statements which fit our criteria. However, the five openers' goal statements do clearly indicate an assessment of the situation whereby goals are considered. It is possible that only the openers were alarmed enough to consider this case a problem-solving situation, in which justifications for actions in terms of goals needed to be made explicit. If the non-openers did not consider this case to be a troublesome, problem-solving situation, they might see no need to assess the situation at a high level. Other evidence supports this claim: the comfort level ratings which surgeons gave at each decision point show that openers were significantly more uncomfortable than their non-opening colleagues at each decision point. The ratings are shown in Figure 7.1. The comfort level scale was a 7-point anchored Likert scale where "7" indicated the surgeon would convert to an open procedure now, and "1" indicated no concerns whatsoever. At the point where the opening residents are most concerned (6.4), the nonopeners have a comfort level of 2.5, which is between "little concern" and "increased concerns."

Only one of five of the statements favoring laparoscopy was made by a resident, and that comment was qualified as "if the patient were a smoker, she may have trouble coming off the ventilator." The four staff surgeons who supported the safety of a laparoscopic procedure for this patient in terms of goals are at the younger end of the experience spectrum, having 2, 2, 4, and 6 years since completing their residencies. Since laparoscopic cholecystectomy was first practiced in the United States around 1990, and the interviews were conducted in the summer and fall of 1995, these surgeons were either in the midst of or just completing their residency programs in 1990. Learning to operate laparoscopically during a residency program ensures that the skills are learned under constant supervision and feedback, perhaps leading to higher confidence than if procedures were learned at a short training course as a practicing surgeon. This might correspond with having seen greater benefits from doing older patients laparoscopically, and hence making goal statements favoring a laparoscopic approach.

One resident did refer specifically to the goal conflict which is relevant in this situation (see number 10 in Table 7.1). This comment was elicited when I asked this surgeon if there was a time in his previous experience when he faced a situation similar to this case. The response was,

> "yes, there's times when we converted to open, and there's times when we, you know, slogged our way around until we got it out. But you're also more concerned post operatively: did I end up injuring something? So there is a cost for trying to get it out laparoscopically in a case like that."

It is typically not the resident's decision whether to convert; whatever the attending decides, the resident carries out, unless extreme discomfort is felt to the point where the resident will violate their customary role and refuse to participate. However, the above quote succinctly captures the tradeoffs involved.

Merging the findings of this research with the literature on goals and expertise reviewed earlier is not possible in a direct way, since methods and measures are not consistent, but I will address how each literature finding relates to this work. We did not map verbal protocols onto an abstraction hierarchy as did Christofferson et al. (1993); such an analysis was considered but rejected as artificial for an interview situation, since our protocols do not reflect problem solving in the stream of real-time behavior. I therefore cannot provide evidence for imposing a goal-oriented structure onto problem solving processes. Although residents accounted for more of these goal statements than did staff surgeons (11 vs. 7 statements), only five residents made these statements, as opposed to six staff surgeons. One resident accounted for five of the statements. I did find that staff surgeons were more likely than residents to invoke higher-level goals in support of continuing this procedure laparoscopically.

Pred1+Pred2	Other Predictions	Total predictions
	(Residents)	
mean 3.1 stdev 1.8	1.3 1.1	4.4* 1.9
	(Staff)	
mean 4.4 stdev 2.0	2.8 1.6	7.2* 2.7
	*These numbers are	different at $p<.001$

Table 7.2 Mean numbers of predictions made by residents and staff surgeons.

As this procedure unfolded on the videotape, and the actual dissection of structures was viewed, surgeons stopped invoking higher level goals in support of continuing laparoscopically. We did not code the short-term goals and how they changed; these would be more consistent with what Klein et al. (1986) refer to as shifting goals. The competing goals which Shalin & Bertram (in press) discuss are apparent throughout this procedure, and have been elaborated earlier: should the surgeon continue laparoscopically and risk potential internal injury, or should they convert and cause a certain increase in recovery time and possible pneumonia? Influences on which goals will win out seem to be a point of conflict within the culture of surgeons. For example, the following excerpt is from the response to the question, "If the surgeon decided to begin this case laparoscopically, would you think that was a reasonable decision?"

> "Depending on the surgeon. I know many surgeons, I don't trust their judgment, other surgeons, I think their judgment's good. I would assume they've made the appropriate insight into the patient's care, if they started it. I would be VERY concerned if the physician had no, I would say almost in an arrogant way, say "I can do this case laparoscopically!" I call those guys the laparoscopic cowboys. Bad judgment, a LOT of bad judgment out there. To have no concerns, and not be prepared to open a case like this, that physician should not be operating....The ability to go out and talk to a family and say how wonderful I am, I've got this very difficult gallbladder I've dragged out in 3 hours, is often there. Ah, I think there's a lot in

> surgery in which physicians make an effort in what they can get away with."

This quote is from one of the surgeons we interviewed with over 25 years since residency. On the other hand, some younger surgeons indicated that their older, more experienced colleagues are often less willing to persevere laparoscopically, being less comfortable with the entire enterprise of laparoscopic surgery. One younger staff surgeon commented:

> "Some people who aren't as comfortable doing laparoscopic stuff might think, I don't even want to mess with this, she's old, I know I can do it faster, especially surgeons who have been doing open gallbladders for many years. They say, I know I can do this a lot faster open, I don't even want to mess with that. ...With having a partner that's significantly older than I, the younger ones of us seem to be less likely to open, or more likely to attempt it laparoscopically."

The more experienced surgeon's perspective is less accepting of the younger, more aggressively laparoscopic perspective, for lack of a better term; conversely, surgeons who are comfortable with laparoscopy in a wider variety of situations expressed respect for other surgeons who want to open, if they do not feel comfortable. Certainly individual differences, experiential biases, and situational factors such as team members and other constraints influence propensity for opening as well. But the above comments indicate that the introduction of new techniques and technology has either initiated or aggravated a rift between older and younger surgeons, and this rift is important to acknowledge in trying to understand the high-level goals involved in the decision to open.

7.4 Review of Studies Related to Prediction and Anticipation

Xiao (1994) observed anesthesiologists over a long period of time, forming hypotheses without formal data collection. He then targeted a series of operations during which he interviewed the anesthesiologist before the surgery, observed and recorded think-aloud data during the procedure, and conducted follow-up interviews to elaborate on the events which had taken place. Xiao proposes that behavior of anesthesiologists does not resemble an information-processing model; instead, the behavior is anticipatory and preparatory. Anesthesiologists prepare their physical *and* mental workspaces for anticipated events, they control the patient's status in a feedforward manner, and they off-load anticipated activities during slow periods. Xiao employed Rasmussen's decision ladder to represent how anesthesiologists use planning to reduce response complexity in future situations.

Similar anticipation of high workload periods was found in Amalberti & Deblon's (1992) study of fighter aircraft process control. In pre-mission planning, which generally

When	Predictions about Difficulty	Rating
a. Pre-Video	1. Acute infection generally means inflammation, edema, ashesions, and difficulty identifying structures (R)	5
	2. Dissection will be difficult, the planes hard to find (R)	4.5
	3. If it's over 48 hours, ductile injury is more likely because you can't see planes as well (S)	4.5
	4. If it is within a three day period there shouldn't be too many adhesions (R)	3
	5. After 48 hours of inflammation the GB gets thick, hard, you can't see planes as much (S)	5
	6. Wouldn't do this laparoscopically because it's an acute GB, dissection will be difficult, planes won't be easy to find (R)	3
d. Draining GB	7. The soft bag of drained Gallbladder is going to make dissection more difficult (S)	2.5

Table 7.3 Predictions made about the potential difficulty of identification, finding planes of dissection, and dissecting in general. Agreement ratings averaged from two independent surgeons are shown in the right column; 5 indicates total agreement.

took more time than the mission itself, the pilots devoted considerable time to analyzing each leg of the route for possible threats. Those pilots classified as experts differed from the less experienced pilots in planning strategy, both in number and type of waypoints they chose and in the number of potential incidents predicted for each flight leg (experts predicted fewer incidents, organized in a more hierarchical manner). During the actual missions, Amalberti & Deblon found that pilots devoted over 90% of their reasoning time during free-time periods to anticipation. Pilots developed a "tree" of possible events during mission planning, and events in the tree became more or less salient over the course of the flight. For salient possible events, the pilot would mentally simulate a response to see if it would work given the constraints of the situation; if not, the pilot would try to change the current parameters so that the desired response would work. "The implication is that most of a pilots' expertise lies in avoiding situations where they have no solution or no chance of applying known solutions (i.e., situations similar to ones generated by totally unexpected events)." (p. 655) When unexpected problems did occur, the pilots generally responded with poor solutions. Thus, it seems as if anticipation was used to engineer a field of safe travel (Gibson & Crooks, 1938; see Section 3.1.1), defined as a field for which the pilots are ready to handle already-predicted problems and threats.

In other research on how pilots and other complex systems operators assess situations, Endsley (1995) has identified three levels of situation awareness, namely *perception, comprehension,* and *projection of future status.* An operator might perceive local information and comprehend its meaning, but to function effectively (and survive!) in a rapidly changing flight situation, it is necessary to anticipate and prepare for upcoming high-workload periods. This third level describes what Amalberti & Deblon (1992) have documented in a general way. It is captured also in the conventional wisdom of the pilot's adage, "always stay ahead of the airplane." Staying ahead means thinking ahead. If a busy period is upcoming, like approach and landing, thinking ahead means getting required chores (i.e., checklists) for that period done early so that there will be more time to handle unanticipated problems should they occur.

7.5 Anticipation & Prediction Findings

7.5.1 Quantitative Differences in Predictions

We would predict that surgeons with more experience would be more likely to be able to make predictions. There are four variables which show how surgeons made predictions about our videotaped case, the three Predictions variables (PRED1, PRED2, and UPRED, or universal predictions) and the subset of the perceptual expertise variable which were predictions rather than inferences or recommended actions. By nature, there was overlap between the predictions and perceptual expertise statements. We used the perceptual expertise variable when the surgeon cited a specific piece of information which led to the prediction. The prediction variable was invoked anytime the surgeon made a prediction, whether or not they provided the underlying reasoning or information used for prediction. For all of these variables, a consistently higher number of statements were made by staff surgeons than residents. Twenty-nine of the 99 perceptual expertise variable statements also involved anticipation. Twenty of these statements were made by staff surgeons, and nine by residents. (This ratio is consistent with the overall higher number of perceptual expertise statements by staff surgeons.)

Table 7.2 shows the number of statements made by staff and residents for the three Predictions variables. PRED1 noted predictions made when the sick gallbladder was first seen and PRED2 was invoked for predictions made when the gallbladder burst open. The other variable, UPRED, was used throughout the transcript when predictions were made, except for at the times covered by PRED1 and PRED2. Statements made for these three variables are added together in the total predictions column in Table 6. The staff surgeons made significantly more prediction statements than residents about this case. I performed a one-way ANOVA on the individual scores and found them to be different, $F(1, 19) = 13.8$, $p < .001$. From these data we can conclude that the staff either had greater knowledge which allowed them to make more predictions, or they were more comfortable or accustomed to verbalizing these predictions than the residents were.

7.5.2 Qualitative Nature of the Predictions

Given that staff surgeons made more predictions than residents, what was the nature of these statements? Two distinct types of predictions emerged from examination of the coded predictions. First, surgeons predicted they would have difficulty in dissecting and identifying structures, primarily because the gallbladder and surrounding areas were swollen and inflamed. Second, they predicted that this patient would have a higher risk of a negative outcome, such as an injury to nearby structures or tearing of the gallbladder wall, which increases risk of abdominal contamination or a post-operative infection from spilled bile. These two types of predictions are associated: the first, inflammation leading to difficult identification, is essentially a lowered ability to assess the situation and understand the configuration of the anatomy. This lowered situation assessment leads to the second type of prediction, higher risk of negative outcome.

In the tables to follow which present predictions and perceptual expertise statements, agreement ratings given by two surgeons who were involved in this research are shown in the right column. Raters were able to see at what time period the statements were made, and were familiar with the videotaped case, and hence had some context for rating their agreement. If the context was not felt to be sufficient, the statement was not rated. These ratings provide a general measure of consensus about the statements.

The first category of prediction statements were typically found early on in the interview. There were several predictions made about the difficulty, or lack of difficulty, which would be encountered in identifying structures, finding tissue planes, and generally seeing what is going on. For instance, in Table 7.3 statements 2, 3, 5, and 6 are predictions that it will be difficult to find planes of dissection in this case; these planes are the junctures between a plane of gallbladder tissue and liver or other surrounding tissue, and between ducts or arteries and their surrounding tissue. When a gallbladder is acutely inflamed, it becomes more difficult to tell what tissue belongs to a duct, artery, or gallbladder and what is just surrounding tissue; all of the tissue becomes pink and swollen, so color and texture cues are lost. One staff surgeon, in explaining why they would be dissecting closer to the gallbladder than the video showed, said:

> "Because you don't know where structures are, because there's so much inflammation around there, it's kind of blind guessing where the important things are going to be, and they are digging through inflamed tissue."

Another comment which captured the difficulty of assessing the situation in a case like this came from a resident, also during the initial dissection:

> "I would be very worried, I have no idea where the cystic duct and artery are, let alone the common bile duct. I would be kind of worried about that, because I can't tell where the gallbladder ends. Grabbing the common bile duct can injure it just by grabbing it alone."

How much time has passed since the patient became acutely ill is also a piece of information surgeons find relevant in predicting difficulty. Predictions 3, 4, and 5 in Table 7.3 refer to how long the patient has been sick. All of these statements seem to be indicating how the surgeon expects this case to go in terms of what operative actions and progress the patient's state of illness will afford. The fourth prediction is the only one which is not an expression of concern.

None of these predictions were solicited per se.[3] Making these predictions seems to be a way that surgeons can prepare their mind to encounter problems and decide ahead of time how to deal with them, as combat pilots do during mission planning (Amalberti & Deblon, 1992). But the anticipation seems to be more of a local, or moment to moment process, since surgery permits more time for devising a solution in response to problems encountered, and is somewhat more predictable than combat aviation (M. Dunn, personal communication, November 6, 1996). Although intensive preoperative planning may occur in trauma or cardiac surgery where the time available for problem-solving is predicted to be minimal, surgeons do not typically set aside time to go over each portion of a routine operation and what problems or threats might crop up. Such pre-surgery planning might be done if the case is complex and difficulty is anticipated, or if the case presents unique educational opportunities for teaching residents, or if the surgeons and anesthesia group had not collaborated previously (M. Dunn, personal communication, November 6, 1996). Some cases are noted on the operating room schedule as "possible open," in which case the operating team would be more specifically tuned in to problems anticipated. Over and above anticipating problems, surgeons make themselves and others on the surgical team aware of risks in a situation through these predictions. One of the primary functions teaching surgeons expressed responsibility for was making students and residents aware of the gravity of a situation.

An intermediate step attending surgeons said they would take for improving their situation assessment and dealing with risk (before deciding to convert) was taking over the operation from the resident. In the initial dissection of this case, one staff surgeon expressed the benefits of taking over:

> **Surgeon:** Part of this too, the dissection involved, is being able to feel what you're doing, you know, the way the tissue feels as you're going along. I'd probably do this myself, now, even if I'd let the resident start it, I'd probably come over and do it myself, because I'd be a little concerned.
> **Interviewer:** What exactly told you that you should take over, that you'd come

[3] We never asked "what do you predict or anticipate the important concerns or problems will be?" in any form. We did ask surgeons what their current concerns were at each decision point.

over and do it yourself?
Surgeon: Because of all the blood and the mush here ((laughs)), some of this dissection, like I said, needs to be done by feel, and if I'm the one that's going to be ultimately responsible for this I really ((inaud.))
Interviewer: Because you have more highly developed tactile skills?
Surgeon: Yeah. I would just want to feel it, because, as I said, my name's going to be the one that's on the chart, and my malpractice insurance is going to go up if something bad happens here.

The second major category of predictions, those predicting higher risk of a negative outcome, occurred with greater frequency as the case progressed. The first five statements in Table 7.4, made during decision point 2, all related to tearing the gallbladder open. The next two, 6 and 7, predicted post-operative complications (abscesses or infection) stemming from the infected gallbladder. Overall, there was disagreement among surgeons on the impact of spilling gallbladder contents in the abdomen. Some surgeons said that you had to expect the gallbladder would tear in a case like this, and that the spillage needed to be cleaned up well, but they would not convert to an open case as a result of the gallbladder tear. Others viewed the gallbladder tear, when it did happen, as another indication that this case should be done open. The view of this occurrence thus depended on the prior frame of mind of the surgeon, whether they saw the circumstances as already indicating conversion or not.[4] Numbers 8 and 9 were general predictions about long-term consequences of errors that could be made in this case; these were not wholly supported by our independent raters, indicating that there is disagreement among surgeons about these consequences. Of the predictions made once the dissection began (numbers 8 through 17 in Table 7.4), the common denominator is potential causes of harm to the patient, such as ligament thickening making it easier to injure the duct or artery (10), causing complications from leaving stones behind in the abdomen (14), causing a bile leak by using cautery on the last structure (15), and cutting the common bile duct if the last structure is sitting on top of it (16).[5] These predictions of injury or complications are consistent with the story told by other variables as well, particularly those which measured when and why surgeons would open, and those coded with the metacognition variable as "knowing consequences of actions which could cause injury, hidden dangers which could 'bite you' right away or later

[4] This frame of mind may be influenced by cultural and generational factors, as discussed in Section 7.3.
[5] Three of the statements, numbers 11, 12, and 17, were made by a staff surgeon who disagreed with, and was critical of, a laparoscopic approach to this case from the start. This surgeon was somewhat of an outlier among staff surgeons, being the only one to recommend opening from the start.

When	Predictions: Injury	Rating
c. Decision Point 2	1. There is an 80% chance of putting a hole in the gallbladder trying to grab it (S) 2. This gangrenous area may easily perforate (S) 3. You will tear gallbladder wall and spill bile if gallbladder wall is inflamed or necrotic (S) 4. If GB opens, won't be able to contain pus (S) 5. If try to grab GB, tips may puncture gallbladder wall and tear tissue (S)	3 4.5 3 3 4
d. Draining gallbladder	6. Abscesses may occur if don't clean up gallbladder fluid leak (S) 7. Wall of gallbladder being slopped around is possible source for post-operative infection (S)	3.5 3.5
e. Initial dissection	8. If 80-year old patient has complication, they will die; cannot tolerate complication (S) 9. Dividing the common bile duct will give the patient a life of liver disease (R) 10. Ligaments surrounding the gallbladder are much thicker due to the edema and inflammation, makes it easier to injure the duct or artery (R)	3 4 4.5
g. Gallbladder opening	11. The gallbladder may open more times if they continue laparoscopically (S)	5*
h. Last dissection	12. The last structure will probably fall apart because they are beating on it (S)	5*
i. Decision Point 3	13. If you get your landmarks confused you're going to cause the patient harm (R) 14. My concern is making sure you don't leave any stones behind, that can cause complications (S) 15. Last structure could be luschka ducts, if divided with cautery could cause a bile leak	4.5 4* 4.5
j. Post - Decision Point 3	16. I would stop the surgeon from clipping that last strucure, it looks like it's sitting on top of the common bile duct, and you can't see the tine (R) 17. If keep beating last structure, it will fall apart before you clip and cut it (S)	3.5 5*

Table 7.4. Predictions made that this patient would sustain an injury to other structures, post-operative infections or contamination, tearing of the gallbladder wall, or some other negative outcome. Agreement ratings averaged from two independent surgeons are shown in the right column; 5 indicates total agreement. Ratings followed by an asterisk were only given by one surgeon, rather than an average of the two.

on." Since greater evidence for the reason and significance of these predictions are found in these other variables, I will expand on this concept more in the next chapter on metacognition.

Prediction number 13 from Table 7.4 includes elements of both of the two most common types of predictions I have discussed here. I will expand on this statement and give background information from the transcript, because this resident elaborates on his self-acknowledged inability to assess the situation and resultant fear of injury:

> **Interviewer:** Do you have any concerns at this time?[6]
> **Surgeon:** Um, my concerns at this time are mainly where are we, I mean in this dissection up to this point what are we seeing here, it's difficult to really, obviously, not being there or being able to manipulate things makes it somewhat more difficult. But what they're showing us, I don't know what is going on, I can't really identify what they are looking at. The one sensation that we always use in surgery is feel, you no longer have it in laparoscopic procedures, the only thing you have left is sight, and that is not helping you (here). So, basically, I mean I think being in that position you would have a sense that you're lost and you really don't know what's going on and the only way to overcome that is to open up.
> **Interviewer:** What errors would an inexperienced surgeon be likely to make in this situation?
> **Surgeon:** I think progressing on, from what I've seen now, progressing on would probably be the biggest error and any other errors that result would be because of making that first decision. I mean obviously you could progress on and misidentify and ((inaud)) a structure that you think is the cystic duct and in fact it is the common bile duct or something like that. And if you get your landmarks confused, you're going to proceed along and it's going to cause the patient a great deal of harm.

In summary, surgeons had a wide range of opinion as to how to deal with the difficulty of identifying structures and the associated risk of injury; there were also differences as to how problematic surgeons predicted certain events, such as the gallbladder spilling, to be. These two types of prediction correspond to the two kinds of feedforward control Xiao (1994) identified in anesthesiology. The first, predicting difficulty in dissection and identification, involves what Xiao (1994) termed "preparing the mental workspace," preparing mentally for dealing with the predicted situation. The second, anticipating injury, have to do with actions which are taken to prevent undesired outcomes in a feedforward manner. In terms of the predictions in Table 7.4, these actions involve treating the gallbladder as gently as possible to avoid tearing it; cleaning up thoroughly after any spillage of bile; using accepted techniques to actively avoid dissecting in the vicinity of the common bile duct; and avoiding cautery on the last structure (no. 15). These techniques, which surgeons use to keep within the boundaries of a self-defined safe field of travel, will be discussed in greater detail in Chapter 8.

[6] Both of the questions in this excerpt were pre-defined, not follow-up questions.

7.6 Review of Studies Related to Perceptual Expertise

> *Novices see only what is there; experts can see what is not there. With experience, a person gains the ability to visualize how a situation developed and to imagine how it is going to turn out. . . .Our emphasis is not on rules, or strategies, or size of knowledge base per se, but on the perceptual and cognitive qualities of experience--experts do not seem to perceive the same world that other people do.* (Klein & Hoffman, 1993, p. 203)

This review has to do with research about how people perceptually recognize and cognitively understand information in their environment, and what they are able to do with that information. Preceding sections have included relevant material. Application of relevant (and sometimes changing) goals impact understanding. Prediction of consequences and risks involved in a course of action are vital to this process. As a result, this section builds on the previous sections, rather than presenting a separate "component" of expertise.

Expertise has only recently been a topic of study in cognitive psychology. In research which later inspired a rich literature on the nature of expertise in problem-solving, deGroot (1965; originally published in 1946) and later Chase & Simon (1973) did ground-breaking studies on expertise in chess players. Chase & Simon compared chess masters with beginning and journeyman chess players, testing their ability to recreate a briefly displayed chess board when the pieces were configured either randomly or placed as if in progress of an actual game. No differences in ability were found in replacing the randomly placed pieces. However, the masters far exceeded journeyman and beginner performance in reconstructing the actual game boards, averaging 16 out of 24 pieces. Chase & Simon suggested that grand masters have developed, over time, a tremendous vocabulary, or repertoire, of familiar patterns which may exist on a board. Each pattern, consisting of many pieces, exists in memory as a single chunk. This is the domain-specific knowledge of chess, which is learned over time.

How does the research on chess translate into a general, abstract notion of expertise in problem-solving? Over time an expert doesn't merely know *more*, they come to know things in a different way. Chess experts don't just accumulate factual knowledge; they learn to identify a configuration of pieces in terms of its meaning, and for appropriate moves which are associated with that configuration. This is in essence a "categorization," recognizing a pattern in terms of its implications for action. Glaser and Chi (1988) also reinforce the importance of recognizing large meaningful patterns as a characteristic of expertise; it is one of seven robust findings on expertise that they highlight. They state that seeing meaningful patterns is not a result of greater perceptual capabilities, but is a function of the knowledge base and its organization. Categorization of perceived events may even be tacit, meaning that the expert is unaware of this process, but nevertheless the categories are associated with appropriate scripts for action (Means, Salas, Crandall, & Jacobs, 1993).

This notion of categorization is an underpinning of Klein's (1989) Recognition-Primed Decision Model. It has been also called judging typicality, pattern matching or recognition, and recognizing prototypes. It may be a simple or a complex process, depending on how straightforward, and how typical, the cues and the situation are. Again, the *knowledge base* which develops over time is the key contributor to this ability to judge typicality. Klein & Hoffman (1993) review research showing that accumulated knowledge develops into conceptually rich representations, meaningful mosaics which guide the assessment of current situations. In current work on expertise in many domains, the importance of the knowledge base and the ability to recognize typical aspects of situations are cited again and again as main features of the difference between expert and novice thinking (for a review see Klein & Hoffman, 1993). For example, research on nurses in a neonatal intensive care unit (NICU) setting has illustrated how subtle the cues can be when assessing a tiny baby's health (Crandall & Calderwood, 1989). Also in the medical domain, Lesgold et al. (1988) present research examining radiologists' diagnoses, and found that the novice radiologists actually "*perceived the film features differently* from their more successful counterparts." (Lesgold et al., 1988, p. 332) They present the idea that skilled radiologists use *opportunities* to perceive important information more effectively than their less skilled counterparts.

A concept which encapsulates recognizing patterns of information with regard to their implications for action is that of affordances (Gibson, 1979), which are functional relations between the environment and a particular actor. Put more simply, we evaluate whether something will afford doing what we want to do with (or to) it. We see affordances everywhere, if we look for them; sometimes meaningful potential for our intended actions are immediately perceivable, and sometimes trial and error is needed to know whether, for instance, a truck affords climbing into by a four-year-old. Gibson (1979) believed we become attuned to invariants in the natural environment which directly specify affordances for us; in other words, we learn to directly perceive affordances. Learning to perceive the affordances of tissues and anatomical structures, and to understand the implications of appearances and configurations of these structures, is an important part of expertise in surgery.

A final representation of expertise which adds to these concepts of knowledge based-categorization and judging typicality is that of Rasmussen's (1983) skills-rules-knowledge based cognitive control (see section 3.2.3). I like this categorization because it goes beyond the fact that experts have superior knowledge bases and addresses how skill and knowledge are alternately employed in situations which are familiar and unfamiliar to the practitioner. Performance fluidly changes between the three levels of cognitive control, depending on how well the requirements of the current task match with the resources of the individual (Olsen & Rasmussen, 1989). Knowledge-based control is always present in the background to provide oversight about whether the appropriate goals are in focus, or to catch errors (Sanderson & Harwood, 1988). This is the metacognitive component of the skills-rules-knowledge model.

7.7 Perceptual Expertise Findings

7.7.1 Introduction

So let us return to the domain of surgery, and consider these concepts of perceptual expertise. Our original coding scheme had no variable for perceptual expertise. Very early in the coding process, as the coders met to compare and discuss differences, we realized that a great deal of interesting verbal protocol material was not being picked up by, or documented with, our scheme. We had variables to note how surgeons were identifying the structures which were dissected, clipped, and cut, but surgeons were frequently mentioning other perceptual information and what it meant to them within the context of the case. Having no way to capture this information seemed like a serious flaw, so we developed the "perceptual expertise" variable. Thus, this variable was conceived of in a descriptive manner, to capture what we were seeing in the transcripts, not to specifically reflect any finding in the literature on expertise. It was described in our variable definition sheet[7] as follows:

> When surgeons provided a *substantial* description of a cue they saw or felt or *might* see or feel hypothetically, and either (1) made predictions based on that cue or (2) drew inferences about the patient's disease or (3) recommended an action based on that information.

When this variable was invoked, we summarized the information cited by the surgeon and the resultant prediction, inference, or recommendation for action in condensed form in the adjacent comments column. The time period in which it was mentioned was also documented. The perceptual expertise statements in which surgeons made predictions have been discussed in the previous section of this chapter.

Once these perceptual expertise statements were extracted into a spreadsheet and sorted by time (the videotape event) in which they were elicited, many different approaches were tried for abstracting out unifying concepts. They were labeled as either action, inference, or prediction, but that did not seem to offer up any interesting results, other than separating out predictions to combine with the other prediction variables. I categorized the statements which had to do with converting to an open procedure, and those which referred to the amount of inflammation in the operative area, but this decomposition still did not seem to be meaningful. It was only in going back to the literature and thinking about the idea of affordances that a clear organization of these data began to emerge.

Many of the theories and findings on expertise I have discussed in the previous section converge on a single concept, that of being able to understand the meaning of patterns of information. For a surgeon, meaning often is synonymous with what course of action would have dangerous consequences, and what course would be safe. I have discussed this concept in the form of the field of safe travel (Gibson & Crooks, 1938) in surgery in section 3.1.1. To judge what is a safe course, a surgeon learns how visual information and "feel" of the tissue signifies the progression of disease and yields cues for identifying structures. Also important is what this information means in terms of how the

[7] This sheet is what the coders directly referred to for definition of the variables when coding transcripts.

tissue can or should be retracted, dissected, or avoided during surgery (affordances).

A representation showing the interaction between information in the environment and affordances, or meaning to the surgeon, is shown in Figure 7.2 (from Flach & Dominguez, 1995). This is a generic figure originally intended to show how "use," or how an operator interacts with environmental information and constraints on action and perception, should be the focal point of design rather than just the "user" alone (Flach & Dominguez, 1995). In other words, when the user and environment are integrated, considered as a unitary system working to achieve certain goals, this figure asserts that boundaries on the affordance space and the information space, along with how the user acts upon or *controls* the rest of the system are important distinctions which emerge.

To elaborate these ideas in the context of laparoscopic surgery, the AFFORDANCES circle blends *possible* action, constrained by what the surgeon can do given available instruments and individual capabilities, with *desirable* action, constrained by the state of the tissues in the patient. Possible action is shown on the left side of Figure 7.2, while desirable action is shown on the right. A surgeon who arrives on the scene where a shooting has taken place may have the capability to remove the bullet, but lack the instruments needed, and hence the situation has different affordances than were this victim seen in an emergency room (removal is desirable, but not possible). Constraints on what action is desirable involve goals such as "fix the problem" and "do no harm," but extend into the cultural realm as well. We saw substantial disagreement as to whether removing the 80-year-old patient's gallbladder should be done laparoscopically. Further, gallbladder removal is far more desirable when the patient is otherwise healthy than if she were being treated for a terminal condition such as cancer (Shalin & Bertram, in press). Removal would be possible, but not desirable. Thus, these constraints interact to form boundaries on what action is afforded in a particular situation.

However, action afforded is independent from the surgeon realizing these affordances. A surgeon in training may not understand that removing the gallbladder from a terminally ill patient is undesirable. The INFORMATION circle blends what information is available for knowing (from the environment, on the right side of Figure 7.2) with what the surgeon 'picks up,' to use a term from Gibson (1979). Each of these is constrained in

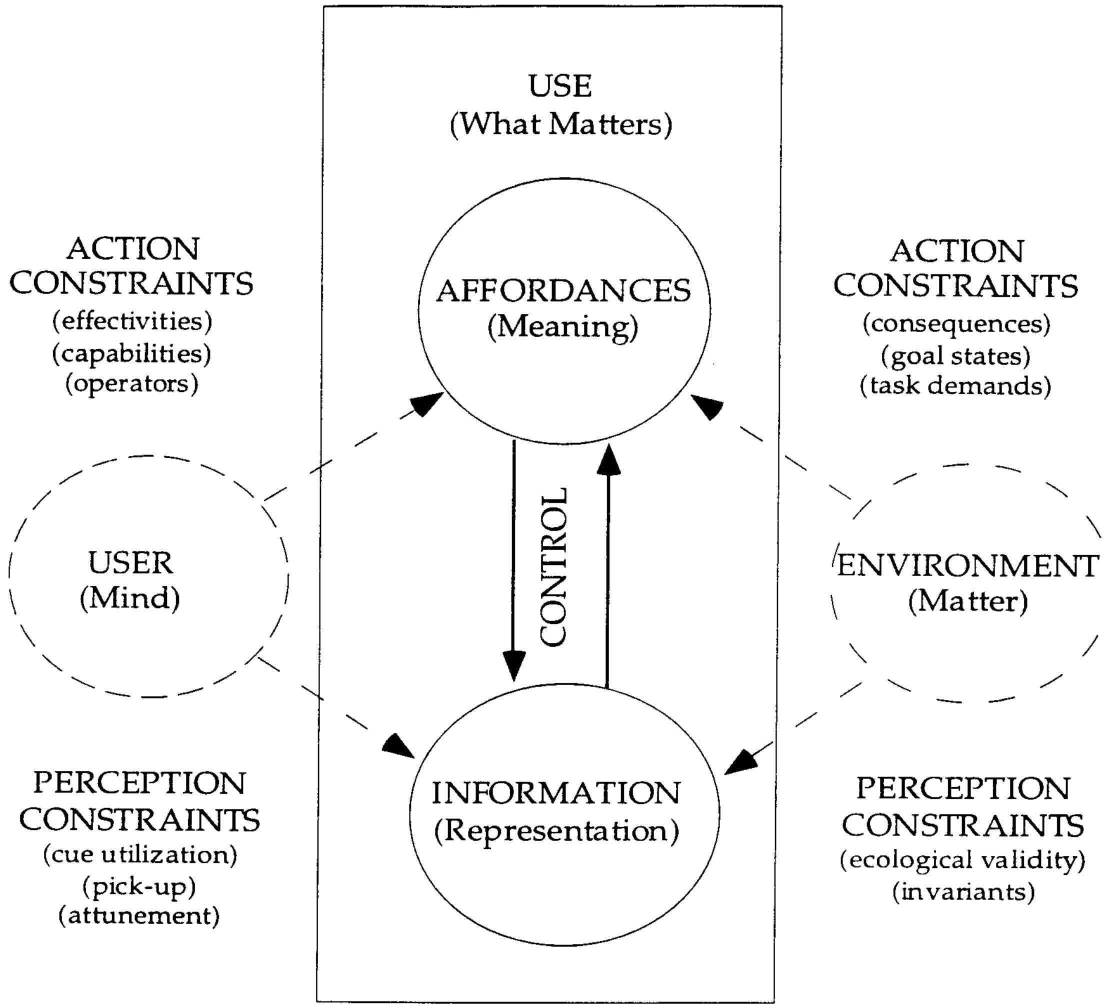


Figure 7.2 Relationship between affordances, information, and control. Constraints on perception are shown in the lower half of the figure, which shows that available information is represented in a way constrained by the environment, and that a user may have constraints upon what is picked-up or used. In the upper half, action is also constrained by the environment (what action is desired) and the user (what action is possible).

a way that can be explained in terms of Brunswik's Lens Model (see Hammond, 1966). On the side of ecological validity, the environment may or may not reflect its true state in cues that can be perceived. For instance, a gallbladder could be severely infected and full of pus, but not display signs which indicate the extent of this infection until it bursts or is drained. On the side of cue utilization or pick up, a laparoscopic surgeon is constrained by the camera operator's skill, the resolution of camera and monitor, and his or her own knowledge base. Any of these factors could degrade or enhance the surgeon's ability to perceive and understand the available information. Interacting with the anesthesiologist and other team members is also necessary; if an attending surgeon is supervising a resident who is operating, the attending surgeon must get critical information from watching the resident's movements and how the tissue reacts.

The concept of CONTROL brings information and affordances together in Figure 7.2. If affordances of the situation (boundaries on what action is desirable and possible) are clearly represented in ways that the surgeon can perceive and understand, then appropriate actions ("precise control") would be expected (Flach & Dominguez, 1996). If these boundaries are not well specified, the surgeon encounters risk which must be evaluated. One course of action could be to take an intermediate action, such as performing a cholangiogram, to gain better information and mitigate the risk. Surgeons also suggested taking action which would change the affordances of the situation through well-known methods like decompressing the gallbladder, or leaving a drain in the abdominal cavity so that potential post-operative bile leakage could be followed and cleared (also improving their *informational* access). At times, however, surgeons simply made their best assessment of the situation and pressed forward.[8] Thus, control can be seen as the actions surgeons are willing to take, based on the information they have picked up and their risk assessment.

In the next section I will present and discuss the data from the perceptual expertise variable as it relates to the Affordances, Control, and Information figure just presented. Then two other variables which are particularly relevant to perceptual expertise, the artery identification variable and the technique variable, will be discussed as they relate to this figure.

7.7.2 Perceptual Expertise Variable

In looking at the statements we coded with the perceptual expertise variable from this viewpoint, a large number of them fell into two categories which are relevant to the representation in Figure 7.2. First, thirty-two of them cited perceptual information and accompanying inferences about pathophysiology, or disease progression, in the operative area. Twenty-five of these statements are shown in Table 7.5. Second, thirty-one

[8] Of course, we have no way of knowing whether pressing forward in an interview situation corresponds to what a surgeon would do in the operating room.

described perceptual information tied to various actions, goals, or states afforded, because of or associated with that information (all of these are listed in Tables 7.6 and 7.7). A few of the statements discussed both disease progression *and* affordances (see numbers 3 and 17 in Table 7.6).

Most of the disease progression statements were using perceptual information to draw a conclusion about the *extent* to which this 80-year old woman's gallbladder was sick. For instance, "Pericholecystic fluid indicates inflammation and infectious response; the inflammation, but not neccesarily the infection, has spread to other organs" (staff surgeon). These statements, although they all have a slightly different message, indicate that the surgeons we interviewed used perceptual information about disease progression to form an assessment of this situation. The initial information given each surgeon about pericholecystic fluid and thickening of the gallbladder wall, the colors and textures of tissues seen on and around the gallbladder, and how the gallbladder reacts to grasping and draining all combine to tell a surgeon that this patient has "acute cholecystitis." For instance, in statements 4, 5, 6, 7, and 9 (in Table 7.5) surgeons told us what the information we gave them about this patient means to them in terms of the extent of inflammation and infection, and that these cues are important in deciding whether they would begin this case as an open one. The perceptual cues for disease progression obviously mean something to the surgeons who mention them; they just do not go so far as to discuss what specific implications for action these cues hold for them. In terms of Figure 7.2, the surgeons are giving us a window as to what information they find notable in this patient, without addressing affordances, or implications for action.

I categorized most of the affordances according to what action the surgeon indicated was afforded. For instance, there were seven total statements concerning whether the gallbladder wall would be graspable, including number 16 in Table 7.6: "The gallbladder looks soft, which is good; it doesn't look as thick as expected, it has a nice ridge which can be grasped." (resident surgeon) Some agreement among surgeons can also be seen in the affordance statements. In statements 20, 21, and 22 (in Table 7.7), surgeons indicate that certain cues (thicker ligaments, how the edema fluid looks, the swollen gallbladder) translate into a higher likelihood of injury. These statements really refer to the

Disease Progression Perceptual Expertise Statement (and staff/resident)	Rating
1. Gallbladder becomes gangrenous partly because it's so tight, blood pressure cannot overcome gallbladder pressure (R)	5
2. She obviously has stones, you can see them, see surgeon kicking them with the sucker (S)	4.5
3. Artery looks large: could be due to acute cholecystitis, more inflammation increases blood flow (S)	3.5
4. Pericholecystic fluid: indication that inflammation is proceeding more rapidly (S)	3
5. Pericholecystic fluid indicates inflammation and infectious response. Inflammation, but not neccessarily the infection, has spread to other organs (S)	5
6. Thickness of hepatic wall needed from ultrasound to see if it's 3mm vs 4mm thick, infer likelihood of acute cholecystitis (S)	4
7. Amount of pericholecystic fluid, white count, thickness of wall & size of gallbladder all influence decision to start open (S)	4.5
8. Amount of edema and stiffness makes surgeon think patient has been sick longer than a couple of days (S)	4.5
9. The fluid around the gallbladder indicates inflammation (S)	5
10. Gallbladder is purple, doesn't have nice pearly grey or white hue to it, therefore is definitely an acutely inflamed gallbladder (S)	4.5
11. Sees fibrinous exudate, indentation in omentum. Concludes "fibrinous inflammatory infiltration of omentum" (S)	3.5
12. Gallbladder is free-floating, shiny surface, omentum comes off easily: response not yet infiltrated through gallbladder peritoneum (S)	3.5
13. After 48 hours, edema fluid attracts white blood cells, which produce toxins, change clear fluid into dull, whitish surface (S)	2.5
14. Mottled, distended, gangrenous gallbladder, sitting in rind of fat, obviously inflamed for a while (S)	5
15. Pussy adhesions, pink inflamed rim where tissue touches the gallbladder shows it's infected (S)	4.5
16. If very advanced, gallbladder would be deep deep purple, almost black (S)	4.5
17. Green stuff around base of wall is classic dead tissue (R)	5
18. After decompressing, you can see if gallbladder is gangrenous better, see if it's black (R)	4.5
19. Inflamed omentum adhered to gallbladder, dark mottled gallbladder color means poor blood supply, it's distended and may be full of pus (R)	5
20. Gallbladder's color and fibrotic bands indicate that it's significantly inflamed (R)	5
21. Distended thickened gallbladder, pus-like material nearby, pericholecystic fluid is worrisome, indicates advanced acute cholecystitis (R)	4.5
22. Seeing what kind of fluid is sucked out of tube. If white bile, then there's a complete obstruction (R)	5
23. Color of bile important: white means cystic duct blockage, possible stone; golden bile or pus means just acute cholecystitis (R)	4.5
24. The fibrinal exudate (combination of scar tissue & white cells) indicates the gallbladder is acutely inflamed (R)	5
25. Sees whiteness, infers white blood cells have invaded this layer of edema, created an opaque picture, gets very concerned (S)	3.5

Table 7.5. "Disease Progression" statements coded with the perceptual expertise variable, along with average agreement ratings from two independent surgeons.

CONTROL aspect of Figure 7.2; the surgeons are "preparing their mental workspaces" (Xiao, 1994) to move more carefully to mitigate these risks. Note the overlap between these statements and *Prediction* variable statements anticipating injury. Another area of commonality were the statements about affordance of visualization: three out of four state how tissue planes will be difficult to see (refer to 28 through 31 in Table 7.7). These four statements describe perception constraints to the surgeon's ability to visualize, and hence identify the structures. Exposure affordance statements (4, 5, and 6 in Table 7.6) describe similar constraints.

Again, this concept ties back to the *Prediction* variable statements anticipating difficulty in dissection and identification. Awareness of these constraints is the first step to dealing with them appropriately through cautious control actions.

Thus, what surgeons told us about information they perceived and what it meant to them in terms of information, affordances, and control supports the view that surgeons perceive the potential for action. They also develop an understanding of how their own perceptions can be obscured or misled by how tissues respond to disease.

However, not all surgeons seem to perceive and understand in this manner. One of the most striking aspects of the affordance statements was the high numbers of them made by staff surgeons. In general, staff surgeons made more perceptual expertise statements than residents did: staff averaged 6.5 per transcript, where residents averaged 3.5.[9] However, staff made more than *three times* as many affordance-related statements than residents (staff made 24; residents made 7). Put another way, only five of the ten residents made these statements, as opposed to nine of ten staff surgeons. These numbers suggest that understanding and verbalizing affordances inherent in a situation develops with experience, and is potentially an essential part of expertise.

7.7.3 Artery Identification

Much of the information which is available for identifying structures, such as size and location, is relative; in other words, it may not provide concrete information towards a certain identification. One concrete, salient cue for confirming an artery identification is whether it pulsates after being clipped and cut. In the video case we showed surgeons, the

[9] These numbers were found to be significantly different with a one-way ANOVA, $p<.05$.

Perceptual Expertise-Affordance Statements	Affordance	Rat
1. Within 2 days the inflammation usually isn't that bad, after 2 days it's harder to dissect (S)	Dissection	4.5
2. Gallbladder looks inflamed, not green or really black, so not necc. gangrenous, looks like dissection may be successful (S)	Dissection	2.5
3. Gallbladder folds over on itself, means it's not a "full thickness inflammatory reaction" but a mucosal reaction, will be a less difficult dissection (S)	Dissection *and* Disease Progression	3.5
4. Stiffness of fat, rigidity (pull it away & it's still there) indicates edema, concerned about exposure further down (S)	Exposure	4.5
5. Traction and counter-traction are difficult when instruments on top of each other, right angle is better, and easier to see (R)	Exposure	4
6. Folds of drained GB are deceptive: should use a splayed GB retraction rather than pulling up (S)	Exposure	3
7. If can palpate GB, is probably not going to be able to take it out laparoscopically, but will try (S)	Laparoscopic procedure	5
8. Sees soft pearly adhesions, means it's fairly early in course, inflammation hasn't organized much, can still get it out (S)	Laparoscopic procedure	3.5
9. Surgeon has only seen one patient with pericholecystic fluid that has been able to do laparoscopically (S)	Laparoscopic procedure	3
10. If patient is sick longer than 48 hours, harder to grab GB without it falling apart (S)	Grasping	4.5
11. If there is one big stone, may not be able to do laparoscopically, there's nothing to grab onto (S)	Grasping	3.5
12. This acute GB generates a "set of information," if can't decompress, can't grab & manipulate, have to open (S)	Grasping	5
13. Sees shadow of stones, means GB's soft enough to grasp (R)	Grasping	3.5
14. GB is getting softer, thus the wall is not so thick that the operation will be hindered by it (S)	Grasping	4
15. Looks like they never could have grasped GB without aspirating, because it deforms easily with the aspirator (R)	Grasping	4.5
16. GB looks soft, which is good; doesn't look as thick as expected, has a nice ridge which can be grasped (R)	Grasping	4.5
17. Pre-gangrenous changes indicate severity of disease, should be cautious, GB will easily perforate (S)	Grasping *and* disease progression	5
18. If liver function is abnormal or heart trouble, then too sick for regular procedure, & too sick for laparoscopy (S)	Insufflation	3
19. Sick old people do better open because CO_2 (insufflation) interferes with respiration, venous return, coronary blood flow (S)	Insufflation	3

Table 7.6 Statements coded with the Perceptual Expertise variable which reveal affordances for dissection, exposure, a laparoscopic procedure in general, grasping, and insufflation. Ratings are average of the agreement ratings of two independent surgeons on a scale of 1 to 5, 5 indicating maximum agreement.

pulsation of the second structure after it was cut was the most concrete evidence shown for

More Perceptual Expertise-Affordance Statements	Affordance Type	Rat.
20. Surrounding ligaments much thicker due to edema and inflammation makes it easier to injure duct or artery (R)	Risk of Injury	4.5
21. Edema fluid is clear and snotty looking, hazardous area to dissect, frequently bloody (S)	Risk of Injury	3
22. The gallbladder's so swollen, have to be more cautious on port entry not to stab the gallbladder (S)	Risk of Injury	5
23. Operates two-handedly, feel with left hand what the right hand is doing, can tell if pulling too hard (S)	Tactile perception	4.5
24. Thickened omentum and inflammatory exudate cause longer procedure, which is bad for an 80-year old (R)	Time (does not afford short proc.)	4.5
25. Fat is more stiff, like a stiff rubbery jello you can scrape and pull down, it bleeds/oozes (S)	Tissue manipulation	4
26. Has a tactile sense for how connected vs. disconnected tissue feels like, what is gallbladder wall vs. fatty tissue (S)	Tissue manipulation	3
27. Sees how tissue is moving and pulling, lot of tension on it for a structure that's inflamed. Stripping roughly (S)	Tissue manipulation	4
28. After 48 hours of inflammation the gallbladder gets thick, hard, you can't see planes as much (S)	Visualization	3.5
29. Decompressing distorts the anatomy because of the folds of the gallbladder (S)	Visualization	3.5
30. Tissue plane lost between gallbladder & fat when both are inflamed and pink, usually fat is yellow and the gallbladder is a different color (S)	Visualization	4.5
31. Wouldn't do this laparoscopically because it's an acute gallbladder, dissection will be difficult, planes won't be easy to find (R)	Visualization and Dissection	3

Table 7.7 Statements coded with the Perceptual Expertise variable which reveal affordances for safe dissection, manipulation of tissues, visualization, and others. Ratings are average of the agreement ratings of two independent surgeons on a scale of 1 to 5, 5 indicating maximum agreement.

identifying any of the three structures. After a structure is clipped and cut, there is an *opportunity* to notice whether blood was flowing through it (Lesgold, Glaser, Rubinson, Klopfer, Feltovich, & Wang, 1988). Whether surgeons took advantage of this opportunity is an important indicator of perceptual expertise. The opportunity was lengthy; the pulsating stump of the artery was visible in the center of the screen for over 30 seconds. For those who did not see it, their attention was focused elsewhere, on the dissector stripping away tissue just adjacent to the pulsating stump.

More staff surgeons (6) than residents (3) noticed the pulsating stump of the artery. A larger number of surgeons in both groups (8 staff and 5 residents) identified the artery correctly using other cues such as location and size. Since seeing it pulsate would tend to increase confidence in the identification, it is not surprising that there was a relationship between whether a surgeon saw the pulsation and whether they decided to open. Of the six staff who saw the pulsating artery, only one would (might) have opened. This staff surgeon discussed opening at the beginning of the last decision point, and only if the last structure could not be identified as the duct. The relationship between seeing the pulsating artery and deciding to open will be further explored in the next chapter.

7.7.4 Techniques

So far, I have illustrated how perceptual expertise is evident in surgeons' discussion of cues which indicate disease progression and affordances, and can be seen in how surgeons perceive salient cues for identifying structures. Information which indicates disease progression and which can be used to identify structures is perceptual expertise for *knowing*. The perceptual expertise which extends this information into the realm of possibilities for *doing* are evident in the affordances shown in Tables 7.6 and 7.7. Another variable which documented perceptual expertise for doing is Techniques. This variable was developed after we began coding and noticed surgical techniques being discussed frequently. The significance of techniques to surgeons is that they seem to be accepted methods for either staying within a safe field of operating, or for actively improving visualization (and hence identification). We used this variable when a surgeon said he or she would use a technique which wasn't currently being shown on the video, or would not use the technique shown (i.e., "don't pull there"). The range of responses was continually developed as we coded more transcripts, but the following shows the final set:

[1] Would move up or down on anatomy (toward or away from gallbladder) when dissecting. (Often expressed as more proximal or more distal)

[2] Wouldn't decompress as much, leave some fluid in gallbladder for better traction (The coder will look for a mention of how the extent of the aspiration would affect subsequent traction on and manipulation of the gallbladder.)
[3] Would do trocar/incision placement different, it's constraining instrument movement
[4] Irrigate more/wash things off
[5] Dissect more, expose area better for visualization
[6] Use different number of clips
[7] Would not pull away from common duct area, pull away from gallbladder area instead
[8] Would be gentler on tissue, use less force
[9] Would flip gallbladder back and forth, or side to side
[10] Other creative or unique technique suggestions
[11] Other more commonly used technique (i.e., provide more retraction, dissect on back of gallbladder)

The total number of each of these techniques for staff and resident surgeons is shown in Table 7.8. The staff generally suggested more techniques, although there was a large standard deviation for both residents (st.dev. = 5.5) and staff (st.dev.=6.5). I examined the numbers of different techniques suggested to see if there was any difference between openers and non-openers, but there was not. The clearest story that seems to emerge from these data is that staff surgeons suggest certain techniques with a greater frequency than residents do. The techniques which showed these differences the most were [2] wouldn't decompress as much, [5] dissect more, [8] should be gentler, and [10] unique approaches. There was disagreement over whether decompressing the gallbladder less would actually lead to better traction; when I pursued this point by asking surgeons who were not interviewed about this technique, some surgeons felt it could help, and others did not. Regardless of agreement, this technique reflects a consideration of how well the gallbladder will afford retraction. An excerpt from a staff surgeon's commentary while the gallbladder is being decompressed captures the concerns about how much to drain:

> "I am not sure I would have waited that long, once I got some decompressed, in the essence of time, I would have tried to decide if I had a little less of decompression and still be able to get to the GB. Actually in one sense of the word, the amount of distension that the GB had, if it had a little bit of distension it could actually help your dissection, when you go to dissect the GB wall. But the downside of that is if you had spillage, you would have more in the GB to contaminate than before."

Surgeons typically recommended more dissection (technique 5) when the video showed a structure being clipped or cut, and the surgeon watching did not feel that they had identified the structure well enough yet. Suggesting more dissection is a suggestion that more information is needed. There is an implicit assumption that dissecting further (action) will yield the requisite information. The large difference between staff and residents on this variable indicates that staff surgeons are more aware of what they have not seen yet (Klein & Hoffman, 1993), and/or they are more willing to verbalize their dissatisfaction with the information they have.

Two residents and five staff surgeons suggested being gentler on the tissue during retraction or dissection (technique 8). This recommendation is also important in the "perceptual expertise of doing," since control actions must reflect knowledge of the impact they will have on tissue. One staff surgeon, when asked at the very end of the case "If a

Techniques	Dissect nearer GB	Drain less	Change trocar loc.	Irrigate	Dissect more	Different # clips	Pull from GB	Be gentler	Flip GB	Misc-Unique	Misc-Common	TOTAL
Residents	14	1	3	19	8	2	2	4	0	2	22	77
Staff	15	5	2	19	17	5	4	10	1	12	26	111

Table 7.8 Total number of different types of techniques staff and resident surgeons suggested during interviews.

resident who did this case asked you 'how did I do,' what would you tell them?" said:

> "I would tell them that I was concerned about their tissue handling techniques. That I think they need to be more gentle and the other thing is not to go into areas they are not certain and particularly working with blood stained tissues in this area. Well one of the things I would tell them is, first of all when you take the fat away from the gallbladder is to grasp it near the gallbladder, extend it, and then <u>pull it down rather than just strip it down, because that is what led to some of the bleeding there. And of course then once the tissue is blood-stained it is hard to identify structures.</u> So by doing that you can prevent that from happening. ....That would be number one. Then to <u>be careful with the technique,with the amount of pressure that you use on it because it is hard to gain a sense of just how much tension</u>

you are using on it. Rather than try to bully your way through it."

This passage illustrates both a caution to be gentle with the tissues, as well as a description of the bleeding and further obscuring of view which can result from not being gentle enough. The difficulty of learning boundaries on force is emphasized later in the excerpt; the long-handled laparoscopic instruments undoubtedly make gaining this sense more difficult.

As Table 7.8 shows, the miscellaneous categories of the technique variable accounted for many of the statements.

7.8 Summary

Some interesting aspects of expertise in laparoscopic surgery have been brought to light by the data from this study. First, we wanted to examine the role of goals in expertise. A complex picture emerged. Goal conflict with regard to the decision to open was evident. Generational division was observed between those who were more comfortable with laparoscopy and those who were critical of performing laparoscopy on this 80-year-old patient. Also, residents did not verbalize the benefits of laparoscopy in this case; only the younger staff surgeons did.

There was overlap between major findings with prediction and expertise variables. This is not surprising, since many statements were coded with both variables. For both, staff surgeons made significantly more statements, indicating increased ability or propensity to predict and understand the meaning of cues with experience. The two types of predictions we found most often are associated: the first, inflammation leading to difficult identification, is essentially a lowered ability to assess the situation and understand the configuration of the anatomy. This lowered situation assessment leads to the second type of prediction, higher risk of negative outcome. These two themes were observed in perceptual expertise statements as well. A representation of the domain in terms of affordances, information, and control was useful for describing and analyzing the perceptual expertise statements made. Evidence seems to suggest that surgeons perceive the potential for action as well as the potential for identifying structures, along with the corresponding constraints on possible action and perception.

What else might be involved in surgical expertise? Many of the analyses already presented have hinted at the importance of self-regulation, or metacognition. It's not new: Glaser & Chi (1988) discuss it as one of seven primary characteristics of experts. Bereiter & Scardamalia (1993) call self-regulatory knowledge part of the hidden knowledge of experts. Olsen & Rasmussen (1989) discuss it, in their article on the "reflective expert." Means, Salas, Crandall, & Jacobs (1993, p. 324) talk about metacognitive skills as "the best candidate for generalizable skills that will aid decision making across domains." The following chapter will be devoted to our findings on metacognition and its potential role in expertise in laparoscopic surgery.

8 Metacognition

8.1 Introduction: What is Metacognition, and What is Not?

I became interested in metacognition as it applies to surgery only after listening to surgeons talk about safe situations in terms of their comfort level; this no doubt reflects how they have been trained to think. Acknowledging personal comfort level indicates that surgeons evaluate whether a situation is within or outside the bounds of their capability to proceed safely. Or it may indicate that the risk involved in the current situation, apart from personal capability, is simply more than the surgeon is willing to take. In any case, using comfort level as a guide for action is a self-regulatory behavior. Through looking into self-regulation and metacognition in the psychological literature, I have come to see many other examples of what *could* be called metacognition in the verbalizations of surgeons we interviewed. In fact, as you might guess by its status as the title of my next-to-last chapter, I have come to see functions of metacognition in surgery as a central theme in this research.

At the end of the last chapter, I hinted that there might be more to expertise in surgery than the goals, predictions, and perceptual expertise data presented would suggest, and that this "more" could be found in the concept of metacognition. The question of whether metacognition adds to thought processes as an executive control function, as it is often termed (Gott, Lajoie, & Lesgold, 1991), or whether it simply *is* our thought processes described in another way, is raised when you look for a definition of the term. First let us define cognition. According to Neisser (1976, p. 1), "cognition is the activity of knowing: the acquisition, organization, and use of knowledge." Now consider meta-. In Houghton-Mifflin's American Heritage Dictionary, meta- has several definitions; those which could possibly relate to cognition are (1) beyond, or transcending; (2) occurring later, and (3) between. *Beyond or transcending* cognition, which suggests surpassing cognition, would be the argument for an executive process situated somehow above cognition, providing a controlling function to our activity of knowing. *Occurring later* indicates reflection, looking back on your knowledge as applied in a situation and possibly evaluating it. *Between* cognition suggests to me a sort of glue that holds separate cognitive activities together. Thus, metacognition is "above," "after," or "between" knowledge activities. Neisser defines cognition as how we get and use knowledge; in other words, perhaps cognition alone can be seen as how we control knowledge. Can another process surpass this one?

The most widely quoted definition of metacognition in the psychological literature appears to be that of Flavell (1976, p. 232), who was one of the first researchers to write about metacognition per se: "Metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them." If Neisser's definition of cognition is inserted into the above definition of metacognition, it would read, "metacognition refers to one's knowledge concerning one's own acquisition, organization, and use of knowledge processes, and products or anything related to them." To paraphrase, it is what we know about what we know. There are two problems with such a conceptualization. First, if you assign the same meaning to "what we know" in both places, a circular argument emerges. The second "what we know" should be good enough to describe it all; therefore, metacognition should equal cognition and there would be no need for the meta- term. The second problem is, what isn't metacognition? It would seem to be everything. Flavell's (1976) definition is extremely broad.

This breadth permeates early discussions of metacognition in child development research. In this context, Flavell & Wellman (1977) have suggested some ways to parse the concept of metacognition. They distinguish between metacognitive *experience* and metacognitive *knowledge*. Flavell & Wellman's (1977) article deals primarily with memory research and the concept of metamemory. They illustrate metacognitive experience with the "tip of the tongue" phenomenon, when you are aware that you have the knowledge called for and that it will soon be recalled, but experience a temporary blockage. In surgery, an experiential, in-the-moment reaction to a situation might be "I am really not comfortable with this situation," or "there is no way to identify structures in that bloody mess, I am completely lost."

The second aspect, metacognitive *knowledge*, is how we use what we already know (both declarative and procedural knowledge) to guide our thoughts and actions. Flavell & Wellman describe four general classes of metacognitive/metamemory knowledge; I will interpret their descriptions based on memory studies with children into examples relevant to surgery. The four classes are: (1) knowledge about tasks, such as knowing how difficult and time-consuming it could be to insert a small catheter into the cystic duct to perform a cholangiogram, and how this may impact the decision of whether to do it; (2) knowledge of self (person variables), to include knowledge about one's own knowledge, experience, capabilities, and proficiency; (3) knowledge of strategies which can be taken to enhance performance, such as always dissecting from known structures to unknown ones; and (4) interactions between the above three categories of information, such as recognizing one's own inexperience on a particular task and therefore asking someone else to help with it, or choosing a strategy with reference to one's own ability.

Furthermore, Brown (1978) has extended Flavell & Wellman's idea of metacognitive knowledge and discussed how it is either *static*, existing in factual form as it might be directly verbalized by someone who is asked about their task knowledge, or *strategic*, knowledge actively applied towards regulating and correcting thought processes. Strategic activities include *planning*, or deciding how to approach a problem; *predicting*, as when estimating the quantitative value of an outcome; *guessing* what might be the appropriate answer or decision; and *monitoring* how well a goal is being attained.

The breadth of metacognition as Flavell & Wellman and Brown have conceptualized it presents difficulties in trying to identify metacognitive statements in interview transcripts. Almost everything in these transcripts could be framed to fit some form of the above descriptions. More specific ideas about metacognition are needed, and they can be found in more recent work examining metacognition in training and in decision making.

For example, Baker & Brown (1984) abstract two categories of activities which they feel are pivotal to understanding metacognition: these are (1) knowledge about cognition and (2) regulation of cognition. This distinction is acknowledged and supported in other, even more recent descriptions of metacognition. For instance, McGuinness (1990, p. 302) states that metacognition "refers loosely to knowledge about, and control over, one's own cognitive system." Gott, Lajoie, & Lesgold (1991) call it a "broad term for both self-knowledge and self-regulation of thinking." Finally, Nelson & Narens (1994) present a framework of metacognition in memory (metamemory) in which a 'metalevel' mechanism monitors and controls an 'object-level' of processing via a dominance relationship. Thus, these two aspects of metacognition, knowledge of our thought processes (monitoring) and control or regulation of them, seem to be universal in current conceptualizations of the topic.

In work which is particularly relevant to this study because it attempts to describe naturalistic behavior, Cohen, Freeman, & Wolf (1996) argue that using metacognitive skills for proficient problem solving and decision making involves two key activities corresponding to the monitoring/regulation distinction just described. The activities are: (1) critiquing, which extends the monitoring aspect to *evaluation* of that knowledge, and (2) correcting, or regulating behavior through control actions. Cohen et al. (1996) explain situations involving time-stressed decision making in naval surface ship warfare with a 'metarecognitional' model which extends recognitional decision processes (i.e., Klein, 1989) to account for how naval officers develop an explanatory story of a situation and modify it over time. Critiquing and correcting occur in an iterative, or cyclical, manner. These activities are assumed to be on a metalevel which is functionally, but not structurally distinct from object-level processes (Nelson & Narens, 1994); in the object level, situation models and plans are developed. Critiquing activities in the Cohen et al. model include testing a situational model for incompleteness, discovering conflicts, and recognizing unreliable assumptions. Correcting involves collecting more data, activating additional information from long-term memory, adjusting assumptions, and/or selecting an explanation. In Cohen et al.'s research, goals of the domain include understanding the intentions of an enemy who could possibly be taking several different courses of aggression. Although some aspects of this model do not relate well to surgery,[1] the idea of critiquing and correcting in a cyclical process is important and I will return to it again later.

What metacognition is not. Returning to the question at the beginning of this section about what metacognition is not, it would seem that in order for there to be metacognition, it should have a separate function from "regular" cognition. This does not seem to be true: few authors describe what "regular" cognition is as separate from metacognition. Cohen et al. imply that object-level activities, such as planning and developing a situational model, are distinct from the critiquing and correcting functions

[1] There is no unpredictable, intentional enemy to guess about in surgery; although there is time-pressured decision making with high stakes, the goals remain to fix the problem and inflict no harm.

(Cohen et al., 1996). However, without object-level activities, what would there be to critique and correct? They cannot be separated from the process.

I have worked under the assumption that surgeons acquire knowledge about anatomy, physiology, boundaries of laboratory values, surgical techniques, and characteristics of illnesses which is part of a working knowledge, an object-level of knowledge if you will. In our interviews surgeons used this knowledge to assess the situation, make predictions, invoke rules, and also to assess risk and personal comfort level. Through analyzing these interviews, and asking what is not metacognition without finding a satisfactory answer, I have come to question whether it is useful to separate between functions of object-level knowledge and meta-level knowledge. Perhaps it is more useful to understand the relationship between self-knowledge and situation knowledge. This question is addressed in detail in the next chapter, Chapter 9.

In the remainder of this chapter the link between expertise and metacognition is explored and several findings from this research are presented to show how surgeons might be using metacognitive processes to accomplish their objectives.

8.2 Metacognition and Expertise

> *Studies of expertise show that the experience of experts--adults or children--enables them to develop executive skills for monitoring performance; experts rapidly check their work, accurately judge its difficulty, apportion their time, assess their progress, and predict the outcomes of their activities.* (Glaser, 1990, p. 32)

Researchers often associate well-developed metacognitive skills with expertise or experience. Research on metamemory in children shows that older children have a more highly developed sense of their own skills, and how to monitor or plan to remember things in the future (see Flavell & Wellman, 1977, for a review). Glaser & Chi (1988) review research on problem solving in physics which shows that experts have stronger self-monitoring skills, manifested in knowing when they are making errors and when solutions should be checked over. They argue that self-monitoring skills reflect the large knowledge base that develops with experience in a domain. In addition, McGuinness (1991, p. 302) states, "conclusions from metacognitive studies indicate that mature thinkers differ from novice thinkers because they have greater knowledge about when and how to use their cognitive resources."

However, metacognition is also viewed as a skill which can improve the learning efficiency of children and trainees. In studies comparing *blind* training with *informed* training, trainees were either taught strategies alone (blind), or accompanied by information about why they were useful and when they should be used (informed)(Brown & Campione, 1986). These and other studies have shown that metacognitive skills can be encouraged in a learning environment, and that these skills have a positive impact. Is there a paradox here? Experts have greater metacognitive skills, yet metacognition should be used to teach novices? I believe work describing expert and non-expert approaches to learning (Bereiter & Scardamalia, 1993) can shed some light on this issue. Illustrated by examples of "expert-like students" as well as experts themselves in several domains, Bereiter & Scardamalia (1993) propose that expert-like behavior is characterized by approaching new problems with a purpose of extending and enriching knowledge, using the difficult situation to push their competence to new levels. What they describe as the opposite of expert-like behavior involves a strategy of trying to find relevant personal knowledge which might apply to this new situation. Rather than see the unique aspects of a situation, a non-expert might employ a "best fit" solution in which relevant information is ignored.[2] Expert-like behavior requires working much harder and often longer to attain solutions in these situations.

Research which looked at how pianists learn a new piece of unfamiliar music (Ghent, 1989) illustrates the differences between expert-like and non-expert-like learning. Ghent asked music students and concert pianists to play on the piano a piece of Indonesian wayang music; this music is typically played on drumlike instruments. Both the concert pianist and a student, who was characterized by faculty as expert-like, spent a great deal of time considering how this piece of music should sound on the piano to capture its true character. They both also recognized the need to overcome the Western tradition of music in which they had been indoctrinated. A more typical student attempted to categorize and play this piece of music in terms of already known styles. A French impressionist

[2] None of the domains described by Bereiter & Scardamalia (1993) involve time stress; clearly, a best fit or satisficing strategy is often appropriate. Research on decision making of Fire Ground Commanders (Klein, Calderwood, & Clinton-Cirocco, 1986) illustrates how time compression, as well as other domain characteristics, influence dynamic decision making.

approach was deemed to be the "best fit," and the student learned to play the piece by applying this style. When Ghent asked a musicologist to listen to recordings of the two students playing this music, he noted that the first student had tried to capture the character of wayang music, and that the second recording sounded like French impressionism (Bereiter & Scardamalia, 1993).

These authors thus characterize expertise as an approach to a career, rather than its pinnacle: "The career of the expert is one of progressively advancing on the problems constituting a field of work, whereas the career of the nonexpert is one of gradually constricting the field of work so that it more closely conforms to the routines the nonexpert is prepared to execute." (Bereiter & Scardamalia, 1993, p. 11) The extraordinary knowledge base possessed by those considered experts in their field is consistent with this career approach; a lifetime of approaching problems so as to expand one's knowledge base would result in a large one indeed. But the way in which expert-like learners most resemble accomplished experts, according to Bereiter & Scardamalia, is in their self-regulatory knowledge.

Metacognition is thus a vital part of the expertlike approach described by Bereiter & Scardamalia. The concert pianist would have to be aware that he or she had no knowledge of how to play Indonesian wayang music, and that time and effort would be needed to study and understand its nature. This is the first part of metacognition cited above, knowledge about one's own knowledge. Further, the concert pianist realized that well-ingrained habits of Western musical interpretations would have to be suppressed in order to play this piece. This is the second part of metacognition, self-regulation. This research shows that monitoring and regulation activities can be used to improve performance at any level of experience. Thus, there is no paradox in asserting that experts have greater metacognitive skills *and* that metacognitive skills can be encouraged in novices.

Learning to play music does not include characteristics of time stress, goal conflicts, and risk assessment that are inherent in surgery and many other domains where expertise is of interest. However, research in air combat has shown different aspects of the common ground between expertise and metacognition. Amalberti & Deblon's (1992) work (discussed in Section 7.4, on prediction and anticipation) showed that pilots devoted most of their free time during flight to anticipating whether upcoming situations were familiar enough so that they knew what action to take; if not, the pilot would try to change the current parameters to stay within known boundaries. "The implication is that most of a pilots' expertise lies in avoiding situations where they have no solution or no chance of applying known solutions." (p. 655) Unlike concert pianists, pilots in combat do not have time to think carefully through an original solution during flight; if they have not thought something through in pre-mission planning, they realize that it is to be avoided at all costs.[3] In addition, pilots in Amalberti & Deblon's (1992) study added extra waypoints to their flight plan because they anticipated they could fall behind schedule. The time scheduled to be over target is not negotiable, and there are no excuses for being late; planning these waypoints and knowing they could be skipped to make up time allowed the flexibility needed to ensure being on time. I would not characterize these combat pilots in Bereiter & Scardamalia's terms of learning the most from every new situation (although they might be). Rather, Amalberti & Deblon's research shows how they apply self-monitoring which is more relevant to their goals of time-driven mission accomplishment, and how anticipation of the familiarity of future situations is an important aspect of a pilot's self-monitoring behavior. Thus, research has shown that metacognition and expertise can be tightly coupled in different ways, and at all levels of experience.

8.3 How Metacognition has been Operationalized

The emergence of particular categories of surgeons' statements (i.e., those indicating comfort level and perceived risk) allowed us to abstract a working idea of metacognition in surgery. In this research, metacognition was operationalized into a variable for coding transcripts to reflect the verbalizations surgeons made in our interviews; poring over the transcripts led to the idea of metacognition as (1) an individual's personal oversight, self-regulation to remain within a safe field of operating, and (2) assessement of risk in a situation with respect to capability. There is certainly some overlap between these, and it would be difficult to derive these directly from available definitions of

[3] Commercial flight crews often have slightly more time to think through problems; the United Airlines crash in Sioux City, Iowa is an example of commercial pilots thinking through and applying an original solution to a previously undocumented dilemma, that of losing all hydraulic power.

metacognition. But the categorizations which Flavell & Wellman (1977), Brown (1978), and other authors reviewed have developed for metacognition can help to ground our observational categories in metacognitive theory.

As with the perceptual expertise variable, the categories of the metacognition variable were developed purely to capture what surgeons interviewed were saying. These were the descriptions used to identify statements to code with the metacognition variable:

> [1] General comfort level: whenever surgeons mentioned comfort level, either hypothetically, their own, or that of the operating surgeon. For instance, "If a surgeon doesn't feel comfortable doing acute gallbladders laparoscopically, then they should do what they feel comfortable with."
> [2] Risk involved: whenever surgeons discussed qualitative or quantitative risk, such as "she's got an increased risk of developing an infection post-operatively," or "unrecognized duodenal injury has a 40-50% lethality rate."
> [3] Knowing consequences of actions which could cause injury, hidden dangers which could 'bite you' right away or later on. For example, "you could poke through the gallbladder into the liver and aspirate blood if you are not aware of where you are," or "there's danger in trying to dissect the common bile duct too well, if you injure its blood supply you can injure it."
> [4] Monitoring/controlling own actions or thoughts. For example, "I would try to be more careful, go slower and be more meticulous because of the inflammation," and "if there are stones in the common bile duct, I don't have any experience with choledocholithiasis, and in an older patient I would therefore begin open."
> [5] Other: general discussion of judgment, or experience level, or other. Examples of statements coded in this catch-all category include "the biggest mistake an inexperienced surgeon can make is not realizing they should have opened," and "judgment is sometimes based on what a surgeon can get away with, not what is best for the patient."

All of these categories of metacognitive statements in surgery can be described in terms of how Flavell & Wellman, Brown, and others have characterized metacognition. First, META1 statements, which reflect general comfort level, are an excellent example of the *experiential* metacognition that Flavell & Wellman describe. In addition, assessing comfort level is a form of self-monitoring and evaluation. Second, META2 statements, whereby surgeons talk explicitly about risk, involve using task knowledge about risk for predicting and monitoring strategies. Surgeons apply knowledge from medical research and previous outcomes of procedures in similar situations to form risk assessments. This activity involves evaluating a situational model in terms of probabilities for success (as described by Cohen et al., 1996). Probabilities that the system is in a particular state are also evaluated; for instance, the chance that a certain patient will have bile duct stones.

Similarly, META3 statements (defined as knowing consequences of actions which could cause injury, and understanding hidden dangers which could 'bite you' right away or later on) also reflect predicting and monitoring strategies. The META4 code was applied when surgeons indicated they were monitoring or controlling their own thoughts through specific monitoring strategies. "I would try to be more careful, go slower and be more meticulous because of the inflammation" is a monitoring strategy employed to prevent injury to the patient. Finally, we coded general discussions of judgment or experience level as META5. An example of this kind of statement was, "you need to know your own experience level, the less experienced you are the more you should do what you know you can do." This, along with many of the surgeons' discussions coded as META5, is a general reference to what Flavell & Wellman call self knowledge. "Doing what you know you can do" relates self-knowledge to specific situations, providing a check on whether a current situation is within the bounds of one's capability.

It is obvious that these authors also expand metacognition to concepts which we used other variables to document (the difficulty is not to be found in matching metacognitive activity observed in surgery with these concepts, but in discriminating what is *not* metacognition). For example, knowledge we coded with the prediction variables, presented in the previous chapter, is part of what Brown (1978) describes as strategic metacognitive knowledge. It is difficult, and somewhat artificial, to separate the idea of prediction from that of assessing risk; the former is inherent in the latter. Assessing the current situation in terms of risk is a vital function of metacognition in surgery, both when planning a surgical procedure and as an up-to-the-minute assessment. The quote from Bosk at the beginning of this thesis illustrates overall risk assessment:

> *In a very real way every time a surgeon operates, he is making book on himself. Besides the enormous amount of theoretic and technical expertise that is his cognitive capital, the surgeon carries in his head an odds-book for each procedure he performs; he knows the mortality and morbidity attached to each procedure he performs; and he is able to revise these odds up or down on the basis of each patient's age and physical condition. . .* (Bosk, 1979, pp. 30-31)

The difficulty in teasing apart some of these concepts suggests that perhaps they should not be isolated and studied as such, but rather the relationships between prediction, risk assessment, expertise, and metacognition should be examined instead.

8.4 Other Current Research on Metacognition

Scientific interest in metacognition seems to be growing. In much research, the emphasis is on metacognition as it develops in children and as it can be used in education (ie. teaching reading, Baker & Brown, 1984). It is not surprising that researchers feel this concept has promise for fostering expertise through training in technical and professional domains as well. In fact, although most aspects of expertise are considered to be domain-specific, Means et al. (1993) propose that metacognitive skills have unique potential as a general skill for enhancing decision making across different domains. Bransford, Sherwood, Vye, & Reiser (1986) review a broad range of studies indicating the importance of metacognitive or executive control processes in training and education. In memory research, metacognition is typically operationalized as a "feeling of knowing," in a paradigm where subjects are asked to recall a certain item of information, and then asked their subjective assessment of its correctness, or if they cannot remember, to assess whether they ever did know this piece of information (Koriat, 1994; Metcalfe & Shimamura, 1994). From the industrial/organizational psychology literature, the influence of self-regulation in work motivation has led to its description in terms of cognitive social learning theory (Bandura, 1991) and to a control theory of self-regulation (Carver & Scheier, 1981). Thus, researchers are interested in the potential of metacognitive processes for improving human performance from many different perspectives, to include reading/education, child development, training, memory, and motivation.

8.5 Analysis of Variables: A Metacognitive Story

To make a transition between a review of research on metacognition and presentation of data from a cluster of variables which indicate metacognitive behavior in surgery, consider what might be metacognitive about the decision to open. I have proposed that metacognition involves monitoring one's own knowledge and capability as to whether a challenging task can be performed successfully, or whether the risk is simply too great. This monitoring reflects the first part of how researchers typically characterize metacognition; the second part, regulation, refers to the action which is taken if the situation is perceived to be too risky or too difficult. Converting to an open procedure is probably the most drastic type of regulatory action taken in a laparoscopic surgery. Converting is not a simple decision. In an editorial on conversion in laparoscopic surgery, Greene (1995, p. 11) stated: "the urge to follow through with an endoscopic approach may be so strong that judgment becomes clouded and the timing of the conversion process is, therefore, delayed until an untoward event has occurred (knowingly or unknowingly!)." Greene recommended that the decision to convert be made early in a case, and that surgeons should have an "internal clock" monitoring the passage of time. The decision to convert thus involves understanding the urge to continue, watching the clock, and monitoring the entire situation for indications that the patient would be better served by an open approach. Metacognition as described in the literature must play a part in this process, and therefore variables reflecting conversion, comfort level, information available for identification, and the metacognition variable will be presented together to better describe this process in surgery.

8.5.1 Conversion to an Open Procedure

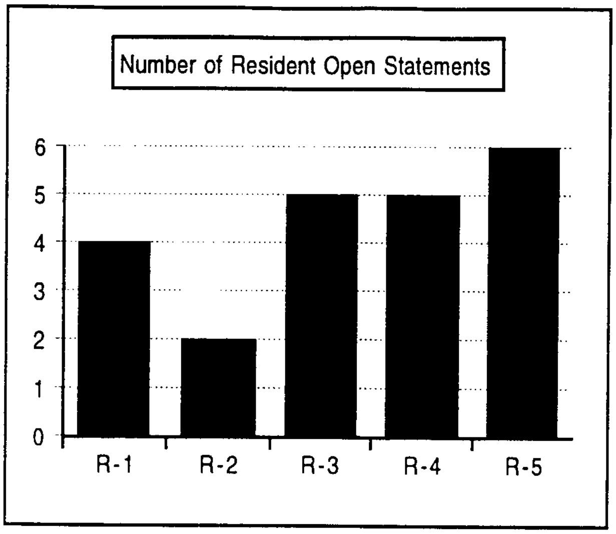
Surgeons either volunteered that they would convert this case to an open-incision one, or said so in response to a question. There was no pre-planned question asking, "would you convert this case now?" At each decision point, we did ask, "If I told you that the surgeon decided to open at this point, would you think that was a reasonable course of action?" In some of the instances where we noted that a surgeon would open, there was hesitancy or uncertainty, and in other cases there was no doubt that they would open. This was documented as the strength of the statement, an argument of the variable indicating 'maybe' or 'definitely'. Where surgeons indicated they might be opening, statements were labelled "maybe open," so that the lack of certainty about this decision could be noted. In the majority of cases, as will be discussed shortly, surgeons were more definite.

Deciding to convert this procedure to an open one has differing significance for residents and staff surgeons. For any surgeon, our 80-year old woman would be considered a difficult case. If a resident is in tune with his or her capability level, or "well-calibrated," one would expect him or her to at least express discomfort with performing this case laparoscopically, and possibly to indicate they would convert the case. Many statements made by surgeons we interviewed suggested that this discomfort and decision to convert would be appropriate for a resident, mainly due to the difficulty and risk involved in this case. For instance, a resident surgeon said, "the biggest mistake an inexperienced surgeon can make is not realizing they should have opened." A staff surgeon would be *more likely* than a resident to feel they have enough expertise to perform this case laparoscopically. However, if metacognitive skills improve with experience, staff surgeons would also be more likely to give credence to their feelings of discomfort.

Of the twenty surgeons interviewed in this study, although similar numbers of staff and resident surgeons stated they would open (5 out of 10 residents and 4 out of 10 staff surgeons), the residents said they would open more often and more emphatically. The total number of times residents said they would open was 22 (6 of which were 'maybes'), but only 12 for staff (5 of which were 'maybes'). Each of the residents who said they would open made more "definitely open" statements than "maybe open" ones. Two of the four opening staff surgeons were less convinced, saying *only* that they would "maybe open" (Denoted by the (m) in Figure 8.1). Viewed another way, the opening residents said they would open with far greater frequency than the opening staff surgeons: 4.4 times, on the average, as compared to 3.0 times for the staff.

Since four staff and five residents said they would open, a categorical blocking of the surgeons interviewed as "openers" and "non-openers" is possible. These numbers are fairly convenient for seeing how the five residents who opened compared to the five who did not on other measures, such as comfort level and metacognition statements. Staff can be compared similarly, although not quite as neatly into equal sized groups.

The numbers of surgeons who indicated opening during various periods in the videotape can shed light upon what points may have been especially uncomfortable, or high-risk. Figure 8.2 shows this distribution across seven periods in the tape (these seven periods correspond with time periods in the storyboard for this case shown in Figure 5.1, except for the comfort level ratings shown in the storyboard). Note the large number of opening statements at period 7, during the dissection of the last structure and the last decision point. This is the period during which surgeons realize there is a third structure



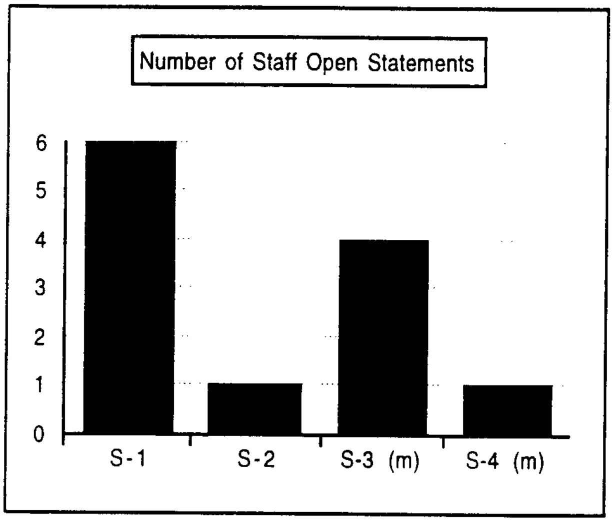


Figure 8.1 Individual data on how many times residents and staff who opened indicated they would open. Each bar represents the number of times one surgeon said he or she would open. The (m) indicates 'maybe open' for the staff surgeons S-3 and S-4.

being dissected, when two structures have already been clipped and cut. Since only two structures are typically clipped and cut during a cholecystectomy, and this is the third structure, identification becomes more uncertain here, and the potential for having already injured the common bile duct increases. Surgeons told us they need to identify structures with 100% certainty. A catastrophic error which could be made in this situation if structures are not identified correctly is clipping and cutting the common bile duct, mistaking it for the cystic duct or artery. When uncertainty about what was clipped and cut became strong, surgeons said they would convert to an open procedure as a way to clarify the anatomy and ensure no mistakes have been made.

8.5.2 Comfort/Discomfort Level Ratings

In these interviews, a seemingly invariant credo was, "if you're not comfortable, you should open." Comfort level is a surgeon's self-assessment of risk, a barometer indicating whether capabilities are aligned with the current demands, or whether the overall situation is simply more risky than acceptable. We elicited a comfort level rating at each of the three decision points, as shown on the storyboard in Figure 5.1. The anchored scale

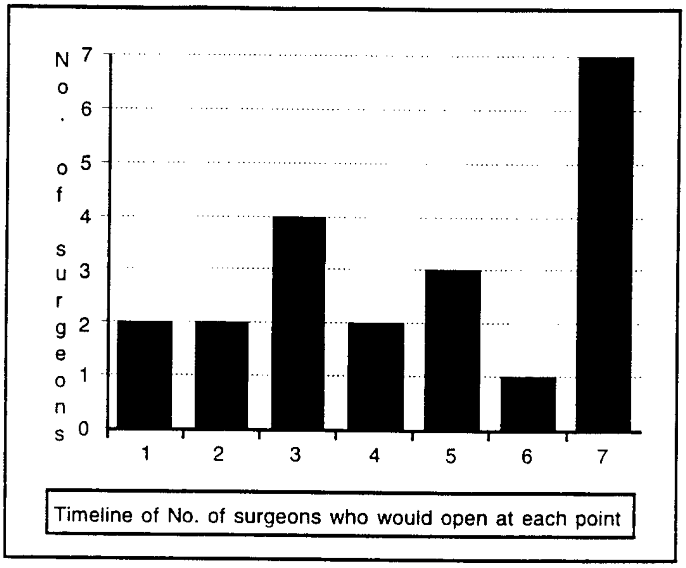


Figure 8.2 This figure shows how many total surgeons stated they would open at each time period of the videotape. Numbers on the x-axis indicate the following time periods:
1. Before seeing videotape
2. After first look at video
3. During initial dissection
4. Dissecting out 1st structure
5. After Gallbladder bursts
6. Dissecting out 2nd structure
7. During Last Decision Point/ dissecting out last structure

used to elicit the rating is shown below:

Comfort level at continuing (or beginning) this case laparoscopically:

1.	No concerns whatsoever	(0)*
2.	Little concern.	(5%)
3.	Increased concerns	(25%)
4.	Moderate concerns; 50/50 chance this will need to be converted	(50%)
5.	Many concerns	(75%)
6.	Very seriously considering converting/beginning as open	(95%)
7.	Would convert/begin as open *now*	(100%)

*Percentage indicates level of concern and probability that this case will have to be done open.

I expected that surgeons who indicated high levels of discomfort (6 or 7 on the scale) would heed their discomfort and indicate they would open. This expectation was confirmed by higher ratings of discomfort by the surgeons who said they would open. I also thought staff surgeons would generally be more comfortable than residents in this case, reflecting their greater experience. But there were no statistical staff-resident differences in comfort level ratings at any of the decision points. Grouping surgeons according to whether they said they would open or not *did* reveal differences in comfort level at the second and third decision points. One-way analyses of variance, examining openers' and nonopeners' comfort levels at decision point 2 ($F(1, 19) = 15.1$, $p = .001$) and at decision point 3 ($F(1, 19) = 16.1$, $p = .001$) were significant.

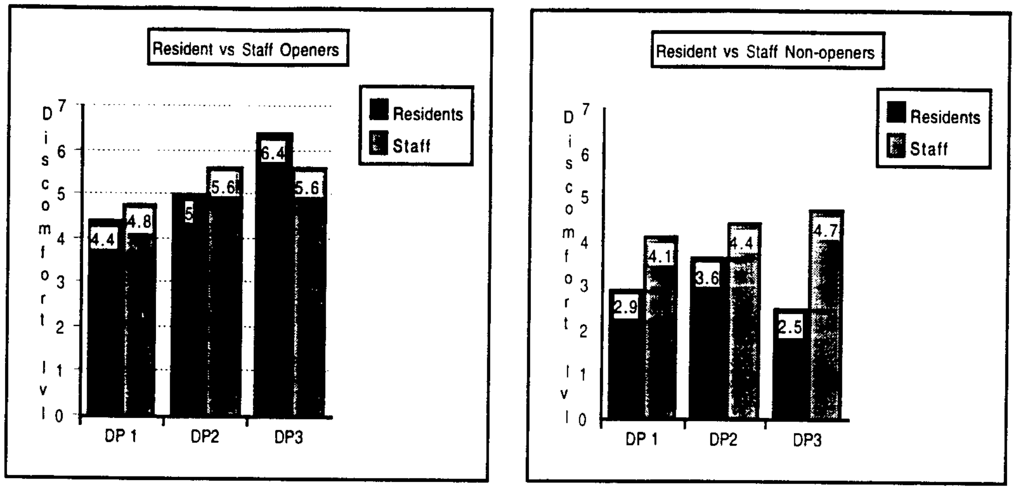


Figure 8.3 At left, the comfort level ratings for the five residents and four staff who decided to open this procedure are shown. At right are these ratings for the five residents and six staff who did not decided to open. DP1 = Decision Point 1, and so on.

Figure 8.3 shows that both staff and resident openers became less comfortable across time, with the greatest discomfort at decision point 3 (this also was the point most surgeons said they would open, as shown in Figure 8.2). Looking at the nonopeners, on the other hand, two different trends are apparent. The staff non-openers are getting progressively less comfortable across time, although they are still more comfortable than their counterparts who opened. The resident non-openers, on the other hand, are more comfortable than any other group, and they are *most* comfortable at decision point 3; this is the *least* comfortable point for all of the other surgeons.

A two-way analysis of variance of comfort level ratings was conducted at each decision point, contrasting the two levels of "opener" and the two levels of experience. At decision point 3, a marginal two-way interaction was found for surgeon type (resident vs staff) and openers vs non-openers, $F(1, 15) = 3.7$, $p=.07$. The value of these numbers is questionable due to the small number of surgeons in the sample, but they illustrate what is visually obvious. That is, resident and staff openers are quite similar in comfort level at decision point 3, while resident and staff nonopeners are quite different from each other. Possible reasons for this difference will be discussed shortly, in light of all the data presented in this chapter.

8.5.3 Perception of Pulsating Artery and Metacognition Statements

In the last chapter (section 7.7.3) I discussed how the pulsation of the cystic artery provided the most concrete evidence for identification of any of the structures in this case. Staff surgeons noticed this pulsation more frequently than did residents: 6 staff and 3 residents saw the pulsation. Figure 8.4 shows a diagram breaking down the numbers of residents and staff by opener vs nonopener, and how many in each group saw the artery pulsation. Beginning with the resident openers at the top of the figure, one saw the pulsating artery and four did not see it. The staff openers showed a similar trend: one saw the pulsating artery and three did not. Since seeing the pulsation is a way to increase certainty about the identification of structures, then we would expect those *not* seeing the pulsation would have a less accurate situation assessment, would have a resultant lower comfort level, and would be more likely to say they would convert, as was the case. The left panel of Figure 8.3 shows that openers did indeed have greater discomfort.

If the above logic holds, those surgeons who saw the pulsation would be more comfortable and less likely to open. Seeing the pulsation would tend to increase their comfort level with the identification, and make them less likely to say they would open. The lower section of Figure 8.4 shows that five out of six staff non-openers did indeed see the pulsating artery. Overall, fewer openers than nonopeners saw the pulsating artery: two of nine openers saw it (22%), and seven of eleven non-openers (64%). Although five of six (83%) staff non-openers saw the pulsation, no such trend is clear with the resident non-openers. The average comfort level ratings of this group, the resident non-openers, were different than the other three groups, as I discussed above (see Figure 8.3).

Another part of the story can be seen in the number of metacognitive statements made by each of these four groups. Figure 8.4 shows the average comfort level ratings and number of metacognitive statements that each of the subgroups made; the median number of metacognitive statements are labelled with an 'M:' in the lower half of each block.[4] The resident opener group, most of whom did not see the pulsating artery, made

[4] There was a large variability in the number of these statements made, ranging from 4 to 26, and hence the median number was used to represent the group in Figure 8.4. The metacognition variable was by far the most difficult variable to code, in that many statements which were missed in the initial coding were discovered later. All twenty transcripts had to be reviewed to specifically look for missed metacognitive statements.

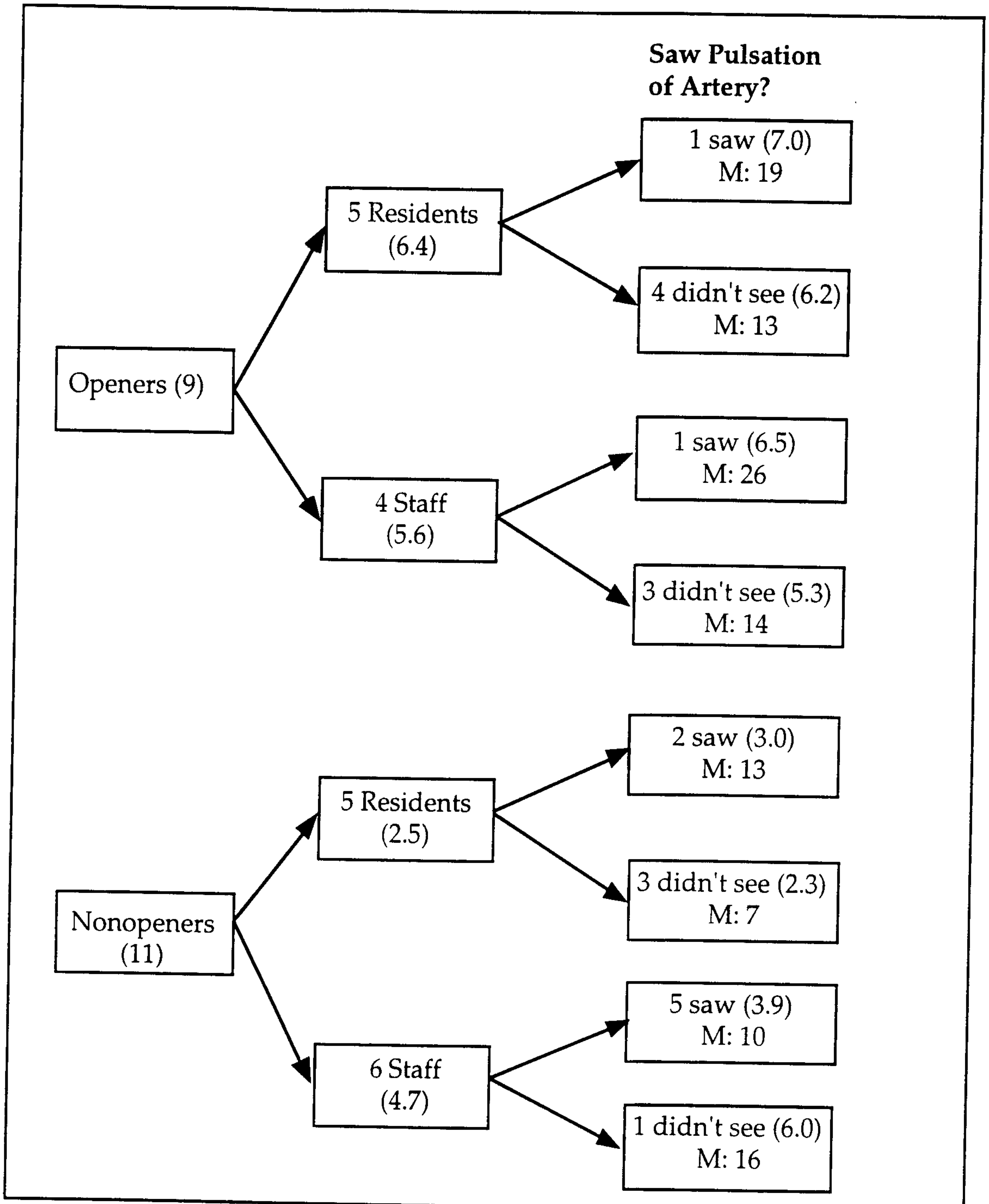


Figure 8.4 Flow chart showing how openers and nonopeners break into subsets of staff and resident and seeing the pulsating cystic artery. The number in parentheses is the mean comfort level at decision point 3 of the group in each subset. The 'M' numbers on the far right indicate the median number of metacognition variable statements for each subset, or the number for the individual represented by the subset.

more metacognitive statements on the average (15.4) than the resident non-opener group (9.4). The same relationship holds between staff openers (18) and non-openers (11.8). This relationship is shown directly in Figure 8.5. Overall, a one-way analysis of variance showed that openers made more metacognitive statements than nonopeners, $F(1, 19) = 4.7$, $p = .04$. There were no statistical differences between resident and staff surgeons in number of metacognition statements. It makes sense that surgeons who said they would open made more statements which reflect an understanding of the risk involved in this case, as the metacognitive statements do, than the non-openers.

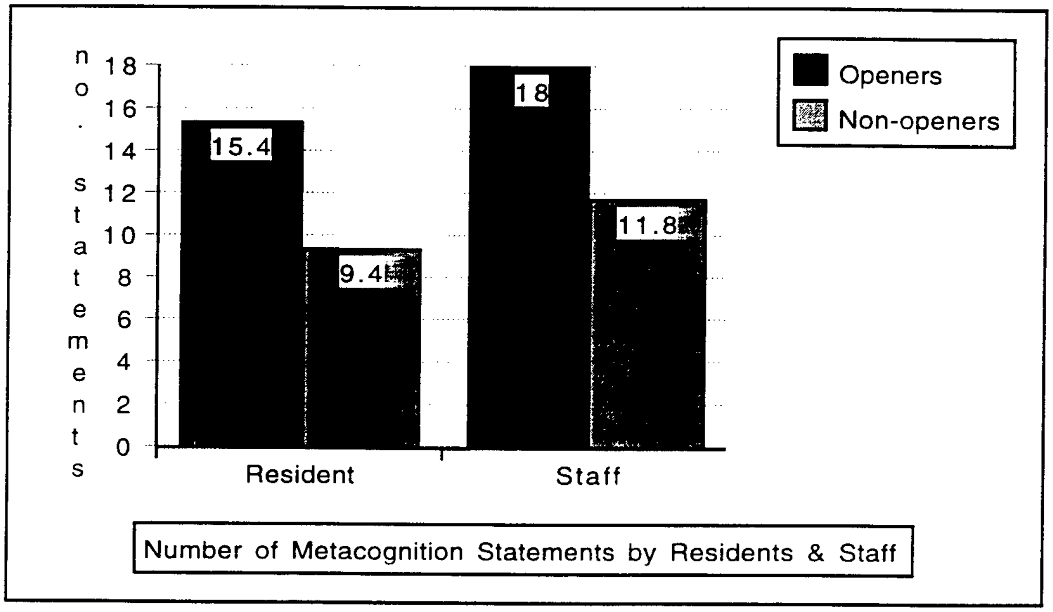


Figure 8.5 Average number of metacognitive statements made by residents and staff in two groups, showing the difference in this variable between surgeons who stated they would convert this case to an open procedure (openers) and those who did not say they would convert (non-openers).

The three resident non-openers who did not see the pulsating artery had a median number of metacognition statements of 7 (see Figure 8.4); individual numbers were 5, 7, and 9. This was by far the lowest number of all the subgroups, and suggests these surgeons are either not aware of the risks which other surgeons see in this situation, or that they are simply not verbalizing the risks.

8.6. Summary

To pull all of these pieces of information together, let me summarize the above findings. First, the resident group was split down the middle as to whether this case was outside their expertise, but residents who said they would open were more emphatic and repetetive than the staff who said they would open. This seems appropriate, considering residents have collectively less experience than the staff. However, there was not a group difference between comfort level ratings of staff and resident; rather, the difference lay between those who said they would open and those who did not. Examining the relationship between experience level and the decision to open showed that staff and resident opener groups were similar to each other on many variables, but staff and resident non-openers were not similar to each other. Staff and resident openers rated their comfort similarly and made a comparable number of metacognitive statements. Staff non-openers followed the rising discomfort trend shown by both opener groups, but resident non-openers were *most* comfortable at the last decision point, the very point at which most decision to open statements were made (see Figures 8.2 and 8.3). Staff non-openers had more information for identification of the structures: only two of the five resident non-openers saw the artery pulsate, as opposed to five of the six staff non-openers, yet the residents were more comfortable. Why were these residents so comfortable with performing this procedure laparoscopically, when so many others indicated it was outside the limits of safe operation? Comparing the numbers of statements coded with the metacognitive variable provides a clue. Resident non-openers made far less of these statements, verbally evaluating the situation and their own comfort level in terms of risk less often than the other three groups.

It is possible that these residents simply weren't as fully immersed with playing the role of surgeon in our interviews as the other surgeons were. There are certainly other factors involved as well: for instance, one resident non-opener rated comfort level at decision point 3 as a 3, but qualified the rating by saying a cholangiogram was needed before any further action could be taken. It is not the purpose of this analysis to pass judgment on the resident non-openers. However, the pieces of evidence associating comfort levels, opening, seeing the artery pulsate, and metacognitive statements indicate that this group diverged from the other three groups, either in their assessment of risk in the situation or their involvement with the interview.

If such a trend were observed in the operating room, it might be likened to a phenomenon observed in other research known as failure to revise, or fixation (see Woods, Johannesen, Cook, & Sarter, 1994, for a review). One fixation pattern that Woods et al. (1994; from DeKeyser & Woods, 1990) cite is acting as if 'everything is O.K.,' seen when operators do not revise their assessment to reflect changes in the situation. Although each transcript tells a different story, the resident nonopeners as a group seem to be maintaining an 'everything is O.K.' stance in the face of evidence which makes their peers think everything is not.

These data also suggest that resident *openers* choose a path and indicate comfort levels which make them more similar to the staff surgeons who wanted to open than to their peers who did not. The number of metacognitive statements made by resident openers suggest that they have a strong sense of risk and danger, and how to act in a way which mitigates this risk, even though their perceptual expertise is not as fully developed as that of the staff. Thus, as both Bereiter & Scardamalia (1993) and Amalberti & Deblon (1992) found, monitoring and regulating one's own performance can lead to better goal achievement at varying levels of experience.

It is possible that monitoring and regulating skills can compensate for a lack of other knowledge. Awareness that you are too inexperienced to safely progress laparoscopically may lead to a new approach, opening, where there is an expanded field of safe travel and risks are less pronounced. Baker & Brown (1978) identified how children might use compensatory skills to overcome perceived reading problems as a topic of interest to psychologists. Whether monitoring and regulation can plan a compensatory role is of considerable interest to psychologists who study training approaches for operators of complex systems (Means et al., 1993).

9.0 Metacognition Re-examined: A Synthesizing or an Overriding Concept?

9.1 Is Metacognition Between the Cracks or Above the Fray?

In the last chapter, I returned again and again to the question posed above. Is metacognition an overriding function or an aspect of cognition which is "between," inseparably entangled with other forms of knowledge? Is it entitled to a privileged executive status simply because it reflects knowledge of our own knowledge rather than knowledge of a system or situation? The manner in which personal comfort assessment and risk assessment integrate knowledge of the surgeon's state with knowledge of the patient's state and other situational factors leads me to believe that "between the cracks" is a better analogy. As I will illustrate later in this chapter with surgeons' discussions of why they would open, self-monitoring and situation-monitoring are mutually dependent.

Although separate variables were used in this research to identify surgeons' predictions, perceptual expertise, rules, and metacognitive statements, many times a single statement reflected of two or three of these concepts.[5] The idea that prediction is an activity associated with metacognitive processes is not new (Brown, 1978; Glaser, 1990). The unique contribution I would like to make is a description of how surgeons accomplish their goals and mitigate risk, framed in terms of monitoring and regulating. In this chapter, I will attempt to show the relationships between aspects of perceiving, thinking and acting which have emerged from the surgeons' transcripts, organized in terms of the monitoring and regulating cycle characteristic of metacognition. A graphic illustration of this organization will be explained. In the last section of this chapter, I will use examples from transcripts to show how self- and situation monitoring and regulatory actions[6] are used to help surgeons define, and work within, a safe field of operation.

[5] Since statements coded with more than one variable were common, the alternative variable(s) were indicated in a cross-coding column of spreadsheets on which we aggregated these statements.

[6] The term 'regulatory actions' will be used in this chapter to refer to the five categories of action listed in the right portion of Figure 9.1. Regulatory does not imply responsive; many of these actions are taken to gain more or better information.

9.2 Thinking in Terms of Metacognition

I have shown how metacognition is considered in the literature to be both monitoring and regulation of our knowledge processes. Recognizing that we focus on ourselves as a target of interest in addition to focusing on environmental information (Scheier & Carver (1988) call this self-attention) makes an important contribution to any model of thinking. However, if monitoring and regulation of self-knowledge are the activities of metacognition, then I will make the case that they can also be considered as interacting activities of cognition.

First let's think about monitoring. Cohen et al. (1996) call this critiquing. It can also be called assessing. It involves being attuned to, and evaluating, task-relevant information. We observe information, assess it, and form some type of picture of the state of the system. As awareness of the external environment develops, we develop a personal reaction to it: a degree of satisfaction or dissatisfaction, whether things are as expected or not, or a level of comfort or anxiety. The situation assessment and the personal reaction feed on each other. When a situation generates discomfort, tuning in to the discomfort through self-attention in turn influences further situation assessment. When things seem normal, there may be a tendency to turn less attention towards the self; it is possible that surgeons in our study who did not say they would open saw the 80 year old woman's case as meeting criteria for a normal laparoscopic approach. If so, this would explain the lower number of metacognitive statements made.

Several variables used in this research to code surgeons' transcripts reflect situation and self-monitoring (refer to the left oval in Figure 9.1). The most obvious is the metacognition variable, with its categories of (1) comfort level, (2) assessing risks, (3) predicting injuries or negative outcomes which could result from a particular action, and (4) self-monitoring strategies. All of the prediction variables fall within this activity, since predicting and anticipating are monitoring projected ahead, foreseeing natural consequences of current states or actions. The two main types of prediction which emerged from our analyses, as discussed in Chapter 7, (1) anticipating difficulty in dissection and/or identification of structures, and (2) predicting that this patient would sustain an unintended injury, illustrate how surgeons monitor a current situation to predict possible

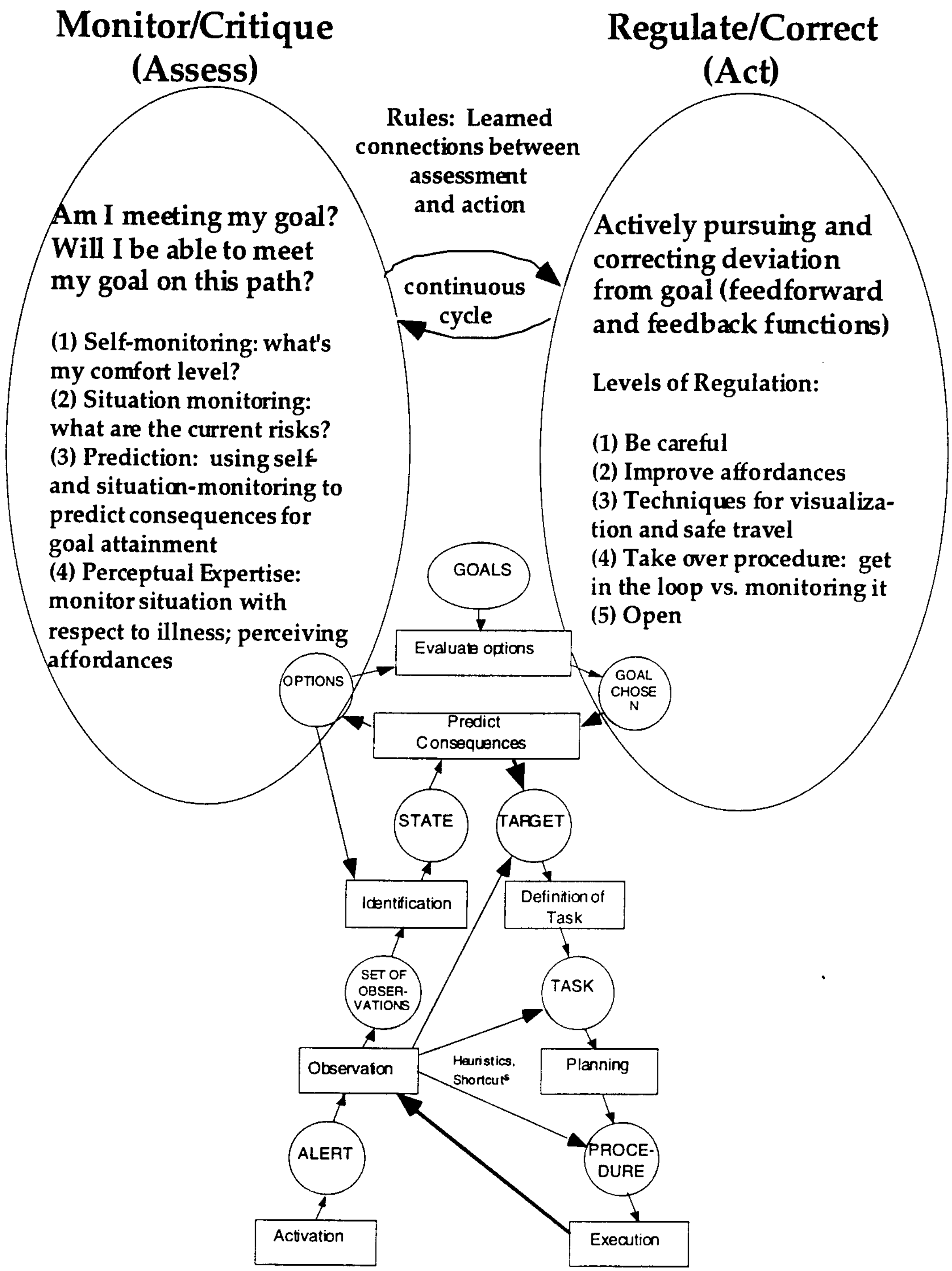


Figure 9.1 Relationship between variables in interview study as depicted in a framework of monitoring and regulating. Perceiving, thinking, and acting are shown relative to assessing the situation and the self with respect to goal achievement. The left side, assessing, corresponds with the left side and upmost levels of the decision ladder, while the right side, acting, corresponds with the right side of the ladder. Rasmussen's decision ladder is shown to illustrate that what might be called metacognition is simply another useful way of viewing goal-directed action in complex work environments. (Decision Ladder figure from Rasmussen et al., 1994, reprinted by permission, © John Wiley & Sons, Inc.)

consequences.

Another variable discussed in Chapter 7 was perceptual expertise; this variable overlapped with prediction of consequences. Two areas also emerged from statements coded under this variable: (1) using information about the progression of disease to add to or update a model of the situation and (2) using perceptual information to infer whether the situation would afford dissection, exposure, grasping, and other actions necessary to complete this procedure. These perceptual statements reflect monitoring activities, monitoring the patient's state and the implications of the patient's state for desired action. This latter activity provides a bridge to regulation activities, shown on the right side of Figure 9.1.

When monitoring of one's self-state and situation state revealed either a disconnect from a desired state or a projected disconnect, surgeons referred to what can be called regulation activities as means for correction. The levels of regulation shown in Figure 9.1 do not constitute a hierarchy, but merely show that there is a range of the *extent* of action which is taken for regulation, from simply being more careful through converting to an open procedure. The interaction between monitoring and regulation is continuous. When surgeons said, for instance, "I would be more careful," both heightened monitoring for feedback and modification of movements are implied in a highly coupled way. When it became clear that the distended gallbladder would not afford grasping, all surgeons agreed that it was time to aspirate the gallbladder so that it could be grasped; evaluation of the gallbladder's graspability and recommended action to improve it were linked by every surgeon we interviewed. (This link implies monitoring and regulating of the situation, but not of the self, hence most authors would not say metacognition was involved!) Further, realizing that anatomy is too obscured by inflammation to see structures and therefore assessing risk of injury as high led to suggestions for using techniques for better visualization and for mitigating the risk of injury (i.e., always moving from known to unknown structures).

Since we typically asked the surgeon interviewed to role-play as an attending surgeon, acting as the assistant to a resident operating under his or her supervision, stating that he or she would now take over the procedure was another form of regulation. This too illustrates the entanglement between monitoring and regulating, since taking over was typically done to ascertain better feedback about how tissues felt, hence providing more information with which to evaluate the situation. Taking over the procedure is a way surgeons can insert themselves more directly into the informational loop, rather than monitoring it from the assistant's position (the assistant retracts the gallbladder, providing tension on structures so that the operating surgeon can manipulate them).

Finally, at the most dramatic level of regulation, a surgeon can decide to convert, changing the entire approach to the operation. The following dialogue indicates how one resident surgeon described the benefits of opening:

SURGEON: You can still have an injury, but you have much more control doing it open.
INTERVIEWER: Control over fixing an injury?
SURGEON: Control over, yeah, you can get better exposure, you can get better retraction, you can feel things with your fingers that you can't feel with the instruments. You can use different instruments. A lot of times, it's much more technically demanding doing the cholangiogram laparoscopically, because you don't have as fine a feel through the catheter, and a lot of times it's easier to do a cholangiogram open technique than closed.

In this passage, the resident focuses on control, which is a particularly appropriate way to describe the benefits of opening in light of a monitoring/regulating view. Opening allows a more accurate assessment of the situation, through better exposure and retraction and through feel, as well as greater ease of doing a cholangiogram. All of these things lead to mitigation of the risk of injury, since injury is often caused by lack of information about what structures are.

A sketch of Rasmussen's decision ladder (Rasmussen et al., 1994) has been included in this figure to make the point that depending upon one's definition of the "SYSTEM STATE" node, all of the monitoring and regulating activities just described could be mapped onto this model. The left side and upper portion (predicting consequences in light of goals) of the decision ladder shows information processing activities and states related to monitoring. The right side of the ladder depicts various stages in selecting, planning, and executing actions, which correspond to regulation. Shunts across the ladder show the adaptive and cyclical nature of these processes. Thus, monitoring and regulation of situation and self could just as easily be depicted in the flexible way that the decision ladder allows characterization of skill, rule, and knowledge-based cognitive control (Rasmussen, 1983).

Another way to view monitoring and regulation activities can be found in control theory. Carver & Scheier (1981) have developed a control-theoretic approach to human self-regulatory behavior which has gained a prominent position in the work motivation literature. In their model, it is assumed that self-regulation requires an individual to focus attention on his or her own behavior and that comparison between a goal (or behavioral standard) and current performance initiates controlling, or self-regulatory, processes to correct any discrepancy which might exist. This process in humans is likened to a negative-feedback loop control system such as a thermostat, where the discrepancy between current temperature and the set point initiates a control action to reduce the discrepancy. However, surgeons use prediction and anticipation to project whether a course of action will lead to goal accomplishment, or will result in deviation from those goals. Such feedforward actions are not accounted for in the negative feedback loop model which Carver & Scheier (1981) propose, but should be incorporated in a control-theoretic model of monitoring and regulation.

Adaptive control models seem particularly suited as an analogy for processes of monitoring and regulation. These models include the basic negative feedback loop described above, but add another loop in which the control strategy is adapted according to how the system state is assessed. There are two general types of adaptive control approaches, the model-reference method and the self-tuning method (Slotine & Li, 1991). Model-reference control, as represented by Figure 9.2, can be interpreted for surgery in terms of an 'ideal operation' that a surgeon (the controller) compares the current situation against. The 'plant' in this figure is the surgical operation. What occurs as a surgeon realizes through monitoring activity that the reference model is not being met, i.e. realizes that vision is too obscured by inflammation and bleeding to continue safely, is that the adaptation law adjusts the approach to bring the situation in line with the reference model. This adjustment for surgery would include the regulatory actions listed in the right oval of Figure 9.1, ranging from being careful to opening. Adaptive control systems can also be designed with a self-tuning mechanism, shown in Figure 9.3. Self-tuning involves an estimator, which in surgery can be considered a model of the patient. The estimator

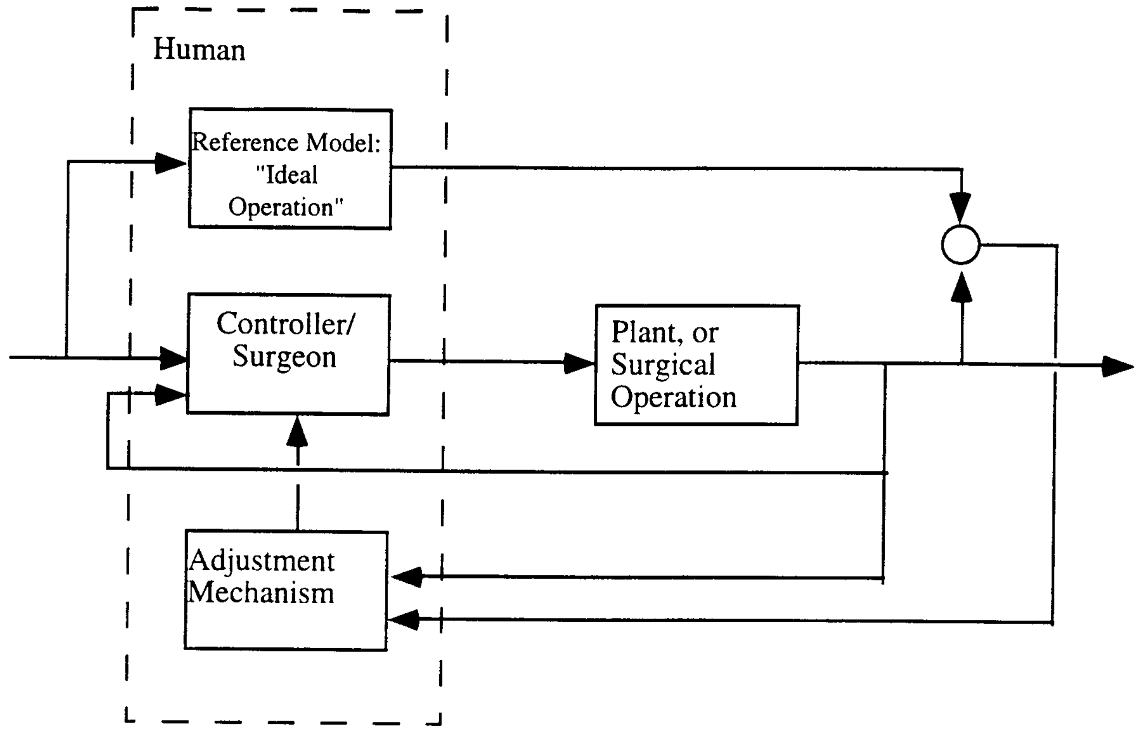


Figure 9.2. Model Reference Adaptive Controller.

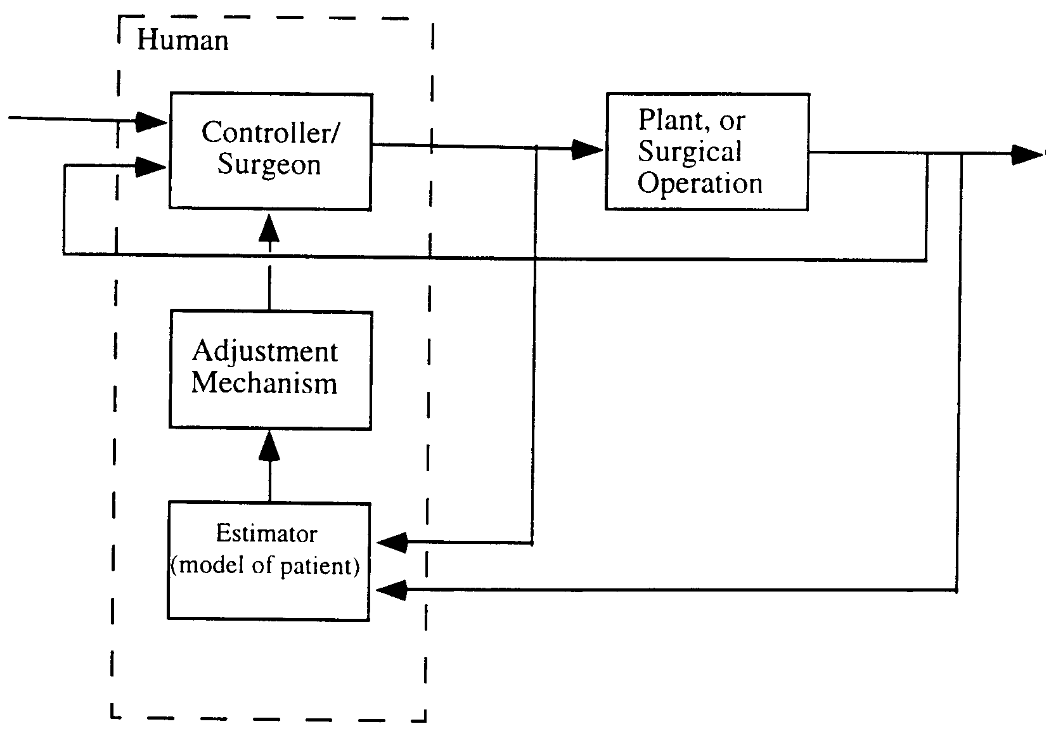


Figure 9.3. Self-tuning Adaptive Controller.

continuously monitors and estimates the 'plant parameters,' or the patient's state, based on the just previous interaction with the patient (or input and output of the plant). This estimate of the patient's state modifies the control actions which follow, which yield a new estimate, and the process continues indefinitely. For example, attempting and failing to grasp a tense and distended gallbladder changes the assessment of the affordances of the situation and influences further control activities accordingly.

Although model-reference and self-tuning methods are used in designing physical systems, such as flight control systems, their relevance to monitoring and regulating is well illustrated in the verbalizations of surgeons we interviewed. In addition, the two loops, the negative feedback loop and the adaptation loop, are not separable in observable activity. The first loop, which is the inside loop from the plant to the controller in both Figure 9.2 and Figure 9.3, is the error signal with regard to the goal. The second loop, the adaptation loop, causes a modification of control *strategies* in response to the observed system characteristics. In one sense, the first loop could be called cognition, and the second, metacognition. But the two loops are intertwined in actual activity, and cannot be separated out except for in the model. Both loops can be encompassed by a theory of cognition which accepts adaptation as a part of the process.

Surgeons' evaluation of whether they are on track to meet their goals must be considered in light of the goal conflict inherent in a risky laparoscopic case. In Chapter 7, reviewing goal statements surgeons made, I discussed how some surgeons felt all through the case that their goal was to attempt to do this case laparoscopically because they felt it would be best for the patient. Other surgeons may have begun the case with a laparoscope, but during the operation revised their assessment to assert that converting to an open procedure would be best for the patient. Understanding why some surgeons said they would change their operative approach to an open one, and why others did not, has been a basic question of this research. Now I will show how self- and situation monitoring and regulation are related in specific excerpts of dialogue during which surgeons explain why they would abandon a laparoscopic approach for an open one.

9.3 Accounts of Individual Surgeons' Opening

Associations between staff and resident surgeons, whether they said they would open in this case or not, and whether they did or did not see the artery pulsation reveal trends which can be explored on a more individual level. In this section, I will synthesize several pieces of information about the residents and staff surgeons who said they would open. Although there were numerous commonalities across all the surgeons in how they talked their way through this case, the particular combination of these which each surgeon presented is unique. This section will depend heavily upon examples from transcripts for illustration. It is in these examples that I feel the functions of monitoring and regulation in surgery become most evident. The individual transcript analyses, illustrated in Figure 5.2, were the primary tool I used to generate main points for the following sections. Those representations will not be used to illustrate these points, since they are more difficult to read than dialog-style excerpts, but they are provided in Appendix C for reference.

Before I begin this section, it is imperative to point out that the following discussion is not intended to imply any value judgment, i.e., that certain surgeons are safer than others, *or* as an indictment of the judgment of any surgeon we interviewed. We presented a challenging videotaped case in a research simulation; one can only expect a small (and unknown) amount of the knowledge and thoughts that a surgeon would bring to bear on an actual case to be applied in this situation. Undoubtedly some surgeons formed expectations about what we wanted to hear, and these influenced what was said. In addition, we interviewed residents who had been working for more than 24 hours, and although they showed interest during the interview, fatigue probably influenced the interview.[7] There may even have been some simplification or omissions because the surgeon interviewed did not feel we would understand the technical language required for explanation. Surgeons were beeped for phone calls during the course of interviews, and other demands of their day could not help but detract from attention available for our research interview. It is hoped only that by describing the range of individual's thoughts as they said they would open, I might characterize the breadth and range of possible streams of thought which any surgeon could experience.

[7] Interviewing residents who were extremely fatigued enhances the ecological validity of this study.

9.3.1 Resident Openers.

This group, the resident openers, could be referred to as well-calibrated for this case. Such an assessment is supported by many variables. First, this case is a challenging one even for a staff surgeon, and these five residents recognized its difficulty and stated their preference for opening repeatedly (4.4 times, on the average). Second, since four out of five did not have the concrete evidence for identifying the artery (seeing it pulsate), they *should* feel uncomfortable enough to convert to an open procedure. Third, the mean comfort rating of the resident openers at decision point 3 was 6.4, the highest average rating (indicating most *discomfort*) of any group. These data show the relationship between lack of information, assessment of risk as high, resultant high discomfort ratings, and the recommendation to open. A fourth piece of evidence about this relationship comes from the high number of metacognitive statements these surgeons made compared to their counterparts who did not say they would open (see Figure 8.5). These resident surgeons stated how and why they felt they were 'in over their heads' with this case, as well as how they would use this knowledge to engineer a change in approach (conversion) to minimize risk of injury to the patient.

There is one other piece of evidence for this group as a well-calibrated one. As a follow-up, to understand how staff surgeons themselves evaluate the thought processes of the residents we interviewed, eight attending surgeons who are members of a committee for resident education were asked to rank order the ten residents interviewed on their surgical judgment, as well as on overall performance. Averaging the eight rank orderings yielded a score for each resident. Seven of these surgical judgment scores fell in a fairly narrow range, from 4.7 to 6.9, with two residents' average falling above this range and one below. The exact same trend was found for the overall performance scores. The top two residents had average surgical judgment ratings of 1.1 and 2.5, indicating fairly consistent agreement among the eight raters that these residents were considered to have excellent surgical judgment. These two residents both fell into the category of resident opener; in addition, neither saw the pulsating artery. Thus, whatever 'good surgical judgment' means to attending surgeons, the two who are considered as having it more than their peers said they would open in this case. In addition, the mean of average rankings for the five residents who would open was 4.5, while it was 6.76 for non-openers. If residents who would open in this case display similar behavior in the operating room, these ratings indicate that being aware of risks and being willing to abandon laparoscopy when it is deemed unsafe is behavior which is valued by staff surgeons.

Individual transcripts provide a context for how monitoring and regulation activities interact with deciding to open for these residents. Sample dialogue is presented in Tables 9.1 through 9.5. The actual dialogue in the left column. In the right column, 'Codes & Comments,' is a combination of (1) variables used to code the corresponding text (as described in Chapter 5), and (2) comments about monitoring, in terms of self and situation assessment, and regulatory actions.

Resident 1. The first resident is one who did not see the pulsating artery, and who wanted to open a total of six times during the interview. This surgeon expressed discomfort from the blood oozing around the inflamed tissues, since it obscured visualization. He[8] mentioned feeling lost several times. The danger of injuring the nearby common bile duct under poor visualization conditions was a major concern expressed by this resident, although it was not explicitly discussed in this excerpt. The dialogue surrounding this surgeon's first decision to open, during the initial dissection, is shown in Table 9.1. This resident seems to be saying, "I don't know where they are, I can't see, and since blindness typically leads to injury, I would open." Recognizing that enough information is not available to safely proceed is a form of self-monitoring, and converting is engineering the situation to stay within a safe field of travel (regulation).[9] Particularly note the close tie between blood obscuring the field and the surgeon's self-assessment of concern. This tie seems almost too obvious to mention: there is too much blood and hence the surgeon cannot see.

In addition, the resident is recommending regulatory actions for improving visualization and situation assessment; these actions are a less drastic form of correction than opening. First, in saying "it looks like they need to go a little high, around the gallbladder," this resident is suggesting a technique which was commonly invoked to deal

[8] Three out of the 20 surgeons interviewed were female; to prevent identification of these surgeons, I will use the pronoun "he" in all cases when required.

[9] This is similar to Cohen et al.'s (1996) two key activities of metacognitive skills, (1) critiquing, or *evaluation* of one's knowledge, and (2) correcting, or regulating behavior.

Resident Opener R-1	Codes & Comments
(When first structure is being dissected) SURGEON: At this point, it looks like they are dissecting down on the cystic duct trying to take perineum off the cystic duct and finding and isolating the cystic duct and the cystic artery. Um, it looks like they need to go a little high, around the gallbladder, . . . but the fact of the matter's that the blood's obscuring your field.	Regulatory action: TECHNIQUE 1: nearer GB Situation assessment: blood's obscuring field
INTERVIEWER: Does that concern you? SURGEON: Yea, I mean it concerns me in the fact that once again, not being able to see what they were doing up to that point, at this point it is very difficult to get an idea of what is going on on the tape. It looks like they've worked to isolate a structure but, and just right there they pull away most of the material that makes up a structure so it's just inflammatory changes. Not having seen how they got up to this point, um, and if I couldn't get that blood off of there, then I would convert to an open .	Self assessment: concerned that I can't see META 4 Regulatory action: OPEN, maybe: if can't improve visualization
INTERVIEWER: Is there some situation in which you couldn't get the blood off? SURGEON: If it continued to bleed, now that looks like it was some bleeding that came from the inflammatory nature of the fat and everything around there. You should be able to irrigate the blood off that with no problem, now, obviously if there is an arterial bleeder that's continued to obscure the field after you washed it off, in that case you can't really clean the field and get the blood off, no.	Regulatory action: TECHNIQUE 4: Irrigate UPRED RULE: if art. bleeder, won't afford visualization
They are not cutting or using really any unusual force in dissecting, but with the area being, having so much inflammatory changes there, you still run the risk of tearing a structure which you didn't mean to, that you wouldn't normally tear with the same amount of force in not as quite as sick gallbladder, in that you did definitely not want to tear. Because you really cannot see a whole lot clearly there.	Situation assessment: Risk of injury (META 3) Self-assessment: can't see clearly
INTERVIEWER: It is easier to tear things when it is inflamed? SURGEON: Right. In fact, they clipped something there, but I have no idea what they clipped, I mean, it doesn't look like it is anything dangerous to clip. But if you can't see things that you are clipping and be able to identify all the landmarks, at least, like once again, we did not see how it took to get up to this point. But it would be difficult to proceed.	META 4

Table 9.1 Resident opener's dialogue with interviewer at beginning of dissection, first time this resident would open.

with uncertainty about what area was being dissected on the tape (captured by the Technique variable, no. 1). This technique can be captured in the adage, "always go from known to unknown," meaning begin your dissection at a place you are familiar with, such as the gallbladder, and then follow structures down towards the unfamiliar area. This awareness of what locations are "known" and "unknown" implies that "known" equals "safe," and "unknown" leads to risk of injury, suggesting that surgeons actively pursue a field of safe travel (Gibson & Crooks, 1938).

A main implication of having blood obscuring sight is recognized when the resident refers to how easy it is to tear inflamed structures using force which is appropriate for more healthy tissue. This realization that force needs to be attenuated when tissues are inflamed shows an awareness of tissue affordances under different conditions. Overall, this resident cannot see what is being done because of the inflammation and bleeding, and is concerned that healthy structures will be injured. Later, when the artery is being clipped and cut, this resident expresses additional concern that an unknown healthy structure might be injured in this case. He again recommends an action which would help ensure that only the intended structure is clipped and cut (visualizing the tips of clips and scissors), but being unable to implement it as a spectator on this case, expresses his desire to open.

Injury seems to be a very real possibility to this resident. As soon as the dissection of structures began and the resident saw how inflamed the tissue around the operative area is, he was ready to give up on a laparoscopic approach. As a spectator to this video case, it was not possible to implement the techniques he has learned for preventing injury; therefore, to accomplish the overall objectives (remove the gallbladder while doing no harm to surrounding structures), he recommended converting. In fact, during the last decision point this resident clarified his concern about the implications of injury relative to inflicting harm:

SURGEON: And by opening this patient, although it may prolong her hospital stay and her recovery, had you transected or damaged one of the other structures, meaning not to, for example her right and left hepatic ducts or common, ...or arteries, the recovery from that would have taken longer than had you opened her up and did it right the first time.

This resident's words illustrate the link between information and comfort level. He cannot see and therefore he has poor information about what's going on, which leads to fear of injury and wanting to open. In other words, low situation awareness leads to discomfort and a change in strategy.

Resident 2. The second resident opener I will discuss here did see the pulsating artery, but was uncomfortable enough to open anyhow, primarily due to worries about injury. This surgeon brings up many of the concerns that the previous resident opener did, such as beginning dissection in a known area, not being able to see the tips of scissors, and the inability to see landmarks due to bleeding and oozing. Excerpts from this surgeon's transcript are shown in Table 9.2.

This resident was not comfortable with cutting the artery without further dissection, because he perceived it to be larger than normal, and because he could not tell from the video that it went into the gallbladder. He looked to see if it was pulsating *before* it was cut, and could not tell. His suggested action was to continue dissecting to establish where this structure ended. When observing the artery being cut, this resident brought up an earlier comment about how the initial incisions and trocars were placed too close together, causing instruments to be more parallel than he would like. This placement constrained the visualization of the tips of the scissors, causing concern that the back tip could be enmeshed in unknown territory. The resident then observed that the cut artery was pulsating, but was not convinced that it was the cystic artery as opposed to the hepatic artery. At decision point 3, this resident said he would do a cholangiogram to better define the anatomy, and if a cholangiogram could not be done, or did not show the anatomy conclusively, he would open.

As with the previous resident, lack of information was a recurring theme here. Resident R-2 wasn't able to determine where the artery went (into the gallbladder or the liver); he could not see the tips of clip appliers and scissors when the artery was cut due to instrument angles, which led to worry about injury; there was too much blood obscuring the field; and finally, information from a cholangiogram was not available. For each of these areas where information was degraded, the resident suggested alternative techniques to make the information available: following the artery, turning the scissors to display the tips, irrigating, and doing the cholangiogram. Uncertainty, concern, and generally low situation awareness results, and the resident indicates he would open as a result. The very last statement in this excerpt suggests that some experience is needed to understand how difficult this case is. Perhaps it is easy to be blind to a potential risk when one has not

Resident Opener R-2	Codes & Comments
(during dissection of the second structure, the cystic artery)	
SURGEON: I don't think they've clearly demonstrated that it goes into the gallbladder, that could be a loop of it coming up, and there could be a branch coming off THAT that goes to the gallbladder, that whole thing might not be the cystic artery. So before I would clip it I would further dissect it along the gallbladder wall.	Situation assessment: identification not certain Regulatory action: TECHNIQUE 5: dissect more
INTERVIEWER: So you're not comfortable with clipping right now?	
SURGEON: No, I wouldn't clip it just now, I wouldn't, I would dissect it further. Because I'm not sure what that is, and it's awful big to be the cystic artery. It's like REAL BIG to be a cystic artery. It doesn't look like it's pulsating, but you can't always, usually you can tell that, but you can't always. Could just be some peritoneum folded over too. I'd further dissect it free, and I would definitely clip it once I was assured that it wasn't anything I didn't want to cut. He really can't see where he's cutting either, because the angle he put the initial trocar in, you can't get around the vessel to cut, he might cut into something behind that vessel too, he can't see the tips of his scissors which is dangerous.	Situation assessment: structure is very big, don't know where it goes Self-assessment: uncertainty CLIP 3: mentions constraints of incisions on angle of instruments META 3: dangerous to not see tips of scissors
INTERVIEWER: Does that follow from your earlier comment about placement of trocars?	
SURGEON: Yeah, I think that hurts, because he can't come in at more of a direct angle. He could get behind the vessel first, then put the blunt end of your scissors around so you could see the tips behind it also. He's just kind of cutting straight into it. At this point it's hard to tell what exactly is going on. . . . probably want to irrigate it and see what's going on. They've come this far, because it's really hard to tell what they've done, for sure. . . . They cut a big structure, some kind of vessel, it's pulsating, but you don't know exactly what that was. It was definitely an artery of some sort.	Regulatory action: TECHNIQUE 11: see tips of scissors Regulatory action: TECHNIQUE 4: irrigate Situation assessment: very hard to tell what's been done Artery identification: uncertain what kind of artery
(during Decision Point 3)	
SURGEON: But I think at any point during that, I mean it was pretty complex, I think it's reasonable to just STOP and convert that to an open procedure at any time during that dissection, because it was not CLEAR, what they were doing.	Regulatory action: OPEN, maybe Situation/self assessment: dissection not clear
INTERVIEWER: Would you have opened?	
SURGEON: No, I would have, before I had divided any of those structures, that first structure that I thought was probably the cystic duct I would have tried to do a cholangiogram through that. If I couldn't do that technically, or if it was inconclusive to show the anatomy, I probably would have opened. So I don't think I would have divided anything or clipped anything without first attempting a cholangiogram.	Regulatory action: CHOLANGIOGRAM: get more information
INTERVIEWER: Can you give me a comfort level rating, from 1 to 7?	
SURGEON: Ahhh, it's pretty low. I'd probably open now at this point, because I don't know what's going on, there's new structures there that I didn't see before, and I don't know what I've cut. I would probably open at this point, maybe have even opened sooner than this point. . . .(Later) if you're not experienced enough to know what's going on, you might not realize you're having any problems at all.	Regulatory action: OPEN, definitely META 5

Table 9.2 Second resident opener's dialogue with interviewer excerpted from dissection of second structure and Decision Point 3.

experienced negative outcomes associated with that risk first-hand. Not understanding that there are risks could be phrased as being unaware that you have low situation awareness. (low meta-awareness?) In terms of Figure 9.1, being blind to potential risk means not understanding the possibilities for injury in the situation, from either not perceiving information, not realizing the significance of information, or not being aware of consequences of the situation.

Resident 3. The dialogue during the first time this resident would open is shown in Table 9.3. This resident expressed uncertainty about what was seen and concern that the common bile duct could be injured, and explicitly stated that his threshold for opening was low at this point in his career. This resident said he would be telling another resident "be careful, be careful, be careful!" To be careful implies both monitoring and regulation combined. Being on heightened alert and using gentle, cautious movements are intertwined in 'being careful.' Statements such as these bring out how monitoring one's comfort level, monitoring the situation to avoid danger, and regulation of movements to avoid injuring things are difficult to separate in naturalistic situations.

This resident did not suggest techniques for attaining more information, only that he would not clip and cut this first structure, and that he would open. This resident had done the least number of laparoscopic cholecystectomies among the resident group (35), which may account for the lack of technique suggestions. Awareness of not having the information needed to progress safely in this situation was quite high, though. Thus, like the first two, this resident's situation monitoring also revealed a lack of information, which causes worry (discomfort), and the only perceived appropriate action is to open.

Resident 4. The risk involved in this laparoscopic procedure was pointed out by the fourth opening resident at the very beginning of this case. When asked if he would do this case laparoscopically, this resident replied:

> "Probably not. I would again, have to see the person honestly to tell you the things I'd look for, again, if it's someone who really sits there and just looks good, they have a bad gallbladder, I know they have a bad gallbladder, but they've had no previous surgery and they feel really good otherwise, and they're not septic, and it looks like
> they'll tolerate surgery, then I'll try. If there's anything wrong, they've had previous surgery and I can feel the gallbladder, then I'll just tell them we'll do it open."

Resident Opener R-3	Codes & Comments
(during the initial dissection of the first structure) SURGEON: I am kind of worried. There is a lot of inflammation here at the gallbladder neck. I can't see where the common bile duct and the cystic duct join together. There is all this fat and inflammation there and if it were me, I am digging into things that I can't identify. INTERVIEWER: Would you do something differently here? SURGEON: Well my threshold for opening this patient at this point in my career is probably pretty low. So I would be leaning towards opening this patient. And if I were the attending proctoring my junior I would be saying, "Be careful, be careful, be careful." And then probably saying, "Wait, let's stop and think about this, maybe we should convert this to a open procedure." INT: What specifically are you worried about that happened here? SURGEON: That if it were me doing the operation, that I would inadvertantly injure the common bile duct. I would probably open. SURGEON: Now I definitely would not be doing that. He is clipping something there, and to me, I don't know where that is coming from or where it is going to. So I would not clip it and I would not cut it. I would open. INT: And why is this different from what you would have expected when you originally saw the acute chole. SURGEON: Yes it is acute cholecystitis, if the patient were stable, but this is my 80-year old lady and if I decided to go ahead and attempt to do this I would want to give a laparoscopic cholecystectomy a chance, and in my own mind if I could not safely identify the cystic duct and it's confluence with common bile duct or the cystic artery then I would open the patient. INT: What specifically did you see that tells you that you are not going to be able to do that here? SURGEON: Well there was a lot of adhesions, there was a lot of scarring, not necessarily scarring, but there was a lot of inflammation and a lot of edema. This picture here, just before he cuts it, there is fat there, there's what appears to be some sort of either an artery or a duct of some sort that he has dissected out. To me, I don't know what it is and I am not going to blindly cut something that I don't know what it is. Yes, it was acute chole, and yes I would try to identify those structures, but again if I don't know what it is I am not going to blindly clip it and cut it.	Self-assessment: worried (META 1) Situation assessment: can't see structures, inflammation, danger Self-assessment: low threshold for opening (META 4) META 4: monitoring & regulation combined META 3: Injure common bile duct OPEN, maybe Self-assessment: don't know where coming from or going to (META 4) Regulation: OPEN, definitely RULE; META 4 META 4 Self-assessment: can't identify; Regulation: shouldn't blindly cut it

Table 9.3 Resident opener's dialogue with interviewer during the initial dissection, the first time this resident would open.

This excerpt brings up a point that many other surgeons mentioned as well, the importance of personal interaction with the patient before deciding how to proceed. Only so much knowledge about the situation can be gained from records and laboratory data; how the patient looks, behaves and feels (is she active? does her skin look

Resident Opener R-4	Codes & Comments
(during the initial dissection of the first structure) SURGEON: Now here, you know, this is a real easy area to make a BIG mistake if you're continuing laparoscopically. INTERVIEWER: You feel like you're in real risky territory? SURGEON: You can't tell if what you're pulling down is 3 mm wide, -see the edema squeeze out right there- you can't tell if it's 3 mm wide because it's the cystic duct, or whether it's peritoneum that's just 3 mm wide because it's distended.	Situation assesesment, META 3: Risky area
Unlike the first case where I was clear with their anatomy, I can't guarantee the safety of the anatomy with this person. I think this is real risky. Most of the time you're probably going to get away with it. BUT is most of the time, worth even 1 in 20 people, dividing their common bile duct and giving them a lifetime of liver disease. Now again, it's easier to criticize when you're not doing the surgery, because you can't take your time and flip the camera where you want it.	META 2: Risk of dividing common duct
Now here this person is clipping, I can't see the other end of the clip applier, like we talked about, I want to know exactly where these clips are going. That clip was fired 3 times and there are only 2 clips on.	CLIP 2: can't see other end of clip applie
They are going to divide it and everything is so thick and swollen, I don't know. And if you look at enough of these tapes, what you should note, is that when you cut something, the cystic duct or the cystic artery, I always refer to the residents as a 'twang,' you can see that thing like a guitar string bounce back. And when he cuts this, he or she, you don't see it bounce back, in fact he pushes it. That to me tells me that may or may not be anything of VALUE. There are only 2 things we HAVE to clip, the cystic duct and the cystic artery. I don't know if he did or not!	Situation assessment: doesn't see 'twang' of cut structure springing back Self assessment: doesn't know what was cut
And although I feel really comfortable doing this procedure at this point, I'd open. I don't think our gain is great for an 80-year old lady. It still, they're spilling stuff, even though they put those clips on those holes. INTERVIEWER: You feel really comfortable at this point? SURGEON: I said even though I feel comfortable DOING LAPAROSCOPIC SURGERY, I wouldn't be doing this.See, I told you it was going to tear, and now they've got more spillage. See what this looks like. It's not pus. Pretty yucky looking bile though. . . But everything in this case is a CATCHUP, because it's all, let's see what we can get away with, instead of let's see what we can do that's safe.	Regulatory action: OPEN, definitely, in terms of goals: gain is not great

Table 9.4 Fourth resident opener's dialogue with interviewer at beginning of dissection, first time this resident would open.

normal? does she speak coherently? is she confused?) provides vital information to be used in conjunction with chart data. Shalin & Bertram (in press) provide support for this idea in their account of an intensive care unit doctor who was initially reluctant to admit a patient based on chart information, but who quickly admitted the patient after seeing her.

Early in the dissection process, R-4 stated "this is a real easy area to make a big mistake if you're continuing laparoscopically. . .I can't guarantee the safety of the anatomy with this person. I think this is real risky" (see top of Table 9.4) Similar warnings were given throughout the rest of the transcript. In terms of monitoring and regulation, these statements were similar to Resident 3 saying "be careful, be careful" in that the surgeon indicated he understood the risk and would be on cautionary alert to prevent incidental injury. Statements that we coded under the perceptual expertise variable were plentiful in R-4's transcript; he made the largest number of these statements of any resident, and this perceptual information was evidently used to support the assessment that proceeding laparoscopically was risky. For instance, in Table 9.4 this resident described how a cut structure should spring back with a 'twang' if it is anything important. Earlier he had described how the inflammation leads to difficulty in telling whether something which looks 3 mm wide is a cystic duct or simply distended peritoneum. Information for identifying structures, in this case size and a 'twang' response, was unavailable in this patient; in addition, the resident could not see the back side of the clip applier. As a result, the perceived risk of injury was unacceptable and this resident felt opening was necessary. In psychological terms, this resident had expectations about what information should be perceived to 'guarantee the safety of this patient,' and when those expectations were not met he recommended changing the approach to meet the top-level goal of 'first, do no harm.'

Resident 5. This resident was the only one who would have definitely begun our 80-year old woman's case as an open one (although R-4 was leaning in that direction, as the previous section shows). Predicted difficulty in grasping, dissecting, and identifying structures as well as the potential for injury were main reasons this resident gave for beginning open (see dialogue in Table 9.5). Over the course of the interview, this resident

Resident Opener R-5	Codes & Comments
(during the first decision point, pre-video) INTERVIEWER: Would you even attempt a lap chole? SURGEON: No, I would just do it open... INTERVIEWER: Okay, and what would be the primary information? (which would lead you to begin it open) SURGEON: Oh, the fact that it's an acute GB. Dissection would be very difficult, the planes won't be easy to find. INTERVIEWER: Why won't the planes be easy to find? SURGEON: What happens is that you have get a lot of.. It would have to be,uh, most GB are taken out now are chronic cholecystitis and they look kind of a dried ((inaud)). Acute cholecystitis can be the size of an orange or better, and if the, if you cut a chronic GB wall, it's probably on the order of oh, say, that thick, and you go with someone who's got acute, it can be as that thick. It makes it much more difficult, these are usually flaccid little bags so you can grab and stretch like that other one; this is extremely distended, and often you end up poking into it, it can be very difficult to get it off the back wall, it can be very difficult to find your structures there. I would just do it open.	Regulatory action: OPEN, definitely Situation assessment: predicts case will be very difficult to do laparoscopically Regulatory action: just do it open PREDICTION: Will be difficult to grasp, dissect and identify Regulatory action: OPEN, definitely
(during the second decision point, after seeing the gallbladder) INTERVIEWER: Do you have any concerns at this time? SURGEON: Yeah, I'd still be wondering about the wisdom of trying to do this laparoscopically. INTERVIEWER: Your previous concerns would be... SURGEON: Oh, just injuring various structures, difficult time getting it out, spilling bile and pus and gallstones all over the abdomen and trying to go back and wash those out and pick those out. INTERVIEWER: What errors would an inexperienced surgeon be likely to make in this situation? SURGEON: Now that they're already in the abdomen? INTERVIEWER: Yes. SURGEON: Once again, going too.. moving too hastily. And also not knowing when they reached the limits of saying: I need to open this up, and not go on.	Situation assessment: risk of injury, difficulty, spilling material PREDICTION: infected bile will be spilled in the abdomen META 4: not knowing when limits are reached (not monitoring & open-ing when appropriate)

Table 9.5 Fifth resident opener's dialogue with interviewer at the first decision point, before seeing any video of the case, and later at second decision point.

became slightly more comfortable, and did not say he would open again after the first decision point; however, he continued to stress the point that a surgeon should be aware of when he or she has reached a limit and should open (see bottom of Table 9.5). This resident did identify the cystic artery correctly, without noting the pulsation of its stump. Throughout the dissection, this resident suggested using techniques to help see better and lessen risk which previous resident openers did, such as irrigating better, turning the clip appliers so that the back tip could be seen, and following the artery further towards the gallbladder to make sure it is the cystic artery. He acknowledged the risk involved here, that you can not be sure that the artery is the cystic artery in this acute case, and expressed slight concern that the surgeons may have inadvertantly injured something by mistake, due to the inflammation.

At decision point 3, this resident felt that the cystic duct and cystic artery had both been identified, clipped, and cut, and he therefore questioned why any surgeon would want to open at this point. He did not notice that there was a third structure being dissected until the tape resumed after this last decision point, and at that point he questioned what the third structure was. At the very end of this case, when asked, "If at the end of the procedure the resident asked you 'how did I do', what would you tell him or her?" this resident gave the following response:

SURGEON: I'd tell them they did a good job, I mean this is a very difficult case. . . And what the caveat is, you know the one thing you have to be careful is: some residents are proud of the fact that they haven't had to open a GB in their last 50 cases, and that's nothing necessarily to be proud of; there might have been something that you should have opened that you didn't open, and you know, this isn't a contest, you know, where you're trying to win; you're trying to take good care of individual patients, and for each patient you need to decide, that's something I don't think that should really be mentioned, how many laparoscopic cases I had to open. Good if you were able to get them out, you could have caused some injuries, there is probably more injuries that happened during this procedure that we even know of: the person felt funny afterwards, and something in their body made an adjustment, missing that artery, or that hepatic duct or something like that, so...

Thus, this resident acknowledged the importance of self-monitoring to reveal when the situation is outside the boundaries of safety, and applied regulatory techniques for safe manipulation of the tissues, but did not mention personal discomfort with this case, which makes him unique from the other resident openers.[10] Having (misplaced) confidence in the identification of structures led him to find little cause for alarm with this case.

Resident non-openers expressed many of the same concerns and regulatory techniques as the opener group, but never felt the situation warranted opening. Since a

[10] This resident simply may not have been role-playing as deeply as the others

primary focus of this research has been on the decision to open, excerpts from the non-openers' transcripts will not be discussed.

At the beginning of this section, I suggested that transcripts of the resident openers showed the relationship between lack of information (of artery pulsation/identification), assessment of risk as high, resultant high discomfort ratings, the recommendation to open, and a high number of statements coded with the metacognition variable. Three of the excerpts presented above are from the *first* structure dissection period, and indicate a high discomfort with the information available to identify that structure as well. The residents' verbalizations show that specific monitoring and regulation strategies can assist a surgeon with relatively less operative experience to stay within a field of safe operation. Careful monitoring (which includes evaluation) of the situation can render an assessment of high risk whether or not the surgeon is noting specific cues, and at all levels of the experience spectrum with laparoscopic cholecystectomy. Often activities of monitoring and regulation are so enmeshed that it is difficult (and perhaps not meaningful) to separate them.

9.3.2 Staff Openers

Like the resident openers, the staff openers pointed out the risks involved in performing this case laparoscopically. The four staff openers differ in a variety of ways, and have characteristics in common as well (refer to Table 9.6). They are a highly experienced group: relative to other staff surgeons interviewed, all four were in the top 50% in years since residency, and three of the four were in the top 40% in number of laparoscopic cholecystectomies. Similar to the resident openers, only one of this group saw the artery pulsation, but in contrast, three out of four correctly identified the artery anyway. They expressed higher levels of discomfort than their non-opening peers (see Figure 8.3), which is to be expected based on the anchors given with the comfort level scale. The staff openers had the highest average number of statements coded with the metacognition variable of any group, primarily due to the high numbers of S-2 and S-4. In sum, this group is experienced, aware of their own comfort level and situational risk, and cautious.

In this section, like the last one, I will excerpt some of the salient points made by

	S-1	S-2	S-3	S-4
Years of experience since residency	22	6	5	22
Number of Laparoscopic Cholecystectomies (estimate)	75	1,000	300	200
Identified artery correctly?	No	Yes	Yes	Yes
Saw pulsation?	No	No	No	Yes
When decided to open?	0, 1(x4), 6	3	2, 4, 6(x2)	6
How many times open?	6	1	4	1
Number of meta statements	9	23	14	26
Certainty of opening	definitely	definitely	maybe	maybe

Table 9.6 Information characterizing the four staff surgeons who stated they would convert to an open procedure. The numbers shown in the fifth block, When decided to open, are associated with events in the tape as follows: 0: Pre-video/First Decision Point; 1: First watching video and decision point 2; 2: Draining and initial dissection; 3: During dissection and division of first structure; 4: After the gallbladder opens; 5: During dissection and division of second structure, the artery; and 6: Last structure dissection, decision point 3, and after.

the four staff surgeon openers and use these points to show how situation assessment, self assessment, and regulatory action are interleaved in the decision to open.

Staff Surgeon 1: Beginning Open and an Internal Clock. The surgeon S-1 in Table 8.2 was uncomfortable with performing this case laparoscopically from the very beginning and throughout the interview, and was the only staff surgeon to suggest that this case should not be started laparoscopically. S-1 was the only staff surgeon to recommend beginning this case as an open one, but that viewpoint will be discussed here. When I asked this surgeon why he would begin this case as an open one, his reply was:

SURGEON: I think, in my hands, sick old people, I think they do better open than laparoscopically. I feel with the diaphragmatic function, and the CO2,[11] interfere with your respiration, interfere with your venous return of the heart, and there are some papers that have suggested that there is decreased coronary blood flow during a laparoscopic procedure. Even if she had a normal EKG, which she'd have to get

[11] Carbon dioxide is the gas used to insufflate the operative area; it provides a working space in the abdominal cavity.

pre-op, and a normal chest x-ray, she's still got an 80-year old heart. And I think an open cholecystectomy is less stressful on that patient. I'd begin as open, number 7. ((on the comfort level rating scale))

This approach, beginning the procedure as an open one, is different from that of the other surgeons in its initial assumptions. In examining the decision to convert in laparoscopic surgery, we make the assumption that cases are typically done laparoscopically unless there is evidence to the contrary. We have been looking at this evidence and how it is interpreted in terms of predicting difficulty and resulting injury or harm (see section 7.5). The approach taken by S-1 is that the evidence against laparoscopy is strong enough from the outset. Although only one other surgeon (a resident) expressed this opinion (but see the discussion of both R-4 and R-5 in the previous section), taking an open approach from the start was viewed as absolutely reasonable by the other surgeons. Each surgeon who said they would begin this case laparoscopically was asked, "If the surgeon decided *not* to begin this case laparoscopically, would you think that was a reasonable decision?" None of the surgeons felt it would be unreasonable to begin this case open, especially if a surgeon was uncomfortable with doing this case laparoscopically, but many expressed a personal preference for always attempting laparoscopically.

Our sample of ten staff surgeons included three who had practiced more than 20 years since residency; the remaining seven surgeons had six or less years since residency. Although this is a less than desirable spread for representing an even range of experience, looking at the highly-experienced three in terms of beginning this case open reveals consistencies in their willingness to begin open. The other staff opener with over twenty years since residency (S-4) said during the pre-video decision point:

SURGEON: This woman, in my mind, in my teaching of residents, is one in which you questionably want to start with a laparoscopic gallbladder in the first place. Sometimes these patients do better and have a better, quicker, cleaner operation by doing an open cholecystectomy, and not even attempting a laparoscope. Our experience is with a lot of these patients, you struggle for an hour, two hours, and finally open the patient anyway, or SHOULD have opened the patient. Whereas if you go at it directly, you do it, and you're done, probably do a woman like this in 25-30 minutes with an open gallbladder, and yes, <u>she hurts more, but sometimes it's safer</u>.

The third surgeon with over twenty years, a non-opener, would begin laparoscopically, but also said he would be ready to open immediately if anything was amiss. Like S-4, this surgeon also warned against muddling through for a long time and *then* converting, rather than seeing straight away this patient should be opened: "Starting out is O.K., but to persist at it for say an hour and then to decide that you can't do it and then to do it open, then that is an hour of your time that you basically wasted." (staff surgeon)

Temporal awareness is a factor we identified in our earliest, non-video based interviews with laparoscopic surgeons. As the above excerpts indicate, time is a factor in deciding to begin a case as an open one. S-1 argues that the carbon dioxide used in insufflation has negative effects upon the cardiac function of older patients, presumably for any length of time, and the other two surgeons with over twenty years since residency warn against persisting for an extended time before converting to an open procedure. F. L. Greene has written an editorial proposing that there is a "golden period" for conversion within the first ten to fifteen minutes of a procedure. He writes:

> "It need only require 10-15 minutes to realize that inflammation or anatomical considerations should dictate conversion to an open cholecystectomy approach. . . the safe surgeon should have an internal clock and understand when further dissection may not be in the best interest of the patient." (Greene, 1995, p. 11)

Monitoring an internal clock, or maintaining temporal awareness (as described in section 4.4) involves some sophisticated reasoning. The surgeon must have already thought through the risk of extended operation with respect to a particular patient, as compared to the benefits expected by continuing laparoscopically. Predicting a patient's response to longer anesthetic and insufflation cannot be done with certainty; in addition, a surgeon cannot predict whether a little more dissection will yield information permitting identification. As the third staff opener, S-3, noted:

SURGEON: Probably in this 80-year old I might just be opening. But I also sorta have this thought, I've gotten this far, maybe I'll just take another couple of minutes, I'll be able to successfully do this laparoscopically, maybe just a little more dissection and suddenly everything will become crystal clear.

The "sunk costs" fallacy comes to mind: having gotten this far, it would be a waste of this effort to abandon a laparoscopic approach now. Several surgeons mentioned "having gotten this far" as support for continuing this case laparoscopically at the last decision point; it is a strong, if faulty, force to consider in the decision to open.

Considering the dimension of time in monitoring a situation as to whether it warrants a change in approach adds pressure to the goal conflict and uncertainty which already exists. Simple decision rules cannot adequately address the complexity of the decision to open in a case like this. The variable we used to note when surgeons verbalized time constraints in this case yielded a difference between residents and staff, residents averaging 1.3 time references each and staff averaging 2.3 each. We categorized time statements according to whether they involved the surgeon's time schedule, the risk of negative outcome for the patient, or a general reference to time. The biggest difference between staff and resident time statements were those referring to the patient: staff surgeons averaged 1.2 statement per surgeon, and residents averaged 0.5.

Thus, development of an internal clock and incorporating it with other aspects of situation assessment is likely to be a skill acquired with experience. It might be likened to learning to assess one's own comfort level; an idea of the relevance of comfort and time passage, and the variables which should influence them, can only be gained through experiencing situations in which they mattered. The most experienced staff surgeons we interviewed (in years since residency) explicitly linked the passage of time with the decision to open.

Staff Surgeon 2 and Staff Surgeon 4. These two surgeons are grouped here because they expressed a similar pattern of observations and regulatory action in stating they would open. The pattern involves (1) assessing the situation, (2) expressing a resultant high level of concern or anxiety, (3) stating that they would take over the case from a resident, (4) citing a technique they would use in the situation, and then (5) stating they would convert to an open procedure. Each of these surgeons said they would open only once. Excerpts from the transcripts of these two surgeons when they said they would open are shown in Tables 9.7 and 9.8.

In the case of S-2, the decision to open was made during the initial dissection of structures, and like resident openers already cited, injury to the common bile duct was a chief concern. This staff surgeon cited specific perceptual information, whiteness and opaqueness of the tissue, to derive an assessment of the patient's disease progression; a self-assessment of concern followed. The surgeon stated he would never let a resident do

Staff Opener S-2	Codes & Comments
(during initial dissection) SURGEON: This is sub-cirrhosal inflammatory response with leukocytic invasion where you see the the white blood cells have already invaded this layer of the edema and have already started to create opaque picture. When you see that then you get real concerned about whether you're going to complete this surgery. This is in the area where the big bucks are, this is the area where you can get in real trouble. INTERVIEWER: Seeing that leukocytic response, does your level of concern rise? SURGEON: Yes. I think I'd go down to 7 on the comfort scale. I may go a little further, I'd keep going to where he is, although I would never let a resident do this. That was a wrong move. He's trying to grab in an area where he shouldn't be grabbing because there you start running the risk of injuring common bile duct. He's probably okay but I would never have grabbed that proximal. At this point in the operation I would stop, I would just not do this because I think you're doing the patient a disservice. The patient just has too much, again, everything's gelatinous.. . .The trouble is, when you get to this point the constistency of the tissue around the cystic duct approaches the same consistency of the normal cystic duct so there has to be a point where you identify one structure from another and I'm getting real worried.	Situation assessment: extent of the illness Self-assessment: real concerned Situation assessment: area of high risk (big bucks, real trouble) Regulatory action: take over from resident Situation assessment: risk of injuring CBD (META3) Regulatory action: grab closer to the gallbladder (TECHNIQUE 1) Regulatory action: OPEN, definitely Situation assessment: can't tell duct from surrounding tissue

Table 9.7 S-2's decision to open during the initial dissection of structures.

this case, and was uncomfortable with grabbing the structure so far from the gallbladder (proximal to the biliary tree) because of potential injury to the common bile duct. If operating, he would use a technique of grasping closer to the gallbladder. Finally, this surgeon stated he would open. I can only assume that "doing the patient a disservice" referred to violating the top-level goal of preventing collateral injury. Lack of information for identifying structures was also mentioned when the surgeon assessed the tissue as 'gelatinous,' and cited the similarity of duct tissue to surrounding tissue. This excerpt shows how situation assessment, self assessment, and regulatory action are tightly interwoven.

The other staff opener to follow this pattern, S-4, considered opening at decision point 3 (see Table 9.8). His assessment was that the cystic duct has not been identified yet, and that it may or may not be the last structure currently being dissected. He cited not being able to see adequately as typical in cases like this one (lack of information is a recurring theme in this case). This surgeon's self-assessment was that anxiety levels will be high, and that he would be likely to take over the case from the resident now. "I have to be there" indicates a need to be in the control loop. A specific course of action was recommended by this surgeon: he would cut into the last structure, clean it up, and make an assessment as to what it is. If it does not look like the cystic duct, then opening would be the only option. This staff surgeon provided an extremely clear and cohesive story of what was happening in the case being watched. When the first structure was clipped and cut, this surgeon looked specifically to see what it was, and concluded that it was not the cystic duct, since it had no lumen. He saw the pulsating artery, but was still concerned about the cystic duct. The following dialogue, from the end of decision point 3, shows the

Staff Opener S-4	Codes & Comments
(during the third and last decision point) INTERVIEWER: Ok, this is the next decision point. Could you tell me what you think is going on here? SURGEON: <u>I think he's lost the cystic duct somewhere, he may have already cut it, ahh, he doesn't have it.</u> I thought his attack on the artery was too quick. I think now he's floundering, trying to find out where he is. And trying to find that duct. I think he realizes, very definitely, I'm not saying this is a sign of a bad surgeon, I think that this is TYPICAL of these kind of cases, you can't SEE down there. <u>My anxiety levels are obviously going to be up now.</u> If I were teaching faculty, and saw this happening, <u>I would probably take over the case</u> from the resident, <u>I have to be there</u>. Because I think the tissue doesn't look like the common duct or the cystic duct to me. Now, if he makes one more incision into this area, and I think <u>I probably would next divide this thing that he's working with a little bit</u>, clean it up, and if it does not look like a duct then I think there's NO QUESTION the question must be opened. INTERVIEWER: To identify.. SURGEON: Identify. You've lost the game here, okay, you've given it the hearty try, you've lost the game, go ahead. I would probably at this point tell the nurses to start opening the packs.	Situation assessment: the duct hasn't been identified, difficult to see Self-assessment: high anxiety Regulatory action: take over Regulatory action to gain better information: divide and decide if it is the duct If not, OPEN

Table 9.8 Fourth staff surgeon opener's reasoning for opening at the third decision point.

importance this staff surgeon placed on identification of the duct:

INTERVIEWER: What errors would an inexperienced surgeon be likely to make in this situation?

SURGEON: A BIG one is to assume the duct is cut. Again, he sees what he believes, believes it's cut, therefore he sees that, and says okay, I've already cut it, and remove the GB, and just leave everything alone and not identify it. I DO NOT THINK, under any circumstances, you can leave a laparoscopic GB without identifying the cystic duct and being TOTALLY CONVINCED that you have seen it, and it looks clear and it's not leaking. I think that'd be a TERRIBLE error, but it happens. (capital letters used to reflect surgeon's emphasis)

How these two staff openers verbalize their reactions to the events on the videotape again supports the idea that self and situation assessment and different regulatory actions are enmeshed. The last staff opener, S-3, discusses a broader scope of constraints involved in the decision to open than we have previously seen.

Staff Surgeon 3. This surgeon said he would open (maybe) a total of four times: during the initial dissection, after the gallbladder burst open, and twice during the last dissection and decision point. At the last decision point, this surgeon acknowledged that he would be "frazzled" by the events in this case, and he recognized that the other doctors and nurses in the operating room might be responding to his projected tension in a way which would make them less efficient. Not only did the surgeon recognize what his self-assessment would be in this case and tie it into opening, he realized the impact of how he would react on the comfort level and therefore the efficiency of *others*. Up until now, comfort level has been referred to as a kind of barometer which a surgeon can learn to use to keep within a field of safe travel. This surgeon's explanation shows how low comfort level can manifest itself in tension which might be counter-productive. Even further, this surgeon would look around and assess this team comfort level and use it as a factor in the decision to open.

This staff surgeon, S-3, was the only one to mention the efficiency of other team members as a primary factor in deciding to open, although I would expect surgeons to be more aware of the other team members had we interviewed them as a team. In general, staff surgeons made reference to other team members far more often than residents did, averaging 3.3 statements coded with the 'team' variable per staff as opposed to 1.3 per resident surgeon. Rather than concluding that staff surgeons are any more aware of other

Staff Opener S-3	Codes & Comments
(during initial dissection)	
SURGEON: See, I'm really kinda confused here, because I don't know quite exactly what they have a hold of here. I usually work my way down from the fundus to the infundibulum, and I really don't know where they are right now, but there's a possibility in my mind that they've got the common duct in their grasper. I can't really see... I think there's a real good chance, because I think this up here is where....see at this point, we'll see where they get in the next minute or so. But I might be willing to kind of give up here.	Self-assessment: confused, don't know where they are META 3: common duct Regulatory action: OPEN, maybe
INTERVIEWER: Why?	
SURGEON: Because there's a lot of blood here. Well, actually they're getting some duct action, maybe. But there's a lot of blood, and I'm just really not able to tell what is really here. That may just be some fat, I think it is, but I'm just a little confused, and ah, it's not becoming immediately obvious. They haven't done anything here yet that I think they're going to regret, but...	Situation & self-assessment: lot of blood, confused
(during Decision Point 3)	
SURGEON: Well, at this point in the case, I would like to know definitively where everything is, and I don't. So I would not be hard on myself right now if I said, let's just open, let's get out of here. But I really can't tell you what I'd do right now exactly, because of the other factors that are involved here. Probably in this 80-year old I might just be opening. But I also sorta have this thought, I've gotten this far, maybe I'll just take another couple of minutes I'll be able to successfully do this laparoscopically, maybe just a little more dissection and suddenly everything will become crystal clear.	Regulatory action: OPEN, maybe
INTERVIEWER: So you have concerns at this time that you don't know where everything is..	
SURGEON: That 's my biggest concern.	
INTERVIEWER: Are there any other concerns you have?	
SURGEON: Obviously the patient, how they're doing, how they're tolerating their anesthetic, how everyone else in the room is doing, because if I start getting frazzled, then so does everyone else in the room, and they tend to sort of not respond as quickly or as efficiently as they might otherwise. So I sort of go for the general, how the room's feeling as well.	Situation assessment: see how patient tolerating anesth., how other team members responding to tension
INTERVIEWER: The other surgeons and the nurses?	
SURGEON: Well, my assistant to a certain degree, but more like the scrub nurse, and the circulator, if I'm starting to ask for a bunch of things they don't have in the room, and they're having to scramble around, or if the scrub, some scrubs at least in our particular institution, if that's the person that's doing the camera work, they can't scrub, like do the handing of the instruments, and operate the camera very well at the same time. So that's something that I also will take into consideration in deciding what to do next.	

Table 9.9 Staff opener S-3's discussion of opening during the initial dissection and at the last decision point.

team members, it may be that staff surgeons are more accustomed to coordinating the action of the entire team, to include residents working under them, and hence are more likely to see and verbalize constraints regarding other team members.

9.4 Summary

A view of cognition in surgery as the coordination of self and situation assessment with regulatory action seems to capture the verbalizations surgeons made about converting this case to an open one. Self and situation assessment were expressed as mutually dependent aspects of monitoring a situation. Typically, metacognition is described as knowledge of our thought processes and regulation of these thought processes. Self assessment (monitoring) and self-regulatory activities are typically given 'metacognitive' billing, while situation monitoring and regulation are considered merely cognitive. I have presented an argument for self-reflective activity existing in a side-by-side relationship with other cognitive processes, rather than in an executive control role, due to the mutual dependence which seems to hold between self assessment and situation assessment.

This view of cognition as including metacognition has led to hypothesizing a representation under which self and situation assessment and regulation can be seen as a continually interacting cycle of monitoring and acting. All of the variables which emerged from preliminary analyses of transcripts and which were used to code these transcripts can be viewed as functional aspects of this representation. Particularly salient in the monitoring/acting cycle shown in Figure 9.1 are predictions, perceptual information, and techniques. Both prediction and perception are imperfect in laparoscopic surgery, prediction because disease progression is uncertain and perception because of the inflammation obscuring sight in this case. Uncertainty and lack of perceived information led to expressions of discomfort, worry, concern, and anxiety as self assessments. Perhaps self and situation are not distinct entities.

When monitoring led to concern, the primary risk perceived was of potential injury. The 'first, do no harm' ethic is well-learned. To minimize the risk of injury, techniques and other regulatory actions from being careful to opening were cited as approaches for proceeding safely. Monitoring an internal clock and awareness of how other members of the surgical team are functioning were shown to constrain safe operation as well, thus extending the space of possibilities to be monitored.

In this chapter I have examined only the nine surgeons who would open in this case, since the decision to open provides a window onto how difficult decisions are made in laparoscopic surgery (the non-openers showed a similar cycle of self and situation monitoring and regulatory action). Opening in this case is viewed in a positive light. The residents who opened were well-calibrated to their experience level, and the staff openers were among the most highly experienced by all measures. Openers saw enough risk in the situation to say they would change the approach. From a viewpoint of questioning whether the video interview tapped into thought processes which would be present in the operating room, surgeons who said they would open can be said to have been involved enough in the interview process to make such a statement, and therefore their transcripts are good ones to examine in depth.

The main thrust of this chapter has been to show that what others call metacognition, self-assessment and regulation as an executive control process, seems to be a vital part of an overall cycle of assessing and regulating all aspects of a complex situation in surgery. Rather than *adding to* the functions attributed to expertise, conceptualizations of metacognition in the literature lead me to see the monitoring and regulating cycle as an integrating concept for what I have already described as rule-based thought and aspects of expertise. If a separate, executive control mechanism does exist, I do not know how surgeons would verbalize their self and situation assessments differently to reflect this. From a standpoint of experimental control, it is a shortcoming to interpret verbalizations in one way and not hypothesize what they might be in order to interpret them differently. However, I do not feel the burden of proof is upon me. If there is an executive control mechanism, there should be experimental evidence to support it, and I have found none.

The concept of metacognition is an important one, and I am certainly not suggesting we do away with it. As I stated earlier in this chapter, recognizing that we focus on ourselves as a target of interest in addition to focusing on environmental information (Scheier & Carver (1988) call this self-attention) makes an important contribution to any model of thinking. The progress made in education and training by teaching students to consider goals and strategies alongside technical material is encouraging. However, there should be a more careful explication of what is meant by metacognition when it is used in any context. Does it includes only self-knowledge monitoring and regulation, or are other aspects of the situation monitored as well? And if they are, how is metacognition different from cognition? In this research I have included monitoring of one's own knowledge, but focused more on the surgeons' expressed worry, concern, and anxiety, since surgeons did not often verbalize that their knowledge was inadequate to handle a situation.[12]

Teasing out differences in self-assessment, situation assessment, and self-knowledge is a difficult proposition. Considering a surgeon's stream of thought in these interviews in terms of monitoring and regulation activities provides an integrating concept for getting back to the basic theoretical premise of this research: that is, perception and action are tightly coupled. Adding the self as a target for perception simply acknowledges that the human in human-system interaction provides important information for goal-directed action.

[12] This may be cultural; I would not expect surgeons to say they have inadequate knowledge to handle a situation to an outsider like me during a research interview.

10 Summary, Lessons Learned, and Implications for Training

In this chapter I will summarize findings of this research in the context of how my perspective has evolved over the course of conducting it. Also presented here will be the lessons I have learned which may be applied to future research projects of this type, and some implications of this research.

10.1 Findings: A Progression and a Journey

In chapters 6, 7, 8, and 9 I have presented data which indicate how surgeons use rules, goals, predictions, inferences, and monitoring and regulating activities to stay within a field of safe travel. The idea behind this organization was to show an increasingly complex progression of variables which characterize interaction between a surgeon, the operating environment, and the patient. The starting point for this progression, rules, were used frequently by surgeons. Often rules were also coded with the perceptual expertise variable or the prediction variable, since many inferences, predictions, and actions were frequently stated in a conditional form. Hence variables contributing to a picture of perceptual expertise (as presented in chapter 7) and to an understanding of self-monitoring and regulation (as presented in chapters 8 and 9) captured thought processes which included rule-based thought, but which also included skill-based and knowledge-based cognitive control.

As I have conducted this research over the past few years, and as I have more recently undertaken to organize it in terms of the above-mentioned progression of cognitive concepts, I have personally experienced an evolving progression of perspective as to the main purpose and contribution of this research. A research undertaking, especially in an educational setting, is expected to adhere to a scientific process of hypothesis generation and testing. An inability to follow this course, due to the exploratory nature of this project, has been the source of continual niggling concern to me. However, had I doggedly adhered to my original main goal, finding expert-novice differences in laparoscopic surgery, what I feel are the most significant implications of this research would not have emerged. Next I will trace a rough outline of the journey I have taken as my perspective on this research has evolved.

10.1.1 Expert-novice differences

I began this research with the desire to use cognitive task analysis techniques to discover something about laparoscopic surgery which a surgeon would find useful. The decision to open was suggested as a topic which needed analysis. Understanding expert-novice differences associated with this decision, and applying these differences as recommendations for a training intervention, seemed like a worthy goal for research. In fact, I did find differences between staff and resident surgeons who were interviewed, and will summarize them now.

The most salient area where staff/resident differences were found was perceptual expertise, to include predicting and anticipating consequences of current situations. Looking at the perceptual expertise variable, which noted inferences, predictions, and actions surgeons derived from specific perceptual cues, staff surgeons made significantly more of these statements than residents (an average of 6.5 vs 3.5). One subset of these statements (about one-third of them) expressed affordances of the situation. Staff surgeons made more than three times as many affordance-related statements than residents. The frequency of these statements and over-representation of staff surgeons in making them suggest that surgeons learn to directly perceive meaning relative to action afforded in a patient's body, just as Gibson (1979/1986) suggested we come to directly perceive meaning in the natural world. Another important finding was that twice as many staff were able to identify the cystic artery through seeing it pulsate. Furthermore, staff surgeons made a significantly higher number of predictions per transcript than residents. The predictions mostly involved either anticipating difficulty in dissecting and identifying structures (lowered ability to assess the situation) or predicting an undesired consequence of current activity. These predictions correspond to the two kinds of feedforward control Xiao (1994) identified, preparing mentally for dealing with the predicted situation, and actions which are taken to prevent undesired outcomes in a feedforward manner. The staff surgeons' enhanced ability to perceive relevant information and make inferences and predictions no doubt reflects their greater number of surgical situations to draw from as an experience base. No surprises are found here, in light of the research on expertise reviewed in Chapter 8.

As I stated before, understanding how staff and residents differ was a primary goal set forth in my dissertation proposal, and I believe the differences just described are important, especially since our resident group is mid-level on the experience continuum rather than at the novice level. The findings imply that the development of predictive and perceptual skills continues well after surgeons have completed residency and become board-certified, and support conclusions from investigations in other domains concerning the importance of prediction and anticipation in complex systems operation (Amalberti & Deblon, 1993; Xiao, 1994).

Another goal originally set for this research was to understand interaction in laparoscopic surgery in terms of what constructs are important and how a surgeon compensates for the perceptual handicaps inherent in laparoscopy. As interview transcripts began to be coded and analyzed, one concept emerged as pivotal to safe operation in any type of surgery. It was the concept of metacognition. Looking into metacognition, both in the library and in my data, represents the next major evolvement of perspective towards this research project.

10.1.2 Metacognition and Expertise

As I have already stated, the role of metacognition was originally suggested by surgeons' frequent mentioning of their comfort level. In the early stages of the coding process, it became clear that a metacognition variable could capture a great deal of the information surgeons cited as important contributors to opening, and we began to code this information with a metacognition variable. Further on, the five categories for organizing the different types of metacognitive statements which appeared with regularity in the transcripts were delineated. The spotlight on metacognition intensified when one of the first looks at transcript data as to whether surgeons opened and whether they saw the pulsating artery revealed a strong dichotomy. Looking at staff surgeons alone, eight of ten met one of the following two descriptions: (1) the surgeon saw the pulsating artery and was a nonopener, or (2) the surgeon did *not* see the pulsating artery, and *was* an opener. Seeing the pulsating artery was associated with feeling comfortable enough to continue laparoscopically, while not having that information was associated with feeling less comfortable and deciding to open. The cluster of variables presented in chapter 8 which describe associations among comfort level ratings, opening, seeing the pulsating artery, and metacognition statements present the full picture which evolved from my early finding.

The realization that metacognition seemed to have an important role in surgery led to the question, what is the relationship between metacognition and expertise?

To understand this relationship, the resident nonopener group deserves special attention. The nonopeners' high comfort level and low metacognitive activity in the face of a situation which was extremely risky, according to their peers who would have opened, is puzzling. It cannot be explained by greater perceptual expertise; in fact, resident nonopeners averaged less perceptual expertise statements than openers, although not significantly so.[1] They saw the same difficulties and potential for injury, but continued down a laparoscopic path regardless, whistling a happy tune and thinking everything was okay.

These findings indicate that the resident opener group, on the other hand, used self-monitoring and regulatory strategies to compensate for their fledgling ability to use perceptual information to see affordances, make inferences, and predict. Self-monitoring reminds a resident that doing what is best for the patient is a primary goal, and makes the connection between obscured anatomy and possible injury, thereby exerting pressure away from a boundary of safe performance (see Figure 3.4 and related discussion). Whether the surgeon opens is not the issue, but is more of a byproduct. For example, one resident nonopener, who saw the pulsating artery, made 22 metacognitive statements (the others made less than 10), stating strategies for obtaining better information continually. This resident's metacognitive statements were in the categories of [4] monitoring and controlling his own thoughts and actions (10 statements), and [2&3] expressing risks and concern for injury (9 statements). This resident could be characterized as an informed, reflective, and concerned nonopener, in contrast to the rest of the group.

In general, self-monitoring and regulation activities serve several functions which help surgeons to attain their goals, and which therefore can be considered as tantamount to expertise. First, comfort level acts as a guide. If a surgeon can learn to monitor comfort level and to utilize it, it can be a powerful tool. In fact, staff surgeons in our study made

[1] Resident openers metacognitive statement mean was 4, while nonopeners averaged 3.

more comfort level statements than residents did,[2] suggesting that ability to monitor comfort level may develop over time.

Second, monitoring a situation with regard to risk and potential negative outcomes in effect provides a warning system that dangerous territory or activity is imminent. The warning system can signal a range of action for avoiding danger, from monitoring perceived information and action taken more closely (i.e., being careful) to engineering the situation to avoid the danger (i.e., opening).

Finally, and related to the above two functions, self- and situation-monitoring permits a comparison between knowledge of own capabilities and demands of the situation. If inequality exists, and the surgeon realizes this, he or she can change the situation to correct the inequality by opening or asking another surgeon to help. The train of thought followed by most resident nonopeners reflects lack of assessment between capabilities and demands. This train of thought could be an artifact of the research interview situation. However, testimony that "the biggest error would be to push beyond a point that personally your skill level doesn't allow you to go beyond" (resident opener), and surgeons' repeated emphasis on "believing what you see, rather than seeing what you believe" leads me to believe that failure to closely monitor abilities and the situation is a real danger in surgery.

The above functions of self- and situation-monitoring and regulation go beyond the frequent characterization of expertise as a time- and exposure-dependent process of building a knowledge base of meaningful chunks of information which are associated with scripts for action. This characterization is for the most part accurate, as evidenced by the differences we found between staff and resident reviewed above. However, it fails to account for the fact that both resident and staff surgeons referred to extensive monitoring and regulation activities for preventing harm to this patient.

The significant departure from my original goal of understanding expertise through staff-resident differences is this: differences *between* residents and *between* staff, based on whether they would have opened this case, caused a reevaluation of expertise in terms of monitoring and regulation, which can be seen to have an impact on goal achievement at all levels of experience. Returning to the literature, Bereiter & Scardamalia's (1993) account of expert-like behavior at all levels of experience indicates that monitoring and regulation,

[2] This difference (staff averaged 3.6, residents 2.1) was not statistically significant, $p = .07$.

towards making the most of every learning situation, are key elements in an expert-like approach to a career. This account provides support for an assertion that monitoring and regulation skills can help enhance the quality of the knowledge base which develops over time. Even further, these skills in surgery have been shown to help moderately experienced surgeons (senior residents) to compensate for lower experience level.

10.1.3 Why Do We Need Metacognition?

The third and final adaptation to the revelations of this research project came about from asking, what exactly is metacognition? The more I looked into it, the more it became clear that we need a better specification of what this concept means. Part of the problem may be the breadth of influence of metacognition in the psychological literature; it has been examined with respect to child development, memory, training and education, naturalistic decision making, and work motivation. When a concept is studied via different paradigms and reported in all of these literatures, it is bound to have an identity crisis. Metacognition is used as an umbrella term to indicate knowledge about, and regulation of, our own cognitive processes, but such a conceptualization asks more questions than it answers. Most critically, it carries the implication that our cognitive processes occur separately from the environment and tasks which they engage. Trying to separate monitoring and regulation of *self* from monitoring and regulation of the *situation* in surgeons' verbalizations a futile undertaking; perhaps it is the relationship between the two rather than their separation which should be of interest.

There are two points I would like to make concerning this issue. First, I feel the concept of metacognition is a useful one, in that it focuses attention on how we guide our own behavior in a reflective, goal-directed manner. Anecdotally, the concept is appealing because everyone can relate to it in their everyday life. A typical route home is reevaluated and changed because of anticipated traffic from a sporting event. While writing a paper we step back and think, is this train of thought really contributing to my point, or am I wasting my time? In a business meeting, words are carefully chosen to make sure their effect will not be counterproductive. These are just a few examples of how we monitor and regulate our behavior continually.

The second point I would like to propose is a question: do we need a concept called metacognition to reflect the monitoring and regulating aspect of our behavior, or should we be simply improving our conceptualization of cognition? In chapter 9 I presented a figure (Figure 9.1) which captures the mixture of self- and situation-monitoring and regulation verbalized by surgeons. The spirit of this figure is inherent in Rasmussen's decision ladder (1976) representation in that it incorporates the variety and cyclical nature of monitoring and regulating. It also is well described by adaptive control theory, as described in chapter 9 (Slotine & Li, 1991).

Therefore, at least two ways to represent cognition which are consistent with monitoring and regulation activities already exist. Monitoring and regulating *is* thinking, whether it is our own cognition, or events external to us, or the interaction between the two which is the subject of monitoring and regulation. If our concept of cognition is well enough defined to reflect the full range of monitoring and regulating, perhaps we can avoid the confusion of labelling some process as 'meta' to cognition.

In some sense, extending cognition to include knowledge about and control over our thought processes themselves, as metacognition is typically defined, is merely expanding the boundaries around how cognition has been defined and modelled in the past. Metacognition, when defined as knowledge about one's own cognitive processes (Flavell, 1976), captures a larger context for cognition, just as cognitive task analysis captures a larger context around tasks which is missing in laboratory research. Perhaps knowledge about one's own cognitive processes has not been accounted for in information processing models of cognition, and the term metacognition was intended to introduce a concept which is 'meta to' such a model.

As a result of this research, I would refrain from calling any statement or thought process metacognitive, because the term is not specific enough, and it can mean too many different things. Are we referring to assessing our ability? Tapping into a measure of personal comfort? Suggesting regulatory action? A combination of these? Once these questions are raised, the appropriateness of substituting a more specific term when one is tempted to use 'metacognition' becomes evident.

10.2 Lessons Learned

There are always areas where one wishes the benefit of hindsight could retroactively inform a completed data collection effort. This section is both a qualification of my findings and advice to others who might conduct similar research. The following are suggestions which I would heed if I could conduct this research again, or in undertaking a similar project:

1. Ask for comfort level ratings more frequently. I found these ratings to be valuable in standardizing surgeons' situation assessment on the same scale. Asking for a rating during the periods of greatest risk, the clipping and cutting of each of the three structures, would have provided a more thorough and up-to-the-minute measure during the interview.

2. I would not pass the VCR's remote control to the surgeon interviewed to permit fast-forwarding through parts of the 15-minute stretch of videotape again. Most fast-forwarding was done as the gallbladder was aspirated. A great many of the interviews were conducted with a VCR which had no remote, and so fast-forwarding was not an issue.

3. At times, surgeons departed from commentary on the tape to relate a story. One staff surgeon related a long story during the time that the artery's pulsation was showed on-screen, and did not see the pulsating artery. In the future, I would capture the surgeon's story on audiotape, but stop the videotape until the surgeon could resume watching without distraction.

4. Verifying information with subject matter experts which appears to be unique and valuable provides a critical sanity check. For instance, several of the statements we coded as 'technique(10),' innovations in technique, seemed to an outsider to be rare and valuable information, good candidates for incorporating in a training intervention. Agreement ratings from collaborating surgeons, however, were quite low. If we had not solicited ratings and had presented these techniques as unique findings, we would have risked seeming uninformed.

5. Only one context was examined in this project. This was primarily due to the in-depth look at this particular case. Using more cases would be a more representative approach for future research. This type of research requires a tremendous amount of time; having

conducted this study, it would be easier in the future to use more cases and focus on a smaller number of variables.

6. Finally, linking statements to events in the tape could have been done more efficiently if the transcriptions had included the events from the start. Original transcriptions included only decision points as events. It was necessary to review and segment each transcript into event categories later on. In another project, I would take time to identify critical events from the videotape before conducting the interviews, and would note surgeons' responses to them during the interview, thus speeding up the analysis process.

These lessons are 'growing pains' which are probably inevitable when an exploratory research project is undertaken. Hopefully including them here can help others to have the benefit of my hindsight.

10.3 Implications for Training

This research carries implications for training surgeons. The group differences found in this research suggest there are two types of training needs, evidenced by the perceptual expertise gap between staff and residents and the metacognitive gap between opener and nonopener residents. Currently, the bulk of resident training occurs through apprenticeship. Staff surgeons teach at the operating table according to personal experience and their own preferred style of communication. Raising awareness among staff surgeons about the specific differences shown in these findings may help provide a focus for feedback and commentary that an attending provides during a procedure, or could be incorporated into instruction via a videotape-based training tool.

Transcript data suggest that staff surgeons see perceptual information in terms of disease progression and affordances, either affordances of the tissue (is it graspable, is dissection, exposure, and visualization possible, what does different tissue look and feel like when manipulated?) or of the situation in general (does this patient afford a safe laparoscopic procedure, or is risk of injury high?). One suggestion resulting from these findings is that staff surgeons might more explicitly point out to residents and students the perceptual cues which are interpreted into inferences about disease progression and affordances. In addition, predictions made from specific perceptual information might be emphasized to trainees, since that was another major area of staff-resident differences. And finally, communicating the anxiety and lowered comfort level which experienced surgeons feel in challenging situations like this one may help residents to better calibrate themselves as to what situations *should* cause discomfort. For instance, hearing an experienced surgeon express "the color of that gallbladder makes me extremely uncomfortable, and this is why..." might be helpful. Many staff surgeons probably teach in a manner consistent with the above suggestions. However, staff surgeons are not given any guidance as to the best way to teach and provide feedback to residents at the operating table. We asked surgeons to describe their approach and style of giving feedback to residents at the operating table; we also asked residents to describe what an optimal approach to feedback would be from the receiver's end. It was clear that some staff surgeons talk and ask questions continuously through a procedure while others only speak rarely. The answers to the feedback questions were not analyzed in this report. Future analyses of these data may provide a better understanding of what barriers exist to providing useful feedback at the operating table, and what optimal techniques could be used, towards designing a training program to help attending surgeons provide better training at the operating table.

A third implication concerning training is the potential for using videotaped cases as a training tool. Reviewing such cases, either for discussion purposes or accompanied by a script for pointing out critical information and what it means in terms of safety, would provide an inexpensive and effective means for increasing vicarious experience of surgeons. With a larger budget, a digital version permitting customized, individual training would be possible. Whether this expense would be justified by the potential payoff of such a tool would have to be determined. Surgeons (especially residents) often asked after their interview how other surgeons had approached the case. Providing a similar challenging case, along with the range of responses to it, could provide a valuable 'norming' function to help residents better understand what situations more experienced surgeons feel are dangerous. The ratings indicating high comfort, few metacognitive statements, and inaccurate perceptual assessment of the situation which some of the resident nonopeners displayed indicate that such a norming function could be quite valuable. In sum, the surgical community could reap safety benefits from using videotaped cases in a range of training situations.

10.4 Climbing Separate Hills

> *It is natural to wonder whether we have decomposed our research efforts in a way that will allow for eventual theoretical unification. One primary concern is whether the many research paradigms that comprise cognitive science are moving along diverging or converging paths. Perhaps that is a question best left for time to decide. I am concerned, however, that although strict and dogmatic adherence to a single scientific criterion may lead to individually successful hillclimbing, when considered overall we may find we have all climbed different hills and, if anything, actually increased the difficulty of the journeys between us.* (Kirlik, 1994, p. 69)

In a research project like this, I might connect with many different areas of scientific literature. For instance, there are large groupings of scientific publications which report research on judgment and decision making; on cognitive systems engineering; on AI and knowledge engineering; on education and training, encompassing learning and sometimes apprenticeship; on expertise; on control theory; and the areas I have already discussed which cover the topic of metacognition (memory, developmental, education research/reading in particular, decision making, work motivation). In addition, there is research to be found on ethnomethodological research approaches, social interaction, situated cognition, basic cognitive psychology, engineering psychology, and the vast literature focusing on medical diagnosis and expertise. The approaches and findings in these traditions, which often ignore each others' existence, boggles the mind. Underlying them all is the invariant human, with ever-variable behavior and thought. It is the task of the researcher to choose theoretical antecedents and frame the problem in a corresponding way.

Informed as well as possible by these various literatures, I specified theoretical concepts which seem to best inform research of this nature in Chapter 3. I have considered the stimulus in this research to be a field of safe travel, as described by Gibson & Crooks (1938). The variability of different kinds of decisions can be captured on a structure such as Rasmussen's decision ladder. I have also asserted the belief that cognition takes place as distributed over a nested system which exerts various pressures upon safe performance.

In conducting this research, I have experienced an evolution of thought, and have been influenced by concepts from all of the areas of study listed above. This is in the spirit of cognitive systems engineering as a 'multidisciplinary marketplace' as described by Rasmussen et al. (1994). In merging separate hills which others have climbed into findings in naturalistic research, perhaps this tradition will make more and more progress towards domain-independent but real-world valid understandings of rules, expertise, and human thought processes in general.

The scientific enterprise tends to emphasize differentiation and categorization. It is natural for scientists to strive to communicate how their chosen area is set apart from others' and how their work makes a unique contribution. Cognition has been differentiated into various specializations, to include pattern recognition, memory, decision making, response execution, metacognition, and situation awareness, but the boundaries between these areas can be unclear. Expertise, however, seems to represent a process of integration. It seems that the distinctions that drive scientific theories are most appropriate for novices. With increasing expertise the boundaries between information processing stages and even between human and environment tend to blur. Rasmussen's decision ladder, with its' explicit recognition of the many paths between observation and action, seems to be an effective way to represent the blurring of the linear stages usually associated with information processing. The concepts of "use" (Flach & Dominguez, 1996), of "affordance" (Gibson, 1979/1986), and of distributed cognition (Hutchins, 1985) reflect the tight coupling of human and environment that is typical of skilled action. In this case, it is the domain of laparoscopic surgery that allows integration over the different hills that Kirlik (1994) refers to, and provides an important perspective that may help us to achieve a more global and unified view of cognition.

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Appendices
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Appendix A. Preoperative Considerations

Patient Factors	Impact
• Age	time under anesthesia
• Medical History	time under anesthesia and insufflation
• Current health	" "
• Chronic vs. acute case	acute case has higher risk of opening
• Blood count up	care with intraoperative bleeding
• Blood coagulation disorders	" " "
• Prior abdominal surgery	scar tissue and adhesions may delay procedure or increase possibility of injury
• Cirrhosis of the liver	" " "
• Distended gallbladder (ultrasound or palpation)	may elect not to proceed laparoscopically, problems manipulating the GB, risk of perforation, or inability to remove GB
• Patient wishes	consent and legal issues

Equipment Factors

• Limited availability of required equipment	unable to perform the procedure competently

Team Factors

• Laparoscopic experience of primary, assisting, and camera-person	time required to complete the procedure
• Confidence, attitudes, comfort/ tolerance levels, patience of decision making surgeon	affects predisposal to open

Appendix A. Intraoperative Considerations

Factors		Impact
Patient Factors		
	• Stability of vital signs and respiration	time available to complete procedure
	• Cumulative damage from dissection	"things aren't going well", time to complete procedure
	• Adhesions hindering progress	time to complete procedure
	• Adhesions causing injuries	time required to repair injuries
	• Identifying anatomy is slow	" " "
	• Bleeding: excessive	time to control bleeding
	non-emergent	time required to irrigate and suction
Equipment Factors		
	• Equipment malfunction	time to repair or replace equipment if available
	• Equipment failure	time to replace if available
	• Obscured vision from bleeding	time required to clean camera
Team Factors		
	• Camera operator is not anticipating next action	time required to communicate what is required from the camera operator
	• Camera operator is not providing a useful field of view	visualization difficulties, time to tell the camera person what view is required for the action
	• Assistant is not providing good countertraction	difficult to identify anatomy and develop a plane for dissection
	• Assistant is "tenting up"	retraction of GB distorts anatomical spatial relationships making identification of cystic duct difficult
	• Primary surgeon is making slow progress due to technical difficulties	time required to complete procedure

Appendix A. Laparoscopic Cholecystectomy: Data Summary for Decision to Open

STAGE 1. INSUFFLATION, SURVEY ANATOMY, AND ESTABLISH OTHER PORTS

PERCEPTUAL CUES	RELATED EXPECTATIONS	ALTERNATIVE TO OPENING
No distension [1]	Faulty equipment Improper setup of equipment	Repair/replace equipment Redo equipment setup
Feel or see adhesions through incision [2]	Lots of scar tissue, adhesions from prior surgery or inflamed organs	Incise in different location
Adhesions prevent visualization of trocars as they enter	Trocars will probably do damage	
Intestinal contents or observed perforation of bowel[3]	Bowel has been injured	Continue only if you can suture bowel
Bleeding [4] incurred from incision or when other trocars inserted	Punctured artery/blood vessel	Control bleeding; irrigate and suction
Malignancy: [5] Studding throughout abd. Tumor implants Ovarian mass	 Cancer Cancer Ovarian cancer	 Continue with l.c.
Distended, discolored GB (pale w/ areas of black)[6]	GB infected, possibly gangrenous; may be difficult to retract and/or remove	Drain GB with needle; or examine GB closely for indications it might fall apart when grasped
CLOSED INSUFFLATION: Droplet doesn't pass	 Needle tip is in tissue	 Try open insufflation technique or change needle placement
Bleeding from needle	Needle has punctured artery	

NOTES:

1. No distension: If patient is morbidly obese, it may be impossible to insufflate; in this case OPENING would be the only course of action.
2. Adhesions: Scar tissue or adhesed omenum or bowel may fall away easily or may resist dissection.
Consider injury to the inflamed surface, injury to adhesed bowel sections, and severity of the adhesions.
If health of patient allows time to work on adhesions, may continue laparoscopically.
3. Injured bowel: Few surgeons feel they have the expertise to suture laparoscopically.
4. Bleeding: quantity and rate are judgment calls. If source can be identified and bleeding stopped quickly, continue.
If not, consider time factor and patient's health in decision on whether to open immediately or keep searching for source.
5. Malignancies: Evidence of malig. is cause for opening when:
   a. Growths are obstructing work area
   b. Growths are probably fast-growing and need to be removed right away
   c. You cannot biopsy the growths laparoscopically

   Consider continuing laparoscopically when:
   a. You feel removing GB is all that can be done for patient
   b. Slow-growing (ie. ovarian) cancer permits treatment later, given you can biopsy growths now
6. Distended GB: May want to feel thickness with graspers and/or try to retract/dissect this area before opening.

Appendix A. Laparoscopic Cholecystectomy: Data Summary for Decision to Open

STAGE 2. DISSECT AND IDENTIFY ANATOMY

PERCEPTUAL CUES	RELATED EXPECTATIONS	ALTERNATIVE TO OPENING
Adhesions[1]	GB is infected; duodenum, omenum, or bowel is adhesed	Try to dissect, consider time factor
Distended, discolored GB (pale w/ areas of black)[2]	GB infected, possibly gangrenous; may be difficult to retract and/or remove	Drain GB with needle; or examine GB closely for indications it might fall apart when grasped
Thickened GB wall	GB infected, possibly gangrenous. May not be able to grasp with forceps	Drain with a needle; continue
Bile	Perforated GB or injured duct	Irrigate and suction bile. If source is cystic duct, clip and transect at point of injury
Intestinal contents or observed perforation of bowel [3]	Bowel has been injured	Continue only if you can suture bowel
Bleeding[4]	Punctured artery/blood vessel or other structure (liver...)	Control bleeding; irrigate and suction
GB tears when grasped[5]	Bile, pus will leak into abdomen	Irrigate, suction, and continue
Cannot identify cystic duct or other structures with 100% certainty	May be anomalous anatomy and/or severe adhesions	Do a cholangiogram [6] if you can find cystic duct; if not, try injecting contrast into the GB to identify structures.
Unable to read cholangiogram or contrast xray with certainty	Can't use cholangiogram to identify	Try again to dissect, considering time and patient factors
Damage to common bile duct (CBD)	Injured CBD	

NOTES:

1. Adhesions: Scar tissue or adhesed omenum or bowel may fall away easily or may resist dissection. Consider injury to the inflamed surface, injury to adhesed bowel sections, and severity of the adhesions. If health of patient allows time to work on adhesions, may continue laparoscopically.
2. Distended GB: May want to feel thickness with graspers and/or try to retract/dissect this area before opening. Distension might prevent proper retraction of GB and identification of the anatomy.
3. Injured bowel: very few surgeons feel they have the expertise to suture it laparoscopically.
4. Bleeding: quantity and rate are judgment calls. If source can be identified and bleeding stopped quickly, continue. If not, consider time factor and patient's health in decision on whether to open immediately or keep searching for source.
5. GB tears when grasped: Contents of GB will spill, and may cause infection in other areas. A thorough irrigation may take care of this. If GB tears, you need to determine if GB can be completely dissected and removed.
6. Cholangiogram: Surgeons often have trouble placing the angiocatheter in the cystic duct. The duct may be too small, or you may not be able to get a seal. There is a high failure rate, especially for inexperienced laparoscopic surgeons. If you are unable to do the cholangiogram, and are otherwise unable to identify the anatomy, OPENING may be the only option.

Appendix A. Laparoscopic Cholecystectomy: Data Summary for Decision to Open

STAGE 3. CLIP AND TRANSECT CYSTIC DUCT AND CYSTIC ARTERY; SEPARATE GALLBLADDER FROM LIVER BED

PERCEPTUAL CUES	RELATED EXPECTATIONS	ALTERNATIVE TO OPENING
Bile	Perforated GB or injured duct	Irrigate and suction bile. If source is cystic duct, clip and transect at point of injury. May need to leave a drain in place.
Intestinal contents or observed perforation of bowel[1]	Bowel has been injured	Continue only if you can suture bowel
Bleeding [2]	Punctured artery/blood vessel or other structure (liver...)	Control bleeding; irrigate and suction
Clip falls off cystic artery, causing uncontrolled bleeding		Attempt to reclip, try using another port if needed.
Clip is not placed right [3]	An error has been made in clipping the duct or the artery	Remove clip(s); examine for injuries
Don't have enough tension on GB to separate easily	1st Assistant is not applying adequate exposure or tension	Show assistant how to hold properly or hold yourself
Observed injury to common bile duct (CBD)	Injured CBD	

NOTES:

1. Injured bowel: Few surgeons feel they have the expertise to suture laparoscopically.
2. Bleeding: quantity and rate are judgment calls. If source can be identified and bleeding stopped quickly, continue. When removing GB from liver bed, electrocautery can be used to stop bleeding. However, the cautery device can also cause injury to surrounding structures if not handled with caution. The CBD is especially at risk.
3. Clip is not placed right: A clip may be used to try to stop bleeding, and this clip might injure another structure. The rule is to not place a clip unless you know exactly what you're clipping, but this isn't always what happens in practice. If a clip is placed over the CBD, OPENING is necessary.

STAGE 4. REMOVE GALLBLADDER AND FINAL SURVEY

PERCEPTUAL CUES	RELATED EXPECTATIONS	ALTERNATIVE TO OPENING
Bleeding [1]	Punctured artery/blood vessel or other structure (liver...)	Stop bleeding quickly or OPEN. Consider time and patient factors here. Irrigate and suction.
GB is dropped from graspers and can't be recovered.		Keep searching. OPEN if takes too long

NOTES:

1. Bleeding: quantity and rate are judgment calls. If source can be identified and bleeding stopped quickly, continue. A big risk at this time is using clips to stop bleeding which injure other structures inadvertently; this might require you to OPEN to repair damage. Severe bleeding from the liver could also indicate OPENING.

After GB removal, insufflation pressure may be reduced by half for removal of the ports. This may induce bleeding from injured structures which was previously inhibited by the pressure. If bleeding can't be controlled, may have to OPEN.

Appendix B: Interview Questions and Rating Scales

Questions:

(1) What do you think is going on here?

(a) Are there any alternative interpretations you could make?

(2) Do you have any concerns at this time? What are they?

(3) What errors would an inexperienced surgeon be likely to make in this situation? Are there cues they might miss?

(4) (If not generated spontaneously) Can you think of a time in your previous experience where you faced a similar situation? What was it?

(5) Can you give me a numerical rating, from 1 to 7, of your comfort level with continuing this procedure laparoscopically, using the anchored scale shown here?

(6) Can you give me a numerical rating, from 1 to 7, of the skill level you think would be needed to complete this procedure laparoscopically, based on the anchored scale shown here?

(7) If I told you that the surgeon (decided to open at this point) (decided to begin this procedure as an open one), would you think that was a reasonable course of action?

(8) Given that your overall goal is to take this gallbladder out safely, what are your current short-term objectives at this time?

(9) (a) Are there any alternative courses of action which might work?

(b) Would you do anything differently than these surgeons are doing?

(10) Are there any other cues you see that are influencing your actions that you haven't mentioned yet?

(a) Are there cues that you expect to see that are not present?

(b) As the attending surgeon, are you satisfied that the structures have been identified?

<u>Become the supervising/attending surgeon now, rather than operating surgeon:</u>

(11) As the supervising surgeon, would you communicate anything to the resident right now?

(12) Would you consider taking over the operation?

(13) If I were watching you in the operating room give feedback on this case, at this point, what tone of voice or non-verbal actions would I hear/see you use to communicate what you want to the resident?

(14) How have you been taught to resist panicking when you face a situation like this? How do/would you teach a surgeon to resist panicking?

Training Questions

1. If at the end of this procedure the resident asked you, "How did I do?"What would you tell him or her?

2. Expert:(a) Can you characterize your style of giving feedback to a resident operating under your supervision?

   Novice:(a) Can you describe a style of feedback an attending surgeon might give you which you feel is most effective?

3. Tell us some things you have learned about feedback over the years?

4. How is your preferred feedback style different from that of other surgeons you've worked with?

5. Can you explain why you've adopted this style?

Comfort Level Rating Scale: What is your comfort level at continuing (or beginning) this case laparoscopically?

1. No concerns whatsoever (0)*

2. Little concern. (5%)

3. Increased concerns (25%)

4. Moderate concerns; 50/50 chance this will need to be converted (50%)

5. Many concerns (75%)

6. Very seriously considering converting/beginning as open (95%)

7. Would convert/begin as open *now* (100%)

*Percentage indicates level of concern and probability that this case will have to be done open.

Resident Surgeon R-1, p. 1 of 4
(23.8)

CUE CODES:

HC - hypothetical
AC - actual given
VC - visual cue, seen
VC/A: visual cue derived from action taken
Q: interview question
TC: tactile cue

ACTION CODES:

C: change entire situation or approach
V: to get visual info.
T: to get tactile info.
ST: to stay within field of safe travel
D: do experiment to diagnose
O: operate, move procedure along
NO: would NOT take action which is shown
SA: to improve SA
LA: to prevent/head off later problems
I: avoid injury now

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. draining	VC/A: seeing GB grasped on video	J: doesn't look like they could have grasped GB w/o aspirating PRED: Usually the bile is extremely thick, doesn't come out quickly, but almost always leaks when you take out the GB		meta2: they usually have good success with draining the GB, makes it easier to grasp, but more difficult to remove GB from liver bed when it's totally drained
E. Init Diss		D: The blood's obscuring your field D: At this point it's very difficult to know what's going on on the tape (they work to isolate a structure and then just pull it away, so it's just inflamm. changes	ST/O: they need to go a little high, around the GB	
			C/SA: Not having seen how they got up to this point, and if I couldn't get the blood off there, I would convert to an open (seems to be lost)	
				meta3: they're not cutting w/unusual force, but with all that inflammation, you run risk of tearing a structure which you didn't mean to, that you wouldn't normally tear w/that same force in a GB which was not as sick, because you cannot see a whole lot clearly here

Resident Surgeon R-1, p. 2 of 4

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
E. Init Diss	Q: is it easier to tear things when it is inflamed?			Right.
F. Lymph	VC/A: clipping lymph	D: they clipped something there, I have no idea what. It doesn't look like anything dangerous to clip. But if you can't see things you're clipping and be able to ID the landmarks, ... it would be difficult to proceed.	O: I would divide CD first before dividing what they just did cut	
G. GB opens		J: getting into the GB happens, nothing to be alarmed about, just another indication of how sick the GB is and this pt. is, indication that it would prob. be better to open this pt up.		
	Q: have you reached the pt. where you would convert?	J: I probably would earlier, in the bloodstained area, because I couldn't really see what was going on		
	Q: is this patient more confusing than you expected from the history?	J: the disease process is a little more advanced than I would have expected		meta4: I think part of the decision making in doing any type of surgery is that you have to keep reevaluating what you are doing as you go along meta4: I definitely wouldn't say it's wrong to convert b/c you knew the rest of the procedure would be like this, difficult to see, a lot more difficult than your average inflamed GB

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
H: ART DISS	VC/A: clipping artery	J: it looks like they are clipping the cystic duct.		
		D: They don't put the edges of scissors around the structure first to make sure they've got it isolated. Looks like they tried to see back of clips, but wasn't clearly shown		meta3: they keep on pulling at things back there, you are not going to be able to delineate structures (CA & CD), and making sure you are not clipping or doing something to another structure that you don't want to
I: LAST DISS		D: I don't know what we're doing here. You can't see enough to ID structures.	C: If I hadn't converted earlier, and unless I could clean all the blood out of there, I would convert to open	meta1&3: You don't know if you're on the GB or are too far down. You can kind of maybe see the common duct coming up towards whoever is grasping right now. I would be very uneasy at this point.
J. DP3	Q: What do you think is going on here?	J: they're looking for identifiable landmarks, it's too inflamed, may have anomalous anatomy or have caused an injury to the common bile duct D: you can't see enough to tell anything		
	Q: What are your concerns?		C: You have to open to overcome being lost	meta5: concerns are where are we? we're lost, don't know what's going on, the only way to overcome that is to open up.
	Q: What errors might an inexperienced surgeon make?			meta3: progressing on would be biggest error: if you get your landmarks confused, you're going to cause the pt. a great deal of harm

Resident Surgeon R-1, p. 4 of 4

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J. DP3	Q: What is your comfort level, from 1 to 7?	J: 7		
	Q: What skill level would be needed to do this procedure laparoscop-ically?			meta5: some surgeons feel converting would be a failure here, others see proceeding lap. as a complication. Most skilled surgeons would have decided long ago in this procedure that continuing lap.would put the patient at risk. Technical skills are not the question, but decision skills
	Q: What are your short term objectives?		D: I would do a cholangiogram	
K. POST DP3		D: You can't see the clips going around the last structure, could be including the common bile duct.		GOALS : opening may prolong hosp. stay & recovery, but if you injured a major structure, the recovery from that would have taken longer than had you opened her up and did it right the first time.

Resident Surgeon R-2, p. 1 of 7
(23.4)

CUE CODES:
HC - hypothetical
AC - actual given
VC - visual cue, seen
VC/A: visual cue derived from action taken
Q: interview question
TC: tactile cue

ACTION CODES:
C: change entire situation or approach
V: to get visual info.
T: to get tactile info.
ST: to stay within field of safe travel
D: do experiment to diagnose
O: operate, move procedure along
NO: would NOT take action which is shown
SA: to improve SA
LA: to prevent/head off later problems
I: avoid injury now

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. Draining	VC: Decom-pressing		V/D: Look to see what kind of fluid is coming out, those clinical findings are important	
	HC: White bile	J: White bile means there's a complete obstruction	HD: If white bile, definitely do a cholangiogram. D: Probably would (do a chol.) anyway	
E. Init Diss		D: Hard to see what they're doing D: It's a dangerous place to be grabbing	O/NO: Don't start grabbing in the middle and pulling down.	meta3: Could be duodenum.
		D: Can't tell if it's end of gallbladder, or the duodenum.	O/ST: Start low.	meta3: They're randomly pulling, could be injuring other structures.
		J: There are not many good landmarks at this point		
			C: Might consider opening, or O/ST: At least be careful when dissecting down	

Resident Surgeon R-2, p. 2 of 7

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
F. Lym	VC: Lymphatic structure	J: Looks like that's the Cystic duct	O/ST: Better to start dissection close to the gallbladder wall than in the middle	
		D: Also a chance that could be common bile duct tented up towards the gallbladder	O/ST/I: Have to dissect further along the gallbladder to find out	meta3: (could be the common bile duct tented up)
	Q: So you want to be closer to GB because you're concerned about the CBD?		ST: Go from known to unknown V: Irrigate also. NO: I wouldn't have clipped that.	
			D: Put clamp high on the gallbladder side and do a cholangiogram.	
		D: That's bold, to clip and divide, you don't know what it is, a vessel, the common bile duct. I'm hesitant to divide it.		meta3: Could be a vessel or the common bile duct, not sure.
	VC: (?)	J: Looks like gall-bladder wall, where he's dissecting.		
G. GB opens	VC: Opening		V/LA: Grasp that to stop more leakage, and irrigate.	

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
G. GB opens cont.	Q: Are you concerned about that?	J: No, you can spill bile in an open procedure too.	V/LA: Irrigate and clamp it.	meta2/3: She's an increased risk of developing an infection post-operatively, but that wouldn't stop the procedure.
H. art diss	VC/A: dissection	J/D: Working in a hole, it's hard to tell what's down there.		meta4: I don't think they've demonstrated that it goes into the gallbladder.
		D: Once you decompress the gall-bladder, it's hard to tell where the GB wall is.		
		D: Because that structure could be right hepatic artery.		
		D: It's awful big to be cystic artery, REAL BIG.	V/I: Before clipping it, I would dissect further along the GB wall.	
	Q: so you re not comfortable clipping it now?		NO: I would not clip it now.	
	VC: cystic artery	J: Doesn't look like it's pulsating. D: But you can't always tell that. It could be peritoneum	O/V: I'd further dissect it free, definitely clip it once I was assured I wanted to cut it.	
		D: He can't see where he's cutting, because of the angle of trocar placement. D: He's just cutting straight into it.		constraint: Trocar placement, can't see back of scissors. meta3: Might cut into something behind the vessel, can't see tips of scissors which is dangerous.

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
I. Last diss, (cont)		D: At this point, it's hard to tell what's going on.	V/I: He could get behind the vessel first, then put the blunt end of your scissors around so you could see the tips behind it.	
		J: They probably think they've divided the cystic duct and cystic artery and can proceed to dissect the gallbladder out of the liver bed.	V: Probably want to irrigate and see what's going on.	
		D: But it's hard to see what's going on. D: It's really hard to tell what they've done, for sure.		
	VC/A: Pulsating artery	J: They've cut a big structure, a vessel, it's pulsating. It was definitely an artery of some sort. D: But you don't know exactly what that was.		constraints: Equip: Color's not real good in the camera, there's a red tinge to everything. Possibly it's an old camera, or it's not set up right.
	VC: Last structure, blood clot	J: That's probably just peritoneum folded over. D: It's hard to tell. J: It looks like it's fairly free.	V: I would irrigate and see what it is.	
		D: Of course, the question is, WHAT DID THEY CUT? J: There's still a structure behind that.		

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
I. Last dissec-tion, cont.	VC/A	J: I'm starting to see, when he pushes down on that band, there's something behind. D: You never really see the common bile duct, for sure.		
	Q: Would you like to see the common bile duct?		D: A cholangio-gram would have helped define more where things are.	meta3: There's danger in trying to dissect it to see it real well too: you can injure the blood supply for the common bile duct.
		J/D: This guy probably thought he divided the cystic duct and cystic artery, and now he's found a new structure, he doesn't know what these are.		
J. DP3	Q: What's going on here?	D: Hard to tell what they divided: they didn't do a cholangiogram, didn't dissect ves-sels all the way back to the GB.		meta3: Those vessels could have been going to the liver. That big thing could have been the common bile duct.
		J: Usually the cystic duct is inferior, cystic artery is behind it, so they probably thought the first structure was cystic duct, second was cystic artery.		meta3/4: There's a lot of variation in the gallbladder extra-hepatic system.

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J. DP3 (cont.)		D: But the anatomy can vary widely, especially now seeing these other structures, there must be concern about what's going on.		meta1: Concern based on anatomy variation and new third structure seen.
	Q: what errors might a inexperienced surgeon make in this situation?	J: Not identifying things better. They weren't starting where they knew the gallbladder was, they dove into the middle.		meta3: When they first put a grasper on the infundibulum, they could have been grasping duodenum.
			ST/I: I would have started dis-section more proximal, at the gallbladder.	
			C: At any point during that, it's reasonable to just stop and convert, because it was not clear what they were doing.	
	Q: Would you have opened?	J: If I couldn't do a cholangiogram technically, or it didn't show the anatomy,...	D: No, I would have done a chol-angiogram through the first structure. C: I would have opened.	

Resident Surgeon R-2, p. 7 of 7

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J.DP3 (cont.)	Q: What is your comfort level on this scale of 1 to 7?	J: 7	C: I would probably open at this point. I don't know what's going on, there are new structures, and I don't know what I've cut.	meta3/5: You could be a cowboy and keep plunging ahead. Could have a major injury at this point, have to go back and open, and do a bypass procedure, there's a high morbidity to that (meta2). Meta5: "If you're not experienced enough to know what's going on, you might not realize that you're having problems at all.

Resident Surgeon R-3, p. 1 of 4
(23.6)

CUE CODES:
HC - hypothetical
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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
d: drain-ing	VC: GB being drained	J: looks like they had trouble prob. grasping the GB, although I don't see grasp marks . . .		
e. init diss	VC: dissection	J: looks like they are trying to ID the CD, CA, CBD		
		D: but I don't see much of any of those things at this point		
	VC: dissection	D: I am kind of worried. There's a lot of inflam. here at the GB neck. I can't see where CBD & CD join together. There is all this fat & inflam. and I am digging into things I can't identify		
	Q: would you do something differently here?		C: So I would be leaning towards opening this pt. If I were the attending, I would say "be careful, be careful, be careful," and saying "Wait, let's stop and think about this, maybe we should convert this to an open procedure"	meta4: my threshold for opening this pt. at this point in my career is pretty low
	Q: What specifically are you worried about that happened here?		C: I would probably open	meta3: That if it were me doing the operation, I would inadvertantly injure the CBD

Resident Surgeon R-3, p. 2 of 4

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
F. lymph			NO/I: I would definitely not be clipping that, I don't know where it's coming from or going to, would not clip it or cut it C: I would open	
	Q: why is this different from what you expected when you originally saw the acute cholecystitis? AC: 80-year old		O/ST/C: If the pt. were stable, I would want to give lap. chole. a chance..	meta4: in my own mind if I could not safely ID the CD and where it joined the CBD or the CA then I would open
	Q: what specifically did you see that tells you you are not going to be able to do that here? (Ans:) adhesions, scarring, inflam. & edema, fat there where he is cutting			meta4: To me, I don't know what it is and I am not going to blindly cut some-thing that I don't know what it is.
G. GB opens	VC: GB rips open	J: The wall of the GB tore where the assistant was giving retraction, that's not uncommon in an edemetous GB.		
H. ART DISS			NO/I/ST: I wouldn't be clipping that either C/O: my hand could be in that lady's abdomen right now	

Resident Surgeon R-3, p. 3 of 4

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J: DP3	Q: You would have already opened?		C: I would have opened before they even clipped that first structure, or whatever it was	
		J: I presume they are now ligating the CD or the CA. D: I don't know what the first thing was they clipped & cut, but if the 1st one was CA, then this one I presume is CD D: I would be real hesitant digging around in that area		meta1&3: they could be near to where the hepatic art. is or where the CBD is. There are distortions of anatomy in an acutely inflamed case: things may be pulled up higher than usual, I wouldn't be comfortable dissecting in that area
	Q: summarize what's going on	J: acute chole., lot of inflam. & edema. The inability to ID structures very clearly due to the inflammation. Dis-section proceeding w/difficulty: it is hard to really identify any structure with certainty		meta4: Two structures have already been clipped and ligated, it looks like there is more
	Q: any alternative interpretations?			meta1&4: maybe the operator is seeing something that I am not seeing on the screen, that gives him a clue as to where that comes from and goes to. meta3: dissecting into the liver parenchyma (liver tissue), getting into a major vessel (hepatic artery, CBD)

Resident Surgeon R-3, p. 4 of 4

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J: DP3 cont.				meta1&4: (continued) Perhaps he saw something that is not on the video and followed it out and felt more comfortable knowing that it was the CD. But based on what I have seen here, I couldn't ID where it was coming from or going to, so I would be uncomfortable.
	Q: What are your concerns?	D: my concerns are I haven't ID'd the CA, the CD, or the CBD		meta3: where they are dissecting now there could be damage to other structures
	Q: What errors might an inexperienced surgeon make in this situation?			meta3: dissecting into the liver parenchyma (liver tissue), getting into a major vessel such as the hepatic artery or common bile duct
	Q: What is your comfort level, on the 7-point scale?	J: 7, I would open now or back then		

Resident Surgeon R-4, p. 1 of 5
(12.8)

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. Draining	VC/A: Gall-bladder drain-ing	J: That's a wise move, it will let them hold onto it and assess the gallbladder contents.		
	HC: If it shrinks completely..	J: AND can get a grip on it, might be able to do it laparoscopi-cally. J: May be one big stone in there.		
E. Init. Diss.	VC/A: Diss-ection	J: That's too big of a bite.		
	VC: Exudate yellow stuff	J: That tells you the gallbladder is acutely inflamed.		meta3: You can't tell structures from peritoneum because of edema, it's easy to make a BIG mistake laparoscopically. meta2: It's real risky, and not worth dividing the common bile duct in 1 of 20 people.
F. Lym	VC/A: Clipping	D: I can't see the other end of the clip applier. The clip fired 3 times, and there are only 2 clips on.		

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
F. Init. diss. cont.	VC/A: Cutting the lymphatic	D: I don't see a 'twang' after cutting, instead the surgeon pushes the end back. J: So they may not have anything of value here.		constraints of operation: In this operation, you have to cut only 2 things, the cystic duct and the cystic artery.
	VC: video	J: They're spilling stuff, even with clips on the holes.	C: I would open now.	GOALS: The gain with laparoscopy is not great for an 80-year old lady.
G. GB opens	VC: spilling bile.	J: That's not pus, but it's yucky-looking bile.	V/LA: I would wash the bile off.	GOAL: Everything on this case is a catch-up, seeing what they can get away with not what it safe.
H. Art Diss.	VC: tubular structure on top.	D: I don't know if it's cystic artery or not, could be the right hepatic artery, or peritoneum. It's inflamed, DISTORTED anatomy.	O/NO: They should work in one area, don't bounce around, that indicates the surgeon is not clear about the anatomy.	
	VC/A: clip	D: I can't see where the clip went, don't know if the structure is completely crossed.		meta1: I would be very uncomfortable if I were the surgeon watching the resident do this. TEAM: the camera is not centered.
	VC/A: cutting the artery	D: They're cutting blindly, can't see what you have to see. D: It had a 'twang' but could be the right hepatic artery.		meta1: I would be having a heart attack if this were my junior resident.

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
H. Art. dissec-tion, cont.	VC: pus	J: He sees pus in the bile, or maybe in the gallbladder wall itself. The gallbladder is dying.	C: I would open. This is not an issue of experience or comfort level.	meta4: They're beyond where they should be. GOALS: It's an issue of what's safe for the patient. You can do 500 laparosco-pic cholecystectomies and still open this patient. They would lose in court if divided this common bile duct, that's a dumb move career-wise.
J. DP3		D: It's clearly unsafe to continue. I can't see their anatomy.		meta4/5: The hardest thing to learn is your limits, this surgeon may not realize it's time to stop.
	Q: What is your comfort level?	J: 7		GOALS: They need to get this GB out safely without injuring the common bile duct.

Resident Surgeon R-5, p. 1 of 3
(12.11)

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. Draining	VC: Draining	J: I would also aspirate this. J: It looks like they aspirate pretty well.		
E. Init. Diss	VC: View of fundus		O: Pull fundus up over the liver, use liver as a solid structure to tent and stretch on top of.	
	VC: (?)	J/D: Ligament is substantially thickened, very difficult to see underlying structures you need to dissect out.		meta3: Thicker ligements and edema make injury to duct or artery easier to do.
F. Lym			V/ST: Should irrigate. I/V: Turn staplers sideways so I can see the teeth in back. LA: Leave more of a proximal tail, the clip could slip off.	constraint: Distortion seen with the videotape, as opposed to being there.

Resident Surgeon R-5, p. 2 of 3

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
G. GB opens			NO: Don't try and staple that, move along and get the gallbladder out. O: Just grasp it at the hole and move on.	time constraints: They've spent too much time doing peripheral things.
		J: This is the problem w/doing Lap. choles on an acute gallblad-der, you break into the gallbladder, and cause bile to run around in the abdomen.		
H. Art Diss.		J: It looks like a vessel up there.	V/ST/I: Follow that vessel up a little more before clipping.	meta3: Sometimes these head back into the liver.
	Q: Back into the liver if it's one of the hepatic ducts?	D: It's probably the cystic, but can't be sure with this acute case.		
I. Last Diss.	VC: (camera moving out and in again)	J: Lost in space!		constraint: The camera operation is causing disorientation, moving in and out.
			SA: (hypothetical explanation of how to pull camera out and put it back in, making a mental note as pulling it out, direct the same path back in)	

Resident Surgeon R-5, p. 3 of 3

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
I. Last Dissec--tion, cont.	VC: blood		V: Irrigate again	
	VC/A		NO/I: He's pulling upward from the common bile duct, should pull down instead	
J. DP3	Q: What do you think is going on here?	J: He's doing a fair job of dissecting from an inflamed gallbladder fossa.		meta3: I'm concerned that they might have inadvertantly taken down something by mistake, because of all the inflammation.
K. Post-DP3	Q: What errors might an inexperi-enced surgeon make here?	J/D: I'm not sure I ever saw the . . . uh, oh that vessel on top is, I assume the cystic artery. J: You just don't see everything quite as clearly.		errors: Moving too hastily, not properly skeletonizing the cystic artery and cystic duct, not knowing when you are into problems and need to convert to an open procedure (meta4)meta4: A lot of surgeons are proud of never opening, that's not the way it should be.
	Q: What's your comfort level?	J: 4		
	Q: If surgeon decided to open, would you think that was reasonable?	J: It appears he's got the CD and CA, I would wonder. why would you want to open now?		
	Q: Are you satisfied that the structures have been identified correctly? VC: Sees last structure more.	J: Yes, as much as you can, given acute cholecystitis. D: What structure is that? I'm not so sure now that the structures have been identified.		NOTES on this resident: Knows injury is easier and that it is an error to not know when you are into problems, but does not recognize that he/she is into problems here.

Staff Surgeon S-1, p. 1 of 5
(12.7)

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. draining		J/D: The surgeon's aspirating the bile, I would hope, to get a culture specimen, but I'm not sure that you can get an alright specimen thru there.		tissue constraints: also aspirating to take some of the pressure off the GB, to try and make it easier to grasp. Frequently the wall itself is so thick it's very difficult to grasp, or it's so friable that it just falls apart.
	Q: would that specimen be sent to the lab and you get the results right away?		D: should be sent over for a Graham stain & culture, to see what kind of bacteria's in there. You should be able to get it back within 10-15 mins., look to see if there's clostridium in there.	
	VC: leak of fluid from the GB	J: they're going down to suck it up, that's a potential place for abscesses, if they don't get it all out of there	ST/LA: I'd see if she was covered with pre-operative antibiotics. they would be helpful. D: Also if it's predominantly Graham positives or Graham negatives, and if she has clostridium.	
	VC/A: she obviously has some stones, you can see them, he's kicking that stone with the sucker.	J: Looks like it's a totally collapsed GB		constraint - contaminated tissue: the only thing that bothers me is the wall of that GB, you can take a swab

Staff Surgeon S-1, p. 2 of 5

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. draining				(constr, continued:) and culture it, and it'll have heavy growth of bacteria, so now it's sort of being slopped around everywhere, everything it touches it contaminates, it's a source for post-operative infection.
	VC: you can see lots of edema, swelling, gelatinous appearance down near the cystic duct	D: could make it difficult. D: There's something missing here, a jump in the tape D: he's clipping a hole here, I can't tell exactly what he clipped		
	VC: fundus of GB	J: there's a little irrigation fluid that falls there...		constraint - surg's attitude: I'm pretending I'm looking at this for an attorney who's suing
E. Init diss	VC: you can see all the edema & swelling down there	J: It looks all clear and snotty looking, that's all swelling, that's edema fluid D: A very hazardous area to dissect, can be very bloody	C: I would be taking this GB down backwards, from the top down, so that you can define the area of the CD and the CBD and not get into trouble	
F. lymph diss		D: even if this were open, it's a difficult dissection, and it's difficult laparoscopically, obviously	C: the safest way to do it is to take it down from the top down, in my opinion	risk: I think from here on anything that happens good is just luck, and anything that happens bad is deserved, b/c there's so much swelling in those tissues you can't tell what's what

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
G. GB opens		D: I won't even comment about that, I already told you that would happen, It just falls apart. I wouldn't be surprised if it happens more, if they persist.		tissue constraints: Sometimes when you do it open, the GB just shreds in your hand, when you're being gentle, and there's nothing gentle about a laparoscopic procedure. You have to put a moderate amount of traction on the GB just to get exposure.
			C: when you get down to where the CD and CBD are, and occasionally if there's enough edemetous reaction, you don't even have to dissect in there, you can (?) in part of the GB in situ and drain it, and get out.	
	Q: do you need less traction on the GB in an open procedure, esp. if you do it from the top down?	J: yeah, from the top down you don't use any traction at all.. J: most acute GBs, in my opinion, should be done that way, even open you can get into trouble down in this area.	HC: You work behind the GB and sort of peel it off the liver, working your way down to where all of the potential problems are, and then you're done, and all you've got left is the CD and CA and CBD, and then you can precisely see where you want to clamp it and take the GB out.	
	Q: would you ever do them from top down laparoscopically?	J: yes, I've done 4-5 of them, but not gangrenous cases like this one		meta4: there's a difference between can & should. Maybe you can do it lap,but should you, abs. NOT.

Staff Surgeon S-1, p. 4 of 5

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
H. Art Diss	VC: looking at operative area on video	D: nobody can tell what's in that mess, it's just all edema, it's hemorrhagic, some of it's acute bleeding, I think it's foolish to try and even do that		meta5: so you've got people who say well, I've done it, I got away with it, and you say yeah, well, you can do it, but the question is whether it's good surgical judgment, it's very poor surgical judgment. risk: Just because you got away with it this time, a significant percentage of time you won't.
				meta3 : occasionally you'll have duodenum stuck up here, people have been known to get into duodenum and not even realize it.
	Q: what would be the impact of that on the patient?			meta2: they'd probably die. Unrecognized duodenal injury on somebody this age probably has a 40 or 50% lethality rate.
		D: He's actually not dissecting the GB out like you do on a normal Lap. chole., this is really more of a debridement of the GB, sort of working it out of its base, because it's necrotic		
I. Last Diss		J: I missed it, not sure I saw cystic artery being clamped, maybe that's what he's thinking about doing there		

Staff Surgeon S-1, p. 5 of 5

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J. DP3	Q: what do you think is going on here?	J: Looks like that might be the cystic artery, it's pretty small, looks like it's got a hole in it where it's bleeding, looks like he's getting ready to clamp it D: although I can't tell for sure what it is. Probably something that needs to be clamped		
	Q: Any alternative interpretations?	J:Could be right hepatic duct, or common bile duct D: I don't know what it is, prob. a blood vessel, I have no idea	D: we can relax a little bit on it and see what comes out. if bile comes out, since we already cut cystic duct, we're in trouble. If blood came out of it, it's probably a blood vessel. Might be right hepatic; probably is the cystic artery	
	Q: Do you have any concerns?	D: they probably should have stopped 20 minutes ago.		meta5: that's why this shouldn't be done laparoscopically, you don't know what that structure is
	Q: What is your comfort level, from 1 to 7?	J: 8, because it doesn't apply, your scale is non-operative		
K. Post-DP3		D: where the clip is actually being applied is an unknown area, it's exactly where people get part of the common duct	ST/NO: wouldn't clip that far away (from the gallbladder), he's awfully far medial, should be towards the GB more	meta3: clipping too close to common bile duct area

Staff Surgeon S-2, p. 1 of 5
(23.1)

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
d. drain-ing	VC/A: Can move the GB around and poke it, GB folds over on itself	J: that's an indication that it's not a full thickness inflammatory reaction, it's a mucosal reaction, it's not as advanced.		
	VC/A: Putting clips in hole used to drain GB	J: He's spent time trying to control leakage from that hole which I think is insignificant because you're still going to get bile leakage.	NO: Wouldn't clip here. ST: retrieve that clip which was dropped.	constr: Equipment, clip applier manufacturer, these clips drop a lot.
e. ini diss	VC: white-ness on the gallbladder	J: means leukocytic invasion, sub-cirrhosal inflam-matory response. D: When you see that then you get real concerned about whether you're going to complete this surgery.		meta1: This is in the area where the big bucks are, this is the area where you can get in real trouble.(raised concern)
	Q: Seeing that leukocytic response, does your level of concern rise?	D: Yes. I think I'd go down to 7 on the comfort scale.	ST/SA: I would never let a resident do this.	

Staff surgeon S-2, p. 2 of 5

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
e. init diss, cont.	VC/A: grabbing in area of common bile duct		NO/ST: I would never have grabbed that proximal.	meta3: grabbing in area of common bile duct is a wrong move, that could cause injury
	VC: every-thing's gelatinous.		C: At this point in the operation I would stop, I would just not do this because I think you're doing the patient a disservice.	
	VC/A: Instead of moving things smoothly, surgeon is moving clumps, not moving easily	J: I don't think he's injured anything at this point	V/ST: Here I use a technique called petting, pet with side of instrument	constr: That instrument is just a little too pointy, I use a dolphin nose.
				meta1: I'm getting real worried.
	VC: Can't tell cystic duct from tissue around it, both have same consistency	This is wrong, what he's doing right here. I'm not convinced that he has a structure that he has positively identified.	V/SA: They could use a technique called saline dissection here to better define the planes. V: I would do that, and irrigate, because there's too much blood here.	meta5: This I would consider an error in judgement.
				meta3: The problem is that an 80-yr old will not tolerate a complication, she'll die.

Staff surgeon S-2, p. 3 of 5

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
e. init diss, cont.			C: Three things I would do differently: 1. Won't use an assistant, use towel clips for retraction 2. Use mechanical camera holder 3. Operate two-handedly	
g. gall bladder opens	VC: hole in gallbladder	J: he's got a big hole in the GB and that's actually not bad, that doesn't really concern me because I think that will all be irrigated out. D: Am concerned because back where he grabbed it where I said I wouldn't grab it, that's where he got his hole,		Meta1: It's more proximal to where I feel comfortable.
		J: It looks like he's okay, even though he's done some things I would not do.		meta1/equip. constr: It bothers me that he doesn't have the camera focused very well. to do this operation with this much meticulous dissection, I think you need to have absolutely phenominal optics for that.
h. Art. dissec-tion				meta1: I'm not real comfortable with what he's doing but I think he's okay.
		J: I suspect that's probably the cystic artery	ST/SA: Should dissect the back wall of the GB out a little more, flip it over and dissect underneath.	

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
h. Art. dissec-tion, cont.		J: This structure that he just clipped is so high and so anterior and it goes to the outside wall although slightly medial, the outside wall. It's probably a vascular structure and he's probably safe.		team constraint: Get the camera in there, quit falling asleep.
	VC/A: You can see that that was relatively easily pulled away.		V/SA: now he's getting to that back wall, I would have gotten to it a little bit sooner. ST (tissue affordanc): somebody keeps pulling on that a little too hard before they know. You can't see under that blood cloud right there	equip constraint: I would use a more blunt instrument
				Meta4: All of a sudden he's realized that that's a structure, and he's trying to figure it out right now because, he knows in his mind that he's already clipped two structures.
i. DP3	Q: What do you think is going on?	D: I'm concerned that the dissection wasn't performed as safely as I would have liked... There have been some sloppy techniques.		meta1: I think that the surgeon is getting a little worried, again he's found a structure that he doesn't know what it is.

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
i. DP3, cont.	Q: any alternative interpreta-tions that you could make?	D: He may very well have an injury to the common bile duct. I think he's probably okay, but I'd be interested to see what he does next.		
	Q: When might there have been a common bile duct injury?	J: The very first time he clipped something, if something bad did happen, that very well may have been it.	ST/V: He should have identified the structure better before that first clip, known exactly what he was clipping.	
	Q: What errors would an inexperienced surgeon be likely to make in this situation?	D: Also, I don't believe this person is using a 2-handed technique. Other error: hasn't visualized well enough, hasn't controlled hemostasis well.		meta5: An inexperienced surgeon is not experienced enough to do this kind of surgery, with this inflammatory response. meta5: his judgement should have been to open sooner based on his level of experience.
	Q: What cues might an inexp. surgeon miss in this situation?	J: that whitish inflammatory sub-cirrhosal induration is the most important when you're dealing with an infectious process. J: It's more white than fat, which is yellow. And it feels more like cottage cheese than jello, which should tell you it's not fat.		

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(23.2)

CUE CODES:
HC - hypothetical
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VC/A: visual cue derived from action taken
Q: interview question
TC: tactile cue

ACTION CODES:
C: change entire situation or approach
V: to get visual info.
T: to get tactile info.
ST: to stay within field of safe travel
D: do experiment to diagnose
O: operate, move procedure along
NO: would NOT take action which is shown
SA: to improve SA
LA: to prevent/head off later problems
I: avoid injury now

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
D. Drain-ing				constr/equip: I wish they'd make...a larger needle, these small ones take a long time to suck up fluid, which is thick
				constr/equip: this person is using the grasper I use, big heavy one for thickened wall
	V: underneath here, viscera seem like they're more in the way than they ought to be		V: some more 'head up' would help viscera fall away in this pt., might see better	
E. Init Diss		D: what the heck are they doing? (ans: they skipped ahead to where they're dissecting)		
		D: I'm really kinda confused here, I don't know quite exactly what they have a hold of. ..I can't really see.	ST: I usually work my way down from the fundus to the infundi-bulum	meta3: there's a possibility in my mind that they've got the common duct in their grasper. I think there's a really good chance, because I think this up here is where... we'll see where they get in the next minute or so.
			C: But I might be willing to kind of give up here.	

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
E. Init. Diss., cont.	Q: why? ANS: Because there's a lot of blood here	D: I must really not able to tell what is here. That may just be some fat...but I'm just a little confused, and it's not becoming immediately obvious.. J: they haven't done anything here yet that I think they're going to regret, but...		
		D: I'm still just a little concerned, this is real friable, real bloody, I just don't know how good my visualization is going to be.		constr/team: the camera person is monkeying around, I find myself trying to see up along there.
F. lymph cut		J: okay, I'm happy with that. That really does kinda look like the cystic duct that person's exposed, so, it's hard to say yet.	T: I'd probably come over and do this myself now	constr/tissue: part of this, the dissection, is being able to feel what the tissue feels like as you're going along.
		D: because I'd be a little concerned.		
	Q: what told you that you should take over? ans: all the blood and mush here, and...			constr/tissue: some of this dissection needs to be done by feel, and if I'm the one that's ultimately responsible for this, I would want to feel it.
		D: I'm not sure what they just put clips in, could be cystic art., cystic duct, could be a piece of schmiel. I can't see if it had a lumen, or if it's just connective tissue	V/ST: if I were doing this, I would be working more towards the front of the GB, up that way. I think it's easier finding the cystic duct from that direction, and the structures become a little more obvious as to exactly what they are.	

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
f. lymph-cut, cont.		D: I'd have motion sickness, this is making me sick		
		J: I think that's cystic artery they're starting to dissect up there		
g. Gall-bladder opens		D: The visualization's really bad, I don't know if they can pull any harder on the GB. The viscera & omentum are kind of clumped up and in the way	C: anywhere along the line here, it's really hard for me to tell you what's going to make me decide to do this, but somewhere along here I might just decide to **open** this person.	meta4: it would depend on if I feel like I'm able to make progress, able to identify some structures as I go along with some confidence that that's what they are then I might continue for a little while yet.
h. Artery dissec-tion		J: I think that big thing is the cystic artery, I'm fairly comfortable with that.		
		D: The duct is where you could get yourself in trouble, and I'm a little concerned about that situation now, esp. now that they've opened the GB and I know that there's bile all around it.		
		D: that's one signal to me that I'm in trouble w/the CBD, et cetera, is that there's bile in there.		constr/disease: once bile spills, can't use the presence of bile as an indicator that the CBD has been injured any more
	VC: there's something I didn't see before, inflammation that's on the GB wall where the GB's been stuck	J: Bad scissors, they just took a lot of chopping to get through. I don't like that, pushing around stuff like that.	ST: I would tell him to cut it out.	

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
I. Last Diss.	VC: there's some blood I wouldn't expect to be there right now	D: I'm concerned they might be dissecting into a portal vein	NO: I don't know why they're working back there, not accomplishing anything.	
		J: Once you've defined where everything is, then you can go back, they're still trying to figure out where the cystic & common duct are. Until you find that, you don't need to do that.	NO/ST: and I don't like that pulling up technique. I was always taught doing open GBs you should always push toward the middle as opposed to pulling back toward the GB. Should put the traction on the GB, which is coming out anyway.	
		D: I'm a little confused, and I think this person is too. They're pulling on this piece of tissue, it's like they're saying, "where does this go?" And I'm not so sure either, so that's why I think they're confused. I also thought I saw cystic duct a few minutes ago, and now I'm not so sure where it is again		
J. DP3	Q: Can you summarize, what's going on here now?			meta1: I'm not comfortable with this dissection. I'm not sure if I could feel it myself, if that would make a difference as to whether I'm going to open, but I'm still not comfortable at all with how this is going.
	Q: Do you think you would have opened back where you said you might?	D: It's hard to say. In a younger, healthier person I might spend a little extra time (cont. on next page)	C: I might just go ahead and open.	constr/age: opening depends on age here.

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J. DP3, cont.		trying to do this lap., as opposed to somebody that's older and had a few extra health problems and didn't need the additional anesthesia.		
	Q: Are there any alternative interpretations you could have of the situation?	D: at this point in the case, I want to know definitively where everything is, and I don't. So I wouldn't be hard on myself right now if I said, let's just open, let's get out of here.	C: Probably in this 80-year old I might just be opening.	meta4: But I also think, I've gotten this far, maybe I'll just take a few more minutes and I'll be able to successfully do this laparoscopically, maybe just a little more dissection and everything will become crystal clear.
	Q: are there other concerns you have?			constr/patient & team: Obviously the patient, how they're doing, how they're tolerating the anesthetic, how everyone else in the room is doing, because if I start getting frazzled, then so does everyone else in the room, and they tend to not respond as quickly or efficiently as they might otherwise.
	Q: the other surgeons & nurses?			constr/team (more): more the scrub nurse, if I'm asking for a bunch of things they don't have in the room and they have to scramble around, or the scrub, if they're doing the camera, they can't do the handing of the instruments and operate the camera well at the same time. So that's something I'll take into consideration in deciding what I'll do next.

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
J. DP3, cont.	Q: what errors would an inexp. surgeon be likely to make?			meta4 : to think that they've definitively identified the structures there and then clip and cut before they've really done that. And I think that's the biggest problem.
	Q: Is there a tendency to do that with inexperience?			meta 1&5: I think it's more of a personality type in that situation, some people who feel real comfortable, and there are those kinds, who would dive in no matter what, would start putting the clips on. I think most people, as least those that I've worked with regularly, if they're less experienced they're more likely to sit there and look at it for a long time, for fear of making a mistake. For the first kind there is a tendency towards overconfidence.
	Q: are there cues a less experienced surgeon might not pick up on?	D: I don't know what cues there are here, it all looks like mush to me. My cue here is that we're still in trouble, we have the potential to get in trouble.		
	Q: What is your comfort level, on the scale of 1 to 7?	J: 6, I'm very seriously converting.		
	Q: what are your current objectives?		O/V: I would continue to dissect in the area where they're working right now, to be able to identify with certainty both the cystic and the common duct. If I could do that, then I would proceed.	meta4: I would probably give myself a time limit, because we're talking about how much anesthetic, so I'd give myself another 5 or 10 minutes, and if it didn't become immediately obvious, I'd open.

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(23.7)

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
d. drain-ing		J: I think this is rather routine, emptying the GB, takes about 3 or 4 minutes, it's well-done.		
	VC/A: It's getting softer, that's good.		NO: I don't think I'd put those clips in there, they don't work anyway.	
e. init diss				metaa5: This is the pandora's box, this is the critical stage, this is where judgment plays an important part.
		D: he's already got a tear on the edge of the GB, by the clamps, it's not anybody's fault, it's just the way this kind of GB is, and it's a question of whether he's going to be able to see, and it's becoming worse.		
f. first struc-ture diss.		J: He's cleaning the GB very good, it's well-done, small bites. D: at this point, I really don't believe that that's been cleaned off well enough to satisfy me.		meta1: At this point my comfort level is going to decrease and my anxiety's going to be up, because of the state of the tissue. meta3: Clip is being placed on what appears to be a duct, or a blood vessel, I think this move, to me, is relatively dangerous now.

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
f. first struc-ture diss., cont.		D: If truly that was the duct, it was not cleaned off enough for me.	LA: I would put two clips on the lower end, because once one of those clips falls off, you're never going to get it through, and I don't think he cut it right there.	equip constr: I'm sure that I would not be able to operate under the resolution that we're working on at this time.
	Q: What makes you think that this person did not cut a duct?	J: It's just too, too easily cut, it was a band of fat or tissue, I didn't see a lumen when I came out, I didn't see any bile, I don't think he cut the duct. D: Now I think this is a dangerous move,		meta5: one of the things I constantly tell a resident is that a GOOD SURGEON BELIEVES WHAT HE SEES, AND A BAD SURGEON SEES WHAT HE BELIEVES
		D: I think the duct is lower on this case, It wasn't cleaned off, I think he's got a problem now.	V: this area is going to have to be pulled down farther to expose it.	meta1: I would be a little concerned at this point.
g. GB opens		J: If you're going to attempt a lap chole on this kind of case, you're going to get into the GB. Would probably get into the GB even on an open cholecystect.		meta4: The problem I see now is that you have a messy, crummy looking tissue hanging down on one side, you have bleeding, you have clips sitting in somewhere, we're not even sure where they are, and you're starting to lose your orientation now

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
h. artery dissec-tion		J: I think he's working 2 to 3 centimeters higher than he should be,..		meta3: he obviously is concerned that he would hit the common duct; next move critical because you could could get into the wall of the GB
		D: He's just kind of fighting around the GB, trying to find out, where am I. Tearing away probably the wall of the GB.		meta4: It's pretty clear now that he's lost. He's just kind of fighting around the GB, trying to find out, where am I.
		D: Now he's got some other duct that is going to be clipped.		meta3: And this is where it gets dangerous, because I don't think he has any idea where he is. I can't see. If that's the only vision he's got of that clip.
		D: He put two clips on the lower side, as you notice. That lower ((inaud)) he doesn't know where he is. Doesn't know what he clipped.		meta1: I'm not so sure I would myself give up on the operation, but if his anxiety levels aren't pretty high now he shouldn't be out there. He's up to his neck in crocodiles.
	Q: What makes you say that he doesn't know where he is?	D: Because he's unpurposeful with his movements, and he's got a hole in the GB on the right that is well up on the GB, and he's working on the left side of the GB at that same level, and he should be much further down, and I just get the feeling that he does NOT know where he is.		

Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
h. artery dissec-tion, cont.		J: If you look at the last structure he clipped, it looks like it's pulsating, it's probably the artery. You can see it's very definitely the artery now because you can see the pulsation. D: Still haven't identified the cystic duct		
i. last struc-ture dissec-tion		J: The duct is probably behind where he is now. D: So that was the clip that he put in earlier, and it just fell out.		meta1: He's missing the most important structure now, I think he's probably concerned.
	VC: That duct may be coming into view here. (.) You can see the tissue juices rolling down in his field, on his vision.	D: Looks like he's got several bands of tissue, like he's lost again.		meta3: common bile duct may be tented up which could wreak havoc because it or the GB might be cut
j. DP3	Q: Could you tell me what you think is going on here?	D: I think he's lost the cystic duct somewhere, he may have already cut it, ahh, he doesn't have it. I thought his attack on the artery was too quick.		meta4: I think now he's floundering, trying to find out where he is. And trying to find that duct. I think he realizes that you can't see with these cases
			SA: If I were teaching, I would probably take over the case from the resident, I have to be there.	meta1: My anxiety levels are up now.

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
j. DP3, cont.		D: I think the tissue doesn't look like the common duct or the cystic duct to me.	D/SA: I probably would next divide this structure, clean it up, and if it does not look like a duct then I think there's NO QUESTION the case must be opened.	
	Q: To identify?	J: Identify. You've lost the game here, you've given it the hearty try, go ahead.	C/LA: I would probably at this point tell the nurses to start opening the packs.	
	Q: Are there other alternative interpretations that you could make about what you see?			meta4: Oh sure, I could make a lot of them, if you're not htere. My interpretations are always the worst, because the worst would be ready to best preserve the patient.
	Q: Are there any other concerns , besides not identifying the structures?	J: No, ahh, The spillage of bile, we expected that, you're going to have that with a closed Gallbladder like this.		
	Q: What errors might an inexperienced surgeon make in this situation?	J: A BIG one is to assume the duct is cut. J: I do not think under any circumstances you can leave a lap. GB without identifying the cystic duct and being totally convinced that you have seen it. That'd be a terrible error, but it happens.		meta4: Again, he sees what he believes, believes it's cut, therefore he sees that, and says okay, I've already cut it, and remove the GB, and just leave everything alone and not identify it.

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Time Code	Cue Type	Judgment/ Doubts	Action Code	Meta or Constraints
j. DP3, cont.	Q: can you give me a rating, from 1 to 7, of your comfort level with continuing laparoscopic-ally?	J: 6 to 7 now.		
	Q: So if I told you that the surgeon decided to open at this point, you'd think that was a reason-able approach?	J: Very reasonable approach. Failure to open too soon is the biggest disaster in this operation.		