TRAINING CRITICAL THINKING FOR THE BATTLEFIELD

VOLUME I: BASIS IN COGNITIVE THEORY AND RESEARCH

by

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13. ABSTRACT (Maximum 200 words):

The three volumes of this report describe research findings on three closely related fronts: (1) Development of a theory of the cognitive skills that individuals need to make effective decisions in fast-paced and uncertain environments; (2) development and testing of methods for training critical thinking skills on the battlefield; and (3) development of an advanced system architecture to support adaptive instruction and feedback in critical thinking training.

Theory development focused on mental models and critical thinking about mental models in a team context, where initiative might be necessary. Training addressed mental models and critical thinking on three major themes: purpose, time, and maneuver. The training was utilized and successfully tested in an advanced tactics course at the Command and General Staff College. Finally, algorithms were developed to simulate both rapid recognitional responding and more reflective reasoning when time is available.

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TRAINING CRITICAL THINKING FOR THE BATTLEFIELD

EXECUTIVE SUMMARY

Research Requirement:

Instructors at Army schools and officers in the field agree that current Army education and training do not adequately address decision making skills. What is lacking is a system of training that combines advanced instruction in flexible thought processes (going well beyond doctrinal publications), immediate relevance to Army applications, opportunity for practice in realistic scenarios, and detailed, individualized feedback (not available in current simulators) – and that accomplishes all this despite severe limits of costs, and time and availability of both instructors and students.

The present research had three main objectives:

(1) Develop and extend a theory of the cognitive skills that individuals need to function effectively in fast-paced and uncertain domains.

(2) Develop methods for training those skills in the context of Army battlefield decision making. Improve the ability of Army tactical staff officers to grasp the essential elements of a complex, uncertain, and dynamic situation, visualize those elements in terms of their organization's goals, and take action in a timely and decisive manner.

Test the effectiveness of the training. Does the training improve critical thinking skills? Does it improve the quality of decisions?

(3) Develop a system architecture to support adaptive instruction and feedback in critical thinking training. The architecture should be able to simulate both rapid responses to familiar situations and more reflective responses to novel and uncertain situations.

The training method, like the theory of cognitive skill it is based on, should be readily applicable to a wide spectrum of domains where individuals work in uncertain and dynamic organizational contexts.

Procedure:

Work proceeded on three parallel and closely related tracks: (1) cognitive theory and research, (2) critical thinking training and training evaluation, and (3) advanced modeling and simulation of critical thinking A separate volume of this report addresses the methods and findings of each of these tracks.

In the first track, previous theoretical work was extended in several ways to meet the needs of critical thinking training development: A review and analysis of existing literature on uncertainty handling, additional analysis of interviews with Army staff

officers, and extension of a theory of critical thinking to support algorithm development and to address initiative in teams.

In the second track, we developed and evaluated critical thinking training. We laid the groundwork for training development, by surveying Army training needs and identifying relevant skills for training. We then developed training content and incorporated it into a training delivery system. The training was evaluated in two stages, at Army posts around the country and in a class on advanced tactics at the Army Command and General Staff College, Leavenworth, KS.

In the third track, we developed a computer architecture and algorithms to simulate human critical thinking. These algorithms can serve as the basis for adaptive feedback in future training development.

Findings:

The project introduced innovative statistical methods for discovering the cognitive structure and thinking strategies utilized by decision makers, and employed these methods to analyze several dozen interviews with active-duty Army officers. The Recognition-Metacognition model of critical thinking was extended to address mental models and critical thinking in a team context in which initiative may be required.

A training package was developed with approximately 500 screens. The training addresses three major battlefield thinking themes (purpose, time, and maneuver) and looks at both mental models and critical thinking for each – making a total of six major modules. The training utilizes conceptual instruction, practice in exercises, and historical examples. Graphical interactive techniques were developed to train officers to use both the knowledge structures and decision making strategies characteristic of more experienced decision makers. The training was incorporated into a delivery system that is accessible either through CD-ROM or over the World Wide Web, and is suitable for classroom instruction, training in the field, or distance learning.

The training was tested with active-duty officers in Army posts around the country and at the Command and General Staff College. A very short period of training has been consistently found to significantly affect on both (1) variables related to critical thinking processes and (2) participants' decisions in a military scenario. With respect to critical thinking processes, training increased the frequency with which participants used both proactive tactics and contingency planning, and the frequency with which they referred to the higher-level purposes of the mission. The effect on decisions was dramatic. Participants significantly increased their use of three key tactical elements after training, and also increased their use of combinations of those tactical elements to counterbalance problems with the individual elements.

An advanced computer architecture was designed and partially implemented to support adaptive feedback in critical thinking training. The architecture consists of two interacting components: a reflexive subsystem, which simulates rapid recognition and retrieval of appropriate responses in familiar situations, and a reflective subsystem, which identifies critical uncertainties in the reflexive system and implements strategies for resolving them.

Utilization of Findings:

This project represents an unusually high degree of success both in terms of original research, successful practical application, and commercial potential. The project introduces, develops in detail, and tests a variety of methods for improving decision making skills (i.e., the derivation of training objectives from expert decision processes, a theory of those processes, research techniques for developing training content by modeling expert mental models and decision processes, graphical interactive techniques for conveying this type of content, flexible computer and web-based media, and highly adaptive feedback and guidance. The project addresses immediate Army needs for effective and economical methods for improving the battlefield decision making skills of officers at every level of command, in the schools, in the field, and at home. Its products are already being put to use by instructors in advanced courses at the Command and General Staff College. The training methods have demonstrated enormous commercial potential in a large number of fields, including business, medicine, and aviation. The underlying mental model and decision making technology has even wider potential, for web-based intelligent information retrieval and evaluation.

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CHAPTER 1
INTRODUCTION

The Persistence of Uncertainty

A U.S. military handbook published in 1939 states, “The art of war has no traffic with rules, for the infinitely varying circumstances and conditions of combat never produce exactly the same situation twice.” Though perhaps slightly exaggerated, this precept sounds a useful warning, at least in the short and middle terms (and probably much longer), against the persistent dream of achieving “near-perfect knowledge and information of the battlefield” (Ullman & Wade, 1996, p. 9).

Uncertainty in military operations has many causes, not simply the “fog and friction” of combat described by Clausewitz, or deliberate enemy deception, but also novel missions and mission environments, on the one hand, and the unexpected effects of new technology, on the other. Recent military missions have involved operations other than war, joint and multinational regional theaters, and littoral operations. U.S. military personnel have had to navigate between competing and sometimes inconsistent diplomatic, civil, and military objectives in ill-defined missions, and to work within unclear or highly restrictive rules of engagement. “Situation assessment” in such missions means keeping track of blurred and shifting distinctions between friend and foe, guessing the ambiguous intent of armed “bystanders,” and ferreting out guerilla fighters in urban or mountainous terrain. In these missions, military personnel have had to overcome communication difficulties and cultural clashes, work with both unstable governments and dissident groups, and to undertake many traditionally non-military tasks, such a police work. Coordinating among own troops, allies, and assisted populations is often more of a challenge than dealing with the “enemy.”

Another driver of uncertainty is the expansion of the battlespace through increases in both force dispersal and operational tempo. The last century saw the introduction of motorized, armored, airborne, undersea, unmanned, and space-based platforms. These developments could not have occurred without parallel improvements in sensor and communication technologies. Yet information technology has not fully offset the effects of increasing dispersal and independent action. There is an inescapable tradeoff between amount of information collected and transmitted versus the time it takes for the appropriate human operator to receive it, comprehend it, and react. The unintended consequence has been increasing uncertainty, if not about the enemy, then about the status and even the intent of one’s own forces. New high-bandwidth communication technologies (such as the Force XXI Battle Command, Brigade and Below Program) will almost certainly continue this trend, by passing more initiative and decision-making responsibility further down the levels of command.

New technology and new ways of operating have also increased uncertainty in the business world. In the internet economy, the cost of producing an additional copy of an information product is miniscule, and potential customers are overwhelmed by information options. The result is fierce competition for customers’ attention, leading to drastic price cutting or free distribution. These investments will pay off in future profits only if a stable base of customers can be created, but such a base is constantly threatened by the possible entry of new competitors and rapidly evolving new technologies.

Technology-based businesses must choose between reliance on open standards to attract a base of customers and to increase the overall size of the market, and development of proprietary products to lock customers in and retain control. Technologies that were intended to increase the accuracy and timeliness of information have shaped a business environment in which uncertainty has increased dramatically.

In the Army as well as business there is a need for training that supports the human's ability to handle uncertainty under time stress. Despite this need, instructors at Army schools and officers in the field agree that current Army education and training do not adequately address decision making skills. What is lacking is a system of training that combines advanced instruction in flexible thought processes (going well beyond doctrinal publications), immediate relevance of the training to Army applications, opportunity for practicing skills in realistic scenarios, and detailed, individualized feedback (which is not available in current simulators). Moreover, all this must be accomplished despite severe limits of costs, and time and availability of both instructors and students.

The present research had three main objectives:

(1) Develop and extend a theory of the cognitive skills that individuals need to function effectively in fast-paced and uncertain domains.

(2) Develop methods for training those skills in the context of Army battlefield decision making. Improve the ability of Army tactical staff officers to grasp the essential elements of a complex, uncertain, and dynamic situation, visualize those elements in terms of their organization's goals, and take action in a timely and decisive manner.

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The training method, like the theory of cognitive skill it is based on, should be readily applied in a wide spectrum of domains where individuals work in uncertain and dynamic organizational contexts.

Overview of the Report

This report is divided into three volumes, corresponding to the objectives described in the last section:

Volume I	Basis in Cognitive Theory and Research
Volume II	Critical Thinking Training Training Evaluation
Volume III	Advanced Simulation System for Training

In this introduction, we briefly describe each part of the report. For convenience, the introduction is repeated at the beginning of each volume.

Volume I: Basis in Cognitive Theory and Research

CTI's critical thinking training has several key features:

(1) Unlike many other approaches, it is not based exclusively on formal models of how people ought to think, but on observed differences in decision making strategies between more and less experienced decision makers.

(2) Instruction does not present a set of abstract, disembodied thinking strategies, but trains the targeted skills in a concrete way, embedded within the specific decision making domain.

(3) Training does not simply focus on the individual, but includes an emphasis on decision making within a group context, in which communication is often imperfect or impossible.

In Volume I, we trace the theoretical and research background for the development of such a critical thinking training strategy. Chapter 2 contrasts different views on decision making strategies and strategy selection. Recommendations for handling uncertainty have been dominated until recently by general purpose rules derived from the formal axioms of decision theory. From this point of view, researchers have tended to interpret actual human performance in terms of biases, or systematic deviations from decision theory's formal constraints. In the past 15 years, however, a critical mass of empirical and theoretical work has accumulated that focuses more directly on the knowledge and skill that experienced decision makers apply in real-world tasks, and on strategies that enable them to exploit that knowledge (Cohen, 1993). Chapter 2 traces some of the research threads that have contributed to this development, and which have influenced the present work.

Chapters 3, 4, and 5 describe the way that we have extended that research background in order to build a foundation for the present training. CTI has collected empirical data over several previous research projects that examined decision making in both Army and Navy battlefield environments (Cohen, Adelman, Tolcott, Bresnick, & Marvin, 1993; Cohen, Thompson, Adelman, Bresnick, Tolcott, & Freeman, 1995; Cohen, Freeman, & Wolf, 1996; Cohen, Freeman, & Thompson, 1998). In the Army, we interviewed nearly a hundred officers prior to the present project, occupying a variety of positions and ranks and possessing varying amounts of experience. The present report examines these data from a new point of view, focusing on insights that pertain specifically to *initiative* in a *team* context. This approach was well-suited to an opportunity to develop training for an advanced tactics course at the Army Command and General Staff College entitled *Initiative-based fighting* (developed by LTC Billy Hadfield).

Chapter 3 describes an innovative methodology for identifying knowledge structures, or mental models, from critical incident interview protocols. The methods categorizes judgments or decisions and then analyzes the correlations among the categories across incidents. Mental models are defined as co-occurring categories of information. The influence of other variables, such as level of experience, terrain, and unit type, on the use of these mental models can then be examined. This chapter emphasizes the use of mental models pertaining to *organizational purpose*; the *intent* not just of the enemy but of others in the same organization; *initiative* as an orientation of action to time; and team member *reliability*.

Chapter 4 describes a model of the cognitive strategies that tend to distinguish more effective from less effective officers in battlefield situations (Cohen et al., 1993; Cohen, Freeman, & Thompson, 1998). The model is based on the combination of rapid recognition of familiar situations together with the ability to think critically about the results of recognitional processes. Critical thinking, from this point of view, is not the use of abstract formal rules of thought, but is pragmatic and time-constrained reflection on the uncertainty in the immediate situation and plan. Critical thinking strategies include the identification of qualitatively different types of uncertainty (i.e., incompleteness, conflict, and unreliable assumptions), and the use of different uncertainty handling responses for each. Although the underlying principles of critical thinking are general across domains, the skills themselves are best-acquired in a specific application context, building on previously acquired domain knowledge of the decision makers.

Chapter 5 uses a (newly analyzed) military incident to illustrate how the theory applies to real-world decision making in a team context. The example emphasizes the ability to *think critically* about mental models in situations that require balancing the benefits against the risks of taking initiative. Critical thinking is not just an individual decision making skill. When exercised by a *team leader* and/or *team-members*, it can profoundly alter group dynamics and have important organizational implication.

<u>Volume II: Critical Thinking Training and Training Evaluation</u>

Volume II describes the transition from theory and research to the development of a training strategy (Chapter 6) and training content (Chapter 7), and the incorporation of that content into a computer-based training system (Chapter 8). It then describes the results of two empirical tests of the training system (Chapters 9 and 10).

Chapter 6 reports the results of a survey of Army training needs, and lays out the critical thinking skills to be targeted by the training based on the data, cognitive theory, and student needs survey. It lays out a training strategy based on this analysis, including such methods as instruction, practice, and feedback. Finally, it outlines the theoretical rationale for the training strategy, and contrasts it with training based on other conceptualizations of decision making skill.

Chapter 7 summarizes the training content itself. The training addresses both mental models and critical thinking about three major battlefield themes: purpose, time, and maneuver. It includes six major segments:

(i) mental models to represent the *purposes* of superordinate, subordinate, and coordinate units in an organization

(ii) critical thinking about organizational *purpose*,

(iii) use of action schemas called *time stances* to achieve the proper balance of initiative in achieving those purposes,

(iv) critical thinking about *time stances*,

(v) mental models used in *maneuver warfare*

(vi) critical thinking about *maneuver warfare*.

Chapter 8 describes an integration technology for incorporating the training content within a distributed learning environment. This technology permits distributed sharing of training system resources, interactive exercises, and collaborative, asynchronous learning. The chapter also describes an automated web-capable tutor that we used for testing and evaluation. The system, called *Training to Think Critically on the Battlefield*, can be distributed on compact disc for use on a personal computer or can be accessed over the World Wide Web. It can be used by instructors in the classroom, can be assigned as homework, and can support distance learning and learning in the field. In addition, we developed an authoring tool that permits the construction of new training sequences and interactive exercises, and developed a more advanced prototype system that provides adaptive feedback to trainees regarding critical thinking strategies.

The bottom line question regarding the training is, does it work? Does it improve critical thinking processes as intended, and do such improvements result in enhanced decision making? Training concepts were tested informally with active-duty Army officers at several different Posts, and at a variety of levels of rank and experience, on a continuous basis throughout the development process. Findings from these tests guided training development in an iterative fashion. A more formal test of the training was conducted with over 50 students of an advanced tactics course at the Army's Command and General Staff College. In both cases, training was delivered by computer running software from a CD-ROM.

Interim evaluation results are summarized in Chapter 9. Participants developed courses of action for a combat scenario prior to receiving training, and then revisited the scenario at several points during the training. Exposure to the training helped participants identify and fill information gaps in their plan, expose and evaluate hidden assumptions, and in many cases change their course of action.

Chapter 10 describes experimental tests of the training system with students at the Center of Army Tactics, Army Command and General Staff College. Training was associated with significantly more attention to higher-level purposes (e.g., regarding the larger spatial and temporal context of the unit's own mission), with a greater use of proactive tactics to achieve those higher-level purposes, with a greater ability to identify uncertain assumptions, and with a greater use of contingency plans or branches to handle those assumptions. Training also lead to significant changes in the courses of action that participants adopted. In sum, training influenced both critical thinking processes and the decisions to which they led.

<u>Volume III: Advanced Modeling and Simulation System for Training</u>

Volume III describes the development of an advanced computer architecture to simulate critical thinking performance and to support critical thinking training. The architecture has two interacting components:

(1) a reflexive subsystem, which simulates rapid recognition and retrieval of appropriate responses in familiar situations, and

(2) a reflective subsystem, which identifies critical uncertainties in the reflexive system and implements strategies for resolving them.

Chapter 11 provides an overview of how these two subsystems, working together, can provide the basis for adaptive instruction and feedback in critical thinking training.

The starting point of the reflexive subsystem was a system called *Shruti*, developed by Lokendra Shastri (Shastri & Ajjanagadde, 1993). Shruti combines speed, scalability, and representation of subtle but crucial relational aspects of real-world decision making. To accomplish this, Shruti utilizes rapid, parallel, neural processing, along with temporal synchrony for tracking the identities of objects and roles through relational inferences.

Chapter 12 describes Shruti and extensions of Shruti developed in this project. The extensions were necessary both to improve its representation of reflexive reasoning and to make it work in conjunction with the reflective subsystem. Among the extensions that we worked on were the following:

- integration of utility and belief so that Shruti can simulate decisions as well as inferences;
- mechanisms required for shifting attention, such as temporarily storing and integrating results through a series of attentional shifts; and
- implementation of supervised learning of link strengths through backpropagation.

Chapter 13 describes work performed in this project on a *reflective* subsystem, which critiques the conclusions of reflexive processing and guides its subsequent progress. Features of the reflective subsystem include:

- methods for identifying qualitatively different types of uncertainty based on activation patterns in the reflexive system;
- methods for identifying beliefs most likely to be responsible for different types of uncertainty;
- strategies for shifting attention to beliefs most likely to be responsible for uncertainty.

Uncertainty handling strategies include both domain-specific and more general methods for diagnosing possible causes of the uncertainty and the use of attention and assumptions to stimulate the activation of new information in long-term memory that might resolve the uncertainty.

For convenience, this Introduction is reproduced in all three volumes.

Guide for Readers

Happily, there are alternative paths through this report for readers who have specialized interests, or who wish to get the main points without all the detail. An abbreviated tour through the report that touches on the main areas might consist of the following:

Volume I		
	Chapter 4	Cognitive model of critical thinking that underlies the training design
	Chapter 5	A military decision making example to illustrate the cognitive model
Volume II		
	Chapter 7	Training Content
	Chapter 10	Evaluation of the training at Command and General Staff College
Volume III		
	Chapter 11	Overview of the advanced simulation model for support of adaptive feedback

Another way to break the report down into smaller chunks is by topic or by the reader's primary interest. For example:

Primary Interest	**Most Relevant Sections**
Army training	Chapter 5, to get a flavor of the research basis for the training from a concrete example Volume II
Cognitive Theory	Volume I Chapter 7, for application of the cognitive model to training Chapter 11, for a computational implementation of the cognitive model
Computational models of decision making	Chapter 4, for overview of the cognitive model Volume III

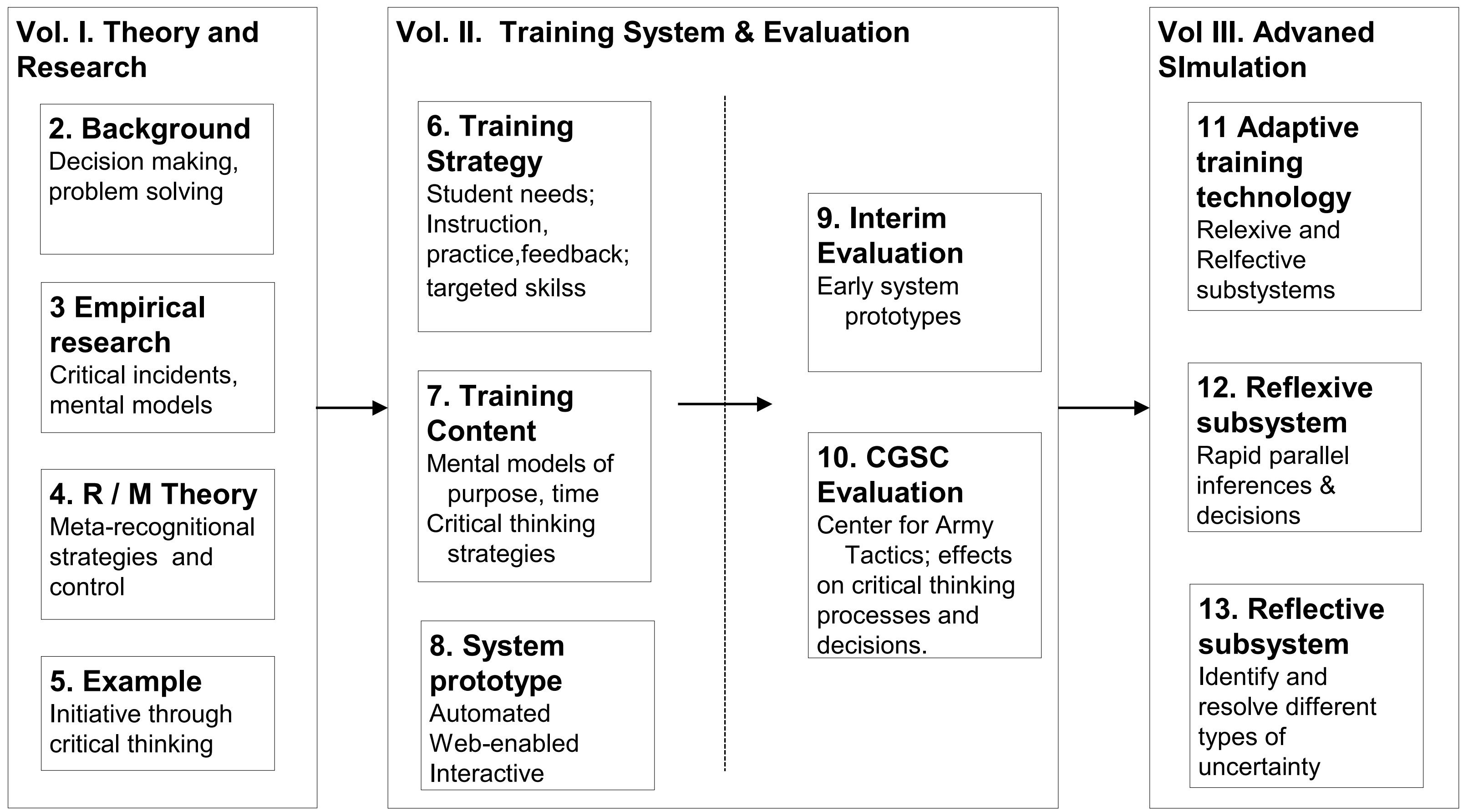

Figure 1. Structure of the report.

CHAPTER 2
DECISION MAKING AND CRITICAL THINKING

The purpose of this chapter is to briefly describe the theoretical and empirical background of our approach to human decision making and to training critical thinking skills. This discussion will provide a context for the cognitive model described in Chapters 3 and 4, as well as the training described in Chapter 7.

There are at present a variety of major competing conceptions of what decision making is. One way to classify them is in terms of whether their primary emphasis is on general-purpose strategies (i.e., weak methods), highly specialized routines or patterns (i.e., strong methods), intermediate strategies, or some combination that is contingent on the characteristics of the task, context, and decision maker. The most significant finding from the analysis reported below is the importance of medium level *strategies* for identifying and resolving different types of uncertainty. Of primary interest to us is the evolution of the notion of uncertainty-handling as a species of problem solving, the definition of a relatively small number of distinguishable strategies, and the specification of conditions under which they might be used.

Strategies: General, Specific, and Intermediate

General-Purpose Strategies: Decision Theory

The dominant framework for study of decision making for many years, classical decision theory, remains a towering intellectual achievement that exerts a strong influence on work in inference and choice. The theory contains two main parts: *Bayesian probability theory* for drawing inferences about any situation in any domain, and *multi-attribute utility theory* for selecting an optimal action in any domain. These can be regarded either as procedures that people explicitly follow or as descriptive constraints that apply to their behavior, but of which they may not be explicitly aware. Bayesian probability theory requires that decision makers consider a set of mutually exclusive and exhaustive hypotheses, each of which is assigned a probability. Each potential observation that might bear on those hypotheses is assigned a diagnostic strength. Then, as new observations occur, beliefs in the hypotheses are appropriately updated. Multi-attribute utility theory is an analogous method for choice. Choices are made based on a combination of the probability of each uncertain state, the importance of each evaluative dimension, and the score of each action-state combination on every evaluative dimension.

We (along with others) have argued that decision theory is not in general *cognitively compatible* with the way experienced decision makers work (Cohen, 1993; Cohen & Freeman, 1996). Problems include the kinds of inputs it demands, the kind of processing it prescribes, and the outputs it produces. (1) By demanding a complete model up front, with fixed assessments of uncertainty and preference, decision theory overlooks the dynamic evolution of problem understanding through time, e.g., as new hypotheses, options, observations, outcomes, and even goals are discovered. (2) By reducing all uncertainty to a single measure (probability), decision theory obscures important qualitative differences in the way different types of uncertainty are handled, such as gaps, conflict, and unreliable assumptions. Decision theory, for example, treats conflicting evidence the same way that it treats congruent evidence, by essentially taking an average.

Experienced decision makers, on the other hand, may use conflict as an opportunity for *problem solving*, i.e., to identify the faulty assumptions in the beliefs that produced the conflict (Cohen, 1986). Similarly, decision theory handles conflicting goals the same way it handles congruent goals, by calculating an overall score for each option that is an average of the different goals. Experienced decision makers, by contrast, may try to learn from the conflict, by creating a better option or a deeper understanding of their true objectives (Levi, 1986). (3) The output of a decision theoretic model is a statistical average – e.g., 70% chance hostile, 30% chance not hostile – rather than a single coherent picture of the situation. Decision makers cannot visualize, anticipate, or plan effectively for an abstract average. They often prefer to prepare against a specific, concrete possibility, while either accepting risk or hedging with respect to others.

Many researchers have claimed that under time stress, behavior no longer conforms to decision theoretic precepts. Janis (1972) attributes this to the irrationality induced by time stress, while others (Payne, Bettman, & Johnston, 1993) see it as a rational adjustment to the lack of time. As opposed to both of these positions, there is evidence that *even when time is available*, proficient decision makers do not typically use systematic methods, e.g., generating and considering a large number of options or outcomes (Cohen, 1993; Klein, 1993)

<u>Behavioral Decision Making: Heuristics and Biases</u>

Problems with the use of decision theory to describe behavior led to a counter-movement in cognitive psychology that focuses its attention on systematic deviations of performance from the constraints of decision theory, i.e., “biases” (e.g., Kahneman, Slovic, & Tversky, 1982). This work was, unfortunately, as limited in its own way as formal decision theory. (1) It focused on highly simplified questions, with no context, designed specifically to elicit errors. Such studies are not likely to be ecologically representative of the problems people deal with in real-world settings, or to shed much light on the processing strategies they use (Christensen-Szalanski, 1993). (2) In many cases, the experimenters assume one interpretation of the problem and define the normatively “correct” answer based on that interpretati0on, when it is not the only plausible one. If alternative interpretations are considered, the subjects’ responses often are seen to be reasonable rather than irrational (Smithson, 1989; L.J. Cohen, 1981; Cohen, 1993). (3) The processing theory adopted by Kahneman and Tversky focuses on “heuristics” that are defined and motivated by the way the behavior deviates from normative theory, rather than being integrated into a more systematic framework of human information processing. (4) Finally, the formal decision theoretic approach and its flip side, the heuristics and biases approach, share a common problem: They both regard decision theory as the final normative standard of decision making, though they differ regarding people’s ability to adhere to it. However, it can be argued that decision theoretic models, as they are typically applied, are not only descriptively inadequate, but normatively inadequate as well. Appropriate normative principles must capture the relevant *qualitative* features of the decision making process. If a normative standard is to be used to identify decision making errors, the standard must be close enough to actual performance for the discrepancies to be meaningful (Cohen, 1993). Other approaches, which define errors more naturalistically, may shed more light on the true strengths *and* weaknesses of decision making.

Specialized Strategies: Pattern Recognition

An altogether different approach to decision making skill looks toward an extremely large number of acquired rules. It identifies expertise in general, and decision making skill in particular, with the accumulation through experience of a set of virtually automatic responses to recognized patterns. On this view, people do not make "decisions"; they simply recognize the situation and retrieve the response that is "typical" for that situation (Klein, 1993). This view has been popular in research on differences between experts and novices, beginning with Chase and Simon's (1973) work on chess.

Although pattern recognition is a key ingredient in proficient performance, it may not be the only one. A problem with the pattern recognition model as the sole explanation for expertise is that it abandons the effort to identify strategies that are general across different domains, or that can recur in different contexts in the same domain. Instead it resigns us to the identification of literally thousands of highly specific, narrowly applicable rules or patterns. In particular, it offers no response to questions such as: How is situation assessment accomplished in new and changing circumstances? How are conflicting and unreliable data dealt with? How do decision makers change their minds? When do they stop thinking and act? The response to all such questions is merely a domain-dependent list of patterns and responses.

This limitation of pure pattern matching approaches is shared with what would seem to be the diametrically opposite approach: the identification of highly general *elementary information processes*, or atoms of computation. This approach, like pattern recognition, responds to questions about what a decision maker did with a list of processing operations. It requires different theoretical tools to create a level of description that might shed some light on consistencies in the ways that people deal with uncertainty.

Intermediate Strategies

Based in part on such findings, an intermediate position has been gathering momentum in recent years. Proficient decision makers appear to use informal thinking strategies (such as, *make predictions and test them*; *look for reasons against your own position*; *look for analogies to previous problems*) that are not as general as decision theory claims to be, but not as particular as domain-specific patterns. A variety of thinking strategies have been identified in studies of expert performance, as well as in reflections of practitioners. Such strategies have been found in studies of self-regulation or metacognition (Metcalfe & Shimamura, 1994), expertise (Ericsson & Smith, 1991), everyday reasoning (Voss, Perkins, & Segal, 1991), and decision making (Cohen, Freeman, & Wolf, 1996). Proposed metacognitive strategies include: self-monitor while memorizing material, and form a hypothesis and test in reading comprehension.

Baron (1994) identifies a *general form of critical thinking strategy*: (i) Propose a statement; (ii) think of a counterargument to the statement (e.g., think of a counterexample to a general statement; think of an alternative explanation in scientific theorizing); and (iii) modify the statement so the criticism no longer applies. Halpern (1998) presents a similar framework in the form of a sequence of questions: what is the goal, what is known, which skills will get you to the goal, and have you achieved the goal. A similar intermediate-to-general strategy form is described in Cohen et al.'s (1996) Recognition / Metacognition framework, where strategies are characterized in general as cycles of identifying and filling gaps, identifying and resolving conflicts, and finding and evaluating assumptions in arguments, while monitoring the relative costs and benefits of continuing.

Some strategies have turned out to be weaker than suggested. For example, *lengthy search* (i.e., generating as many alternative solutions as possible, as suggested by de Bono), is not correlated with superior outcomes. Moreover, some have argued (e.g., Perkins, 1995) that there may be too many strategies for decision maker to remember, consider, select, and apply. On the other hand, Ericsson (1996) notes that it requires 10 years to acquire the body of knowledge needed for proficiency in complex domains. He speculates that there may be several hundred different plausible strategies. It remains a challenge, however, to understand how decision makers *select* the appropriate strategy for a particular decision problem.

<u>Problem Solving Strategies</u>

An appealing way to understand the selection of strategies is to view decision making as a special case of problem solving. Strategies may be the result of decision makers' generating subgoals to deal with impasses during search for a solution in a problem space (e.g., Newel, 1990; Anderson, 1983).

Unfortunately, problem-solving researchers have thus far not explicitly addressed the central role of *uncertainty* and *risk* in decision making (Fischhoff & Johnson, 1990). None of the classes of strategies that are studied (e.g., breadth-first versus depth-first search, backward versus forward reasoning, subgoal generation) shed any *specific* light on the way decision makers deal with uncertainty. This has primarily been left to researchers in other areas (e.g., non-Bayesian inference theory), where work has been done, for example, on strategies reflecting epistemic caution versus epistemic risk in inference, or worst-case strategies in choice (e.g., Levi, 1986; Gardenfors & Sahlin, 1982). This work, however, has not been linked to mainstream work on problem solving.

Another issue concerns the tendency in problem solving work to treat the relation between weak and strong methods as mutually exclusive, with strong methods replacing weak ones with growing experience, through a process of *chunking* (Newell & Rosenbloom, 1981) or *compiling* (Anderson, 1982). Explicit declarative knowledge, which is used by general-purpose strategies, is supplanted by relatively automatic domain-specific recognitional procedures. One problem with this viewpoint is that much, and perhaps most, recognitional knowledge is acquired directly, e.g., through associative and/or reinforcement learning, rather than by compiling initially declarative information or instructions (Berry & Broadbent, 1987). Another difficulty is that recognitional and reflective processes appear to *interact with and enhance* one another (Cohen et al., 1998). Reflective skills build on a base of recognitional knowledge, and in turn help people add to and make better use of their recognitional knowledge. In fact, it is this interaction, we believe, that holds the key to understanding how humans deal with uncertainty. A full-scale problem solving approach has not yet been applied to decision making under uncertainty and stress.

Control over Strategies

Contingency Models

The problem solving approach can be seen as an instance of an even wider class of *contingency* models. Such models assert that strategies are selected based on properties of the task, the context, or the experience of the decision maker. For example, Klein (1993) argues that familiar situations are recognized quickly and the obvious response is implemented. In less familiar situations, on the other hand, another strategy prevails: The decision maker evaluates the most typical option by a process of mental simulation; if problems are found, the option is modified or rejected in favor of the next most typical reaction. Klein does not address issues of the cost of time required for mental simulation versus the potential benefits.

These issues are explicitly addressed by Payne, Bettman, and Johnson (1993), and Beach and Mitchell (1978). According to them, people adaptively adjust their decision making strategies in accordance with a cost-benefit balance between the demand for accuracy and the cost of being accurate. Payne et al., operationalized cost in terms of effort, defined as the number of elementary information operations required by a strategy. They picture the choice process as initially involving a set of "metacognitive productions that have as their actions the explicit (conscious) consideration of accuracy and error conditions…" Over time, these metacognitive processes become automatic, and are invoked directly by task features such as complexity, e.g., the number of options or the variance among probabilities and importance weights. These metacognitive choices can lead to the highly formal strategies dictated by normative models when accuracy is vital, or to highly approximate, abbreviated strategies, when time is more costly than errors. Unfortunately, as noted in Cohen (1993), this model does not tie either effort or accuracy to domain-specific knowledge, including recognitional patterns. It seems possible, for example, that experts might sometimes bypass the tradeoffs Payne et al, focus on: An immediate recognitional strategy could be *both* less costly *and* at least as accurate for an expert than more formal methods. Yet Payne et al.'s model does not permit this.

Hammond's cognitive continuum theory (1993) relates the choice of strategy type (in this case, *analytic* versus *intuitive*) to intrinsic properties of the task (e.g., redundancy and number of cues, continuous versus discrete distribution of cue values, linear versus nonlinear relation between cues and criterion, etc.) rather than personal familiarity or expertise (as in Klein's model). It might be possible, though Hammond does not do so, to formulate this model in terms of the Payne et al., framework as basing strategy selection on the relative effortfulness and likely accuracy of different strategies, as determined by the structure of the task stimuli.

A more long-range contingency hypothesis has been proposed by Holyoak (1991) in the area of expert problem solving. Holyoak argues that experts are not characterized by any specific processing strategy. For example, in some domains experts appear to use a recognitional strategy of working forward from the given to the goal (a strong method), while in other domains they use the more analytical strategy of working backwards from the goal to the given (regarded as a weak strategy). Experts adapt to the inherent constraints of the task, and perform it in whatever way is most efficient.

As we shall discuss shortly, Cohen et al. (1996) offer a model of contingent decision making which integrates features of the above models within a problem solving framework. In their Recognition / Metacognition model, the amount of time devoted to critical thinking about a recognitional response is a function of the familiarity of the situation (as in Klein's model), the amount and type of prior knowledge (as in Hammond's and Holyoak's approach), as well as the cost of errors and the cost of time (as in Payne et al.'s model).

The availability of alternative strategies, which are effective in different situations, implies an ability to choose either globally or locally. It seems plausible that persisting individual differences in the use of one or the other type of strategy might indicate differences in cognitive styles.

Cognitive Style

Another factor that may influence the choice of strategy is an individual's cognitive style. Cognitive styles are regarded by Baron (1994) as stable, general dispositions to behave a certain way in mental tasks, and as the most general level of decision making skill that is learnable. Baron identifies two style parameters: (1) The amount of search for goals, possibilities, and evidence relative to the optimum range of the search processes. This dimension corresponds to the impulsivity (too little time spent searching) and reflectivity (too much time spent searching). (2) Whether the person is equally fair to possibilities that are already weak and strong in the search for additional evidence and in the use of that evidence. This corresponds to open-mindedness or flexibility versus a tendency to premature closure (Langer, 1989). According to Baron, these styles are usually under voluntary control (although they can be influenced by stress and other affective states). These parameter settings are affected by values, expectation, and habits, as well as by emotions and beliefs about one's self. They are also subject to long-term modification by learning. As a result of relatively persistent styles, decision making behavior should be correlated across moderately discrepant situations, and the styles themselves should be teachable in general form. Baron speculates that styles rather than strategies may account for observed differences in use of thinking strategies and for transfer effects in strategy training.

Epistemic attitudes, described by King and Kitchener (1994) as fundamental beliefs about the nature of knowledge, can be regarded as a variant of cognitive style. involves a sequence of qualitatively different stages of cognitive development, characterized by. Each stage of development is characterized by a different, coherent system including assumptions about what kind of knowledge is possible and corresponding justification strategies, e.g., a pre-reflective stage in which knowledge is either certain or derived from unquestioned authority, followed by a quasi-reflective stage in which all opinions are questioned and considered relative, followed by a reflective stage in which opinions can be evaluated and accepted, and subjected to reevaluation if necessary.

Stress and Workload

Stress is another likely influence on the choice of strategies. One view of stress's impact on decision making is that it disrupts "rational, logical" thought: the careful generation and evaluation of alternatives characteristic of analytical thinking (e.g., Janis, 1972). As we have seen, however, there is evidence that even unstressed decision makers do not evaluate options in the way required by normative models. This view appears to be supported by recent research on stress effects.

Pennebaker (1987) cites evidence for several effects of stress, which he combines under the idea of a *reduced level of thinking*. Stress (i) narrows the breadth of perspective, both in terms of time horizon and considering divergent information; (ii) makes people less self-aware, less likely to *reflect* on the causes and effects of their own actions, and less able to *self-regulate*; and (iii) makes people less aware of their own emotions. High-level thinking, by contrast, involves a broad perspective, self-reflective thoughts, and reference to emotions and moods. Most of these effects of stress appear to involve the disruption of reflective, self-regulative abilities.

Driskell and Johnston (1998; Mandler, 1982) present evidence for a model of stress that involves reflective processes in self-reinforcing cycles, which consume ever increasing amounts of the decision maker's cognitive resources. Novel and unpredictable situations cause people to lower their judgments of their own self-efficacy. These negative self-evaluations then lead to autonomic symptoms of stress, which seize attention. The symptoms may then be “overinterpreted” as suggesting incapacity, leading to even more stress. At the same time, the situation itself makes direct demands on attention because of its unpredictability, reducing resources for performing the task, leading to still lower judgments of self-efficacy, and more stress. Finally, attempts to remove the source of stress, or maladaptive responses such as worrying and negative self-evaluations, can consume even more attention.

The effects of stress on decision making appear to be mediated in large degree through metacognition or reflective judgment. Entin (Entin & Serfaty, 1990) lists three typical causes of stress in a decision making context: overload, conflict, and uncontrollability. Uncontrollability refers to a reflective belief that one does not have control over events. Overload requires the perception that task difficulty outstrips ability, whether because time is too limited or because standards of success are too high. Conflict requires the perception that all one's goals cannot be achieved by available options, or that competing interpretations of a situation cannot be resolved by accessible knowledge.

On a more optimistic note, a variety of training methods can be effective in breaking these vicious cycles (e.g., Driskell & Salas, 1996). In addition, situations where decision makers experience moderate stress do not produce the pathologies described above, but lead to a reasonable adjustment to changes in *workload*. Decision makers have been observed by a number of researchers to adaptively adjust their workload under moderate stress. For example, Payne and his colleagues found that under time stress decision makers adopted more "attribute-based" information-search strategies: they tended to evaluate all options against the most important attribute first, then move on to the next most important attribute, and so on. They were thus assured of having some reasonably significant information about every option. Similarly, in an air defense identification-friend-or-foe context, Cohen, Adelman, Bresnick, Chinnis, and Laskey (1988) found that high target density led operators to examine fewer classification cues per contact, while continuing to examine all contacts. Several studies have observed that time stress causes selective focusing on negative attributes or worst-case outcomes of options (Leddo, Chinnis, Cohen, & Marvin, 1987; Wright, 1974), which might be construed as the most critical attributes in a time-stressed choice problem. In some studies, time stress has caused subjects to select options that conservatively hedge against different possible enemy actions rather than seize an opportunity, since time is not available to resolve the uncertainty (Leddo et al., 1987; Ben Zur & Breznitz, 1981). Entin (Entin & Serfaty 1990) observed that subjects under time stress became more likely to select information in the form of a predigested recommendations than in the form of raw data.

In sum, the effects of stress and workload on decision making may involve a reasonable metacognitive adjustment of strategies to adapt to the lack of time or task difficulty. In more severe cases, however, they may involve more pathological effects of diminished cognitive capacity, to which metacognitive self-evaluation also contributes, in this case negatively.

Expertise

In addition to cognitive style and stress, a major determinant of strategy selection is degree of experience or expertise. Studies of expert-novice differences suggest that expertise develops along two paths over time, one leading to better performance in *familiar* situations, the other leading to improved ability to handle *unusual* situations. A considerable body of research has focused on the first path: Experts accumulate a large repertoire of patterns and associated responses, which they use to recognize and deal quickly with familiar situations (Chase & Simon, 1973; Larkin, McDermott, Simon, & Simon, 1980; Klein, 1993). The difference between experts and novices, however, goes well beyond the quantity of patterns they draw on or the number of situations they regard as familiar.

A key hallmark of expertise is *goal-setting*, or intentional creation of novelty. In fields such as writing and historical or scientific research, for example, experts are more likely than novices to identify opportunities for original, productive work, establish their own goals, and create challenging tasks for themselves, which cannot be solved by pattern matching alone (Ericsson & Smith, 1991; Anzai, 1991; Holyoak, 1991). Novel ideas and strategies are also important in military and business environments.

When performing a challenging task, whether self-created or externally imposed, experts and novices differ in other ways that are not fully accounted for by pattern recognition. Scardamalia and Bereiter (1991) found that expert writers, compared to novice writers, discovered more problems with their own work and struggled longer to find solutions, revising both their goals and their methods more often than novices. Patel and Groen (1991) found that expert physicians spent more time *verifying* their diagnoses than did less experienced physicians. Physics experts are more likely than novices to verify the correctness of their method and result, and to actively change their representation of the problem until the solution becomes clear (Larkin, et al., 1980; Larkin, 1981; Chi, Glaser, & Rees, 1982). Expert programmers pay more attention to the goal structure of a task than novices, searching first for a global program design, while novices tend to be more "recognitional," plunging rapidly into a single solution (Adelson, 1984). In foreign policy problems, expert diplomats spent more time formulating their goals and representing the problem, while students primarily focused on the options

(Voss, Wolf, Lawrence, & Engle, 1991). VanLehn (1998) found that less successful physics learners were more likely to solve new problems by analogy with old problems (a recognitional strategy), while more successful learners used general methods for solving new problems, drawing on analogies only when they reached an *impasse* or wished to *verify* a step in their solution. Chi, Bassok, Lewis, Reimann, and Glaser (1987) found that better performing physics students were more likely to generate self-explanations and self-monitoring statements than poor students. Glaser (1996) identifies effective self-evaluation and self-regulation as key components in the acquisition of expertise.

Tactical battlefield problems tend to be viewed differently by experts and by novices. Novices often regard them as puzzles, which have "school book" solutions, while more experienced officers view them in a more challenging light, acknowledging the possibility that the enemy may not succumb so readily to a predictable course of action. Serfaty, MacMillan, Entin, and Entin (1997) compared experienced Army planners to novice planners, and found that the experienced planners did not appear to use recognitional strategies; that is, they did not did not generate an initial plan more rapidly (e.g., based on similarities with prior situations), tended to see the situation as more *complex*, and felt the need for more *time* to think about their plan than novices. Among the distinguishing features of experts that Shanteau (1992) identified in his research was the ability to handle adversity, to identify exceptions, and to adapt to changing conditions (Shanteau, 1992).

If expertise develops along two paths, what is the nature of the second, non-recognitional path? One view distinguishes it sharply from the first path: Experts define and deal with challenging problems by substituting formal analytical methods for pattern matching. This is the general approach urged by decision analysts (e.g., Watson & Buede, 1987), who define *normative* methods that require breaking novel problems down into components parts (e.g., options, outcomes, goals), assessing them quantitatively, then recombining them in order to calculate a recommended decision. The research reviewed above, however, suggests that this characterization of the second path is wrong. Formal methods are both too time-consuming, and too divorced from the knowledge experts have accumulated (Cohen, 1993). Dreyfus (1997) puts it well: "Usually when experts have to make such decisions they are in a situation in which they have already had a great deal of experience. The expert, however, is not able to react intuitively, either because the situation is in some way unusual or because of the great risk and responsibility involved… the experts draw on their context-based intuitive understanding, but check and refine it to deal with the problematic situation…"

Instead of dropping pattern recognition in novel situations, experienced decision makers learn to pause and *think critically about the results of recognition*. For example, according to Baker (1985), skilled readers exercise *meta-comprehension* skills, by continually looking for problems, such as inconsistencies or gaps, in the current state of their comprehension, and adopting appropriate corrective response, such as referring back to earlier parts of the text or relating the text to information already known. In both reading comprehension and in situation assessment more generally, decision makers ask, in effect: "What in this situation conflicts with my expectations? How can I stretch the pattern, i.e., tell a new story, to make the pattern fit? What assumptions must I accept to believe this story? What information is missing that would clarify the assumptions? How plausible is the story? What alternative patterns might apply? What story must I tell to make one of these other patterns fit, and what assumptions does it require? Which story is more plausible?" Reflective processes of this kind amplify the power and flexibility of recognitional processes without altogether throwing away their advantage in rapid access to knowledge. Moreover, critical thinking can make itself unnecessary the next time round. Decision makers sometimes handle novel situations by identifying regularities underlying exceptions to known patterns. Mental models embodying these newly discovered regularities provide patterns that can be recognized in later situations (Chi, Feltovich, & Glaser, 1981; McKeithen, Reitman, Rueter, & Hirtle, 1981; Adelson, 1984; Larkin et al., 1980; Thompson, Cohen, & Shastri, 1997).

Because their function is to monitor and regulate recognition, we call the reflective processes used in unusual situations *metarecognitional*.[1] and we call this framework the Recognition / Metacognition Model (Cohen, Freeman, & Wolf, 1996; Cohen, Freeman, & Thompson, 1998). The R / M model implies that the two paths along which expertise develops are intertwined. Reflection increases the power of recognition, but itself gains power as a base of recognitional knowledge is built. We will discuss it in more detail in Chapter 4.

It is reasonable to suppose that expertise in *teamwork* evolves with increasing experience in a domain along the same two paths as expertise in *taskwork* (McIntyre & Salas, 1995). Yet Orasanu and Salas (1993) note that "most current team training aims at developing habits for routine situations… Habit and implicit coordination will carry people a long way in routine situations; we need to prepare them for the unusual." In this report we will explore how the dual nature of expertise sheds light on the tension between initiative and coordination in teamwork, and provides a framework within which both initiative and coordination can be trained.

Teamwork Strategies: Coordination and Initiative

The concept of initiative plays a key role in the theory of critical thinking processes, in the real-world practice of critical thinking, and in critical thinking training. To see why, we can start by distinguishing two advantages that teamwork may provide over an individual acting alone, and then look at why each of these advantages may fail to materialize: (1) The first advantage is based on *bringing together complementary inputs*, and derives from the coordination of multiple hands, eyes, heads, etc. to accomplish a complex task. Increased effectiveness comes from sharing of both physical and cognitive workload and through specialization of knowledge and skills.

However, there is another side of the coin. Increasing the size of an organization tends to reduce its overall efficiency unless there is also an increase in departmentalization and standardization of tasks (Blau, 1970). The latter features reduce flexibility of response in a changing or novel environment (Donaldson, 1995). A related problem is *goal displacement*, in which specialized units lose sight of the larger

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[1] This name is by analogy to other so-called *metacognitive* skills, such as *meta-memory* (skills for monitoring and improving memory performance), *meta-attention* (skills for improving the control of attention), and *meta-comprehension* (skills for monitoring and improving the understanding of text). See Forrest-Pressley, MacKinnon, & Waller (1985); Metcalfe & Shimamura (1994); Nelson (1992).

organizational purpose, and pursue their own goals as if they were fixed ends rather than means, which should be reevaluated when conditions change (Scott, 1998).

(2) The second advantage of teamwork is based on *choosing from among substitutable alternatives*, and derives from the diversity of competing solutions to the same problem that different members of a team can generate. Better decisions result if there is an effective organizational mechanism for selecting from, averaging, or mixing these diverse ideas to arrive at a single decision (e.g., Kerr, MacCoun, & Kramer, 1996).

But there is another side to this coin as well. Groups may be affected by socialization biases, such as "groupthink," which induce conformity rather than diversity of thought (Janus, 1972; March, 1996.). For this reason, group decisions tend to be better when individuals think about the problem independently before arriving at a group judgment (Castellan, 1993; Sniezek & Henry, 1990).

Both dangers –slowness of response to change and lack of innovative thinking – can be addressed by organizational structures that emphasize *decentralization*: granting individuals or subteams the autonomy to make decisions in their own spheres (Burns & Stalker, 1962; Van Creveld, 1985). The degree of appropriate autonomy varies. Decentralization and initiative are adaptive responses to specific organizational environments, and are not everywhere appropriate. Interdependency among team tasks, on the one hand, heightens the importance of coordination (Thompson, 1967), whether it is achieved implicitly on the basis of stable, shared knowledge of tasks, procedures, and other team members (Cannon-Bowers, Salas, & Converse, 1993; Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Kleinman & Serfaty, 1989), by contingency planning that begins when unexpected possibilities first become apparent (Orasanu, 1993), or by mutual monitoring, feedback, back-up, and closed-loop communication as the tasks are carried out (McIntyre & Salas, 1995). On the other hand, when the task environment is rapidly changing and uncertain, and especially when individuals or teams are *spatially dispersed*, decentralization and initiative gain in importance. In some cases, outcomes may be better when individual team members bypass standard procedures, question the accepted beliefs or practices of the group, and act on their own responsibility.

This is a not uncommon predicament in combat: Company E's job is to guard Company F's flank while Company F secures a bridge that the division intends to cross. Now, however, Company F appears to be stalled in a major firefight some distance from the bridge. Company E cannot raise either Company F or higher headquarters on the radio (and it will take too long for runners to find them and return). Should Company E sit tight until Company F is ready to seize the bridge or until communications are reestablished? Should it go help Company F in the firefight, at the risk of getting bogged down itself? Or should Company E take over Company F's task and attempt to seize the bridge now – a risky choice, but possibly the only way to accomplish the higher-level purpose of supporting the division in a timely manner?

The combination of time stress, spatial separation, and uncertainty – along with varying degrees of task interdependency – can alter the nature of teamwork, overlaying a set of qualitatively different decision tasks on the traditional ones. For example:

- *Should we communicate?* When events unfold in an unanticipated manner (*uncertainty*), advance planning and shared task understanding may fail to bring about coordination. The obvious solution is to communicate in real time, as the unexpected events occur. Yet the *dynamic, time-stressed* character of the situation limits the time available for real-time communication. Moreover, *spatial separation* imposes a bandwidth limitation on communication, slowing it down drastically and exacerbating the impact of both uncertainty and time constraints.[2] The upshot is that real-time closed-loop communication can no longer be regarded as routine. When an unexpected, time-critical problem arises, team members or subteams must decide whether or not the potential benefits of communicating and/or waiting for a response are worth the delay.
- *What will other team members do?* In time-critical situations, subteams will sometimes be unable to communicate, or choose not to communicate, with one another. If their tasks are interdependent, however, the success of one will depend on coordination with the actions of another. In these cases, team members or subteams must make autonomous decisions that depend on plausible assumptions about concurrent decisions being made by other subteams in other locations. Shared task, team, and team member models may help support such predictions, but cannot be fully relied on in novel circumstances.
- *How good is the information?* Even when team members and subteams do decide to communicate, the combination of bandwidth and time constraints will prevent them from sharing information fully. Communications (e.g., reports, feedback, orders, or advice) from another subteam will have to be evaluated with incomplete understanding of the sources and assumptions behind them, and, conversely, with the benefit of other information that is available locally but not to the subteam that originated the message.

Evidence for the role of reflective processes is relatively pervasive in decision making contexts: in solving complex and novel problems; in electing strategies as a function of the task and situation; in generating stress and in abating stress; in the way individuals differ in the time they spend thinking about a problem, and in the strategies used by proficient or expert decision makers. We have also noted that there is comparable evidence for reflective, or metacognitive skills in other domains, which in some cases seem analogous to those exercised in decision making. Later in this report (Chapters 3, 4, and 5), we will describe an empirically based theory that addresses skills of this kind. We will argue that the skills underlying initiative involve *critical thinking about mental models* of the task and the team. We then describe a training strategy that is based on the theory and which focuses on the mental models and critical thinking skills that underlie decisions about initiative (Chapters 6 and 7). The value of such training should be quite

[2] In earlier historical periods, commanders could often see a large part, if not all, of the battlefield, and could both see and be seen by their subordinates. In this situation, the shared visual context provided a high-bandwidth channel of communication, which could be effectively supplemented by a few quick words and gestures. By contrast, the lethality and mobility of modern war has led to a high degree of dispersion, for which modern communications technologies, such as radio, and sensors do not fully compensate (Van Creveld, 1985).

general. Virtually every team is to some degree a *distributed* team. Even when team members are within plain sight and hearing of each other (e.g., in an emergency room, airline cockpit, or the combat information center of a cruiser), the high workload associated with uncertainty and time stress can be quite sufficient to limit the rate of communication (Kleinman & Serfaty, 1989) and make initiative essential.

CHAPTER 3
EMPIRICAL RESEARCH ON MENTAL MODELS UNDERLYING INITIATIVE

Initiative means taking "the first step, or the lead; the act of setting a process or chain of events in motion" (Brown, 1993). Extending this definition, we can define *degree of initiative* in terms of *when* in a chain of events someone intervenes and the amount of influence over the chain of events that person achieves: the earlier and more influential the intervention, the more initiative the person has shown with respect to that process. Interventions are often (though not always) targeted at the decision-action-outcome cycle of other agents. In business, for example, one may try to influence, predict, or react to the actions of competitors, customers, superiors, subordinates, or co-workers. In combat, one may try to influence, predict, or react to actions of the enemy, other friendly forces, superiors, or subordinates. In all these cases, greater initiative means that the decision-action-outcome cycle of other agents has been more thoroughly shaped in accordance with your own goals or purposes. The essential questions for training are: What must people know, and how must they think about what they know, to make appropriate decisions about initiative within an organization? What are the mental models and the critical thinking processes that underlie initiative?

Method and Findings

The following analysis is based on 25 critical incident interviews and problem-solving sessions with active duty Army officers serving on operations, planning, and intelligence staffs at a variety of organizational levels (battalion, brigade, division, and corps).[3] The goal of our analysis was to uncover cognitive structure beneath the surface descriptions of the incidents. (For more details on this analysis, but omitting the present emphasis on initiative, see Cohen et al., 1995.) We extracted structure in three successive stages, which the following three sections describe.

Identification of Concepts

We grouped judgments and decisions within the incident that occurred at the same time or in reference to the same event. We then classified these judgments and decisions by topic, using categories relevant to the domain, such as the higher level *purpose* of an operation, enemy or friendly *capabilities*, observation or analysis of *terrain*, enemy or friendly *intent*, enemy or friendly *action*, enemy or friendly *rate of movement*, *reliability* of an information source, and so on.

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[3] These data were collected under funding from the Army Research Institute, Contract No. DASW01-97-C-0038. A total of 33 interviews and problem-solving sessions were conducted with active duty officers. These officers were located at Fort Stewart, Hunter Army Airfield, Fort Leavenworth, Fort Ord, and Fort Riley. We evaluated the 33 sessions for appropriateness to the goals of the research. Ten of the interviews (those at Fort Riley) were rejected because the brevity of the interview period (about one hour) did not yield sufficiently rich material to permit inferences about mental models and thinking strategies. The 23 sessions that we utilized each involved a half-day interview. Five of these interviews involved officers who had held positions at the division level. Nine of the officers had held positions only as high as the brigade level. Seven of the officers had held positions only at the battalion level and two only at the regimental level. All individuals in the selected sessions served as G3's, Assistant G3's, XO's, or S3's, with the exception of one, who was a Fire Support Officer (FSO). Two of the participants described two incidents, yielding a total of 25 critical incidents or problem solving sessions.

Identification of Mental Models

We then identified clusters of such topics that tended to be associated with one another within and across incidents. For example, assessments of enemy intent were typically associated with assessments of relative force strength enemy, opportunities afforded by terrain, enemy doctrine or higher-level goals, and/or actual enemy actions. These correlated groups of concepts constitute a narrative, or *story*, about how certain aspects of a situation are expected to lead to certain decisions and certain kinds of events (Pennington & Hastie, 1993). We call these correlated groups of concepts, together with their implicit or explicit causal relationships, *mental models*. Figure 2 outlines an *enemy intent* mental model of this kind.[4]

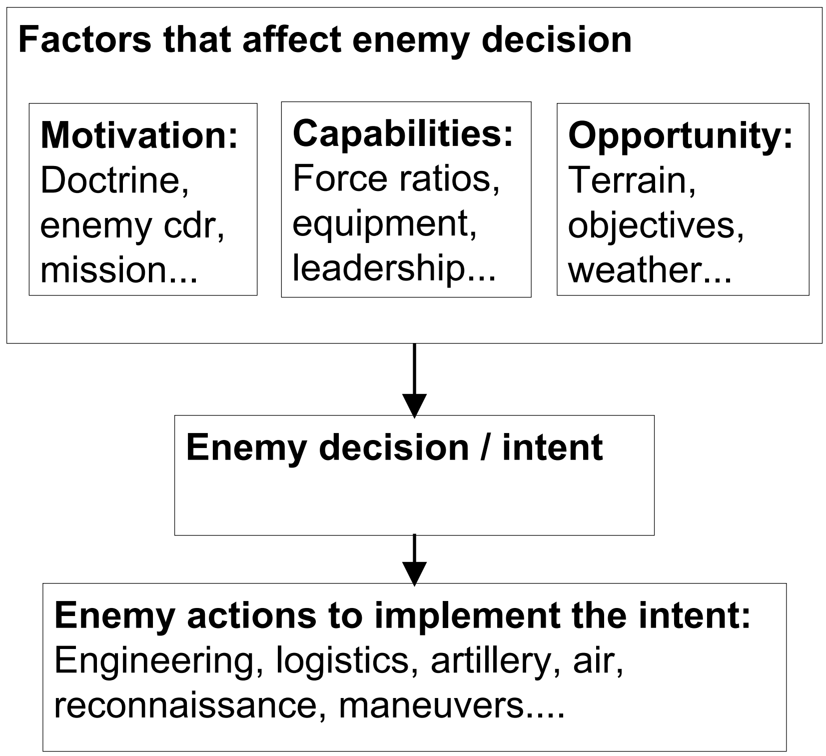

Figure 2. Components of *enemy intent* mental model.

Three types of mental model can be defined to represent degrees of initiative, or *time orientation*. As shown in Figure 3, the three time orientations differ in terms of where and how they intervene in the chain of events representing another agent's decisions, actions, and outcomes. The *proactive* time orientation represents the maximum amount of initiative. It was present if a friendly action was designed to *influence* future enemy or friendly intent (e.g., to eliminate an enemy option or lure the enemy into a trap; to degrade the enemy's decision making process; to create an opportunity for a specific

[4] We do not mean to suggest that mental models exist as isolated structures. The mental model construct is simply a convenient way to isolate concepts that are meaningfully related and tend to co-occur in working memory and attention. A more realistic (but less tractable) view would involve graded degrees of connection across the entire web of long term memory.

action by another friendly unit; or to influence a decision by your own commander). The *predictive* time orientation represents the next highest degree of initiative. It was present if a friendly action was adopted because a future enemy or friendly action was expected to occur (without our doing anything special to bring it about). Predictive actions include disrupting or defeating the planned enemy action; exploiting an enemy weakness or avoiding an enemy strength that will be caused by the enemy action; and preparing to provide support where and when other friendly forces are likely to need it. The *reactive* time orientation represents the least amount of initiative. It occurred when a friendly action was adopted because of an enemy or friendly action already accomplished or underway (e.g. to limit the damage from a surprise attack; to take advantage of an enemy blunder; or to rescue a friendly unit in trouble).[5] The three time orientations are not mutually exclusive. A decision maker might be reactive at one level but proactive and/or predictive at other levels, with respect to other decision cycles that belong to the same or different agents.

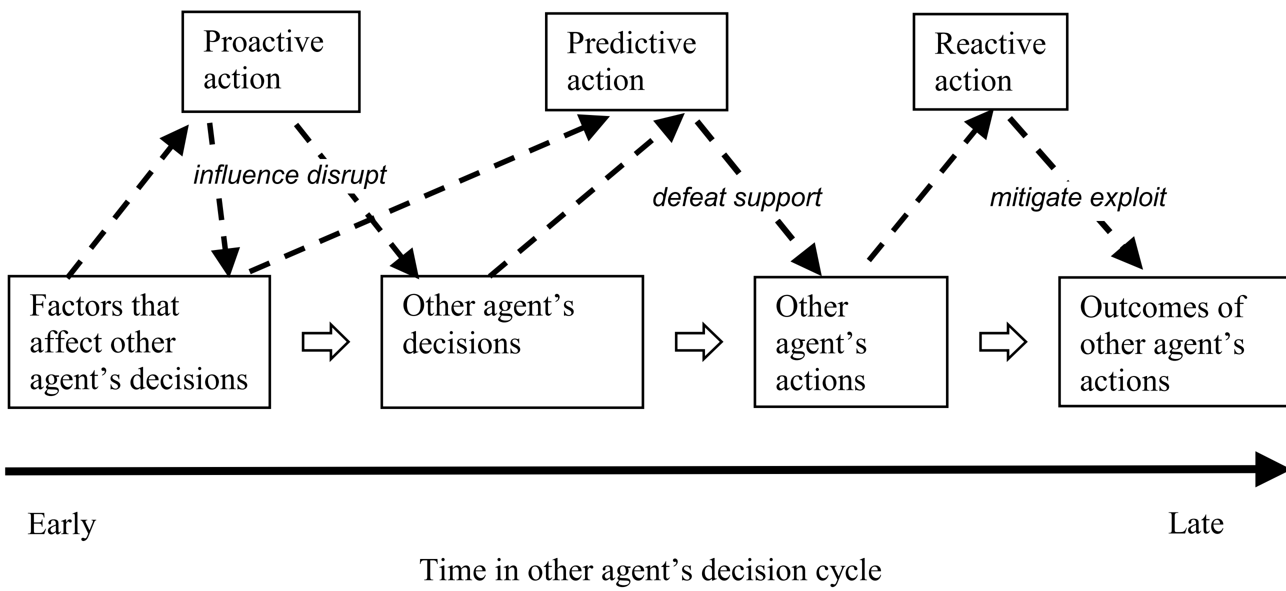

Figure 3. Three different time orientations differ in where and how they intervene to cause changes in another agent's decision cycle.

<u>Identification of Correlations among Mental Models</u>

The third stage of analysis involved examining correlations of mental models and time orientations with one another and with other variables. To score the presence of a mental model in the description of a particular incident, we did not require the presence of all components of the model as defined in step 2. We did require the explicit mention of two or more out of the cluster of correlated topics associated with that kind of model, as indicated in Table 1.

[5] The same concept of initiative could also be applied to intervention in natural chains of events, e.g., proactively preventing a hurricane by seeding a tropical storm, predicting and preparing for the hurricane's point of impact, or reacting by declaring a state of emergency after it hits.

We can visualize this higher level of structure spatially by applying non-metric multidimensional scaling to the mental models, time orientations, and other variables (Kruskal, 1964). The closer any two items are situated in Figure 4, the more highly correlated they were across incidents. In addition to mental models and time orientations, two variables are also shown: officers' experience and the degree to which an incident surprised them.

Table 1. Types of mental models, criteria used for their identification, and the percentage of incidents containing at least one example of a mental model fitting the criterion.

Mental Model	Criterion -- To score mental model as present, description of incident must include mention of the following:	% of incidents (n=25)
Intent	(i) Enemy or friendly intent and (ii) two or more other concepts, i.e., factors affecting the decision to adopt intent or actions taken to implement the intent	80
Friendly intent		64
Enemy intent		56
Friendly & enemy intent		32
Proactive time orientation	(i) A friendly action designed to (ii) influence future enemy or friendly intent or decision making process	32
Predictive time orientation	(i) A friendly action adopted because of (ii) a prediction of future enemy or friendly intent, strength, or weakness	56
Reactive time orientation	(i) A friendly action adopted because of (ii) an enemy or friendly action that is already accomplished or underway	12
Purpose	(i) Friendly intent that is motivated by (ii) a higher-level or longer-term objective or general principle of warfighting, extending beyond the immediate mission	36
Action sequence	(i) Two or more enemy actions or two or more friendly actions (ii) with the explicit constraint that one must be performed before the other	52
Rate of movement	(i) Estimate of rate of enemy or friendly movement and (ii) two or more factors influencing that rate (e.g., slope, firmness of terrain, type of equipment)	28
Reliability	(i) A claim or prediction re the situation or a recommendation re course of action, (iii) its source, and (iii) an assessment of the reliability of the source	76
Alternative causes/effects	(i) An event (e.g., an enemy action) and (ii) two or more competing causal explanations of the event, or two or more competing causal consequences of the event	28
Evidence interpretation	(i) A claim, (ii) mention of one or more pieces of direct evidence for the claim, and (iii) one or more reasons for or against the soundness of inferring the claim from the evidence	16

Initiative and Time Orientation

Initiative serves a useful organizing principle for the mental models in the space of Figure 4. Hierarchical cluster analysis (Payne, Bettman, & Johnson, 1993) of the correlations in Figure 4 reveals three basic clusters of mental models, and these correspond to the three time orientations: *reactive*, *predictive*, and *proactive*. The two dimensions shown in Figure 4 are suggestive. They are anchored on the three clusters, and provide a natural interpretation of the contribution of different mental models to initiative. One dimension reflects *when* uncertainty about another agent's action is reduced (early versus late), and the other reflects *how* it is reduced (by assessment or by action).

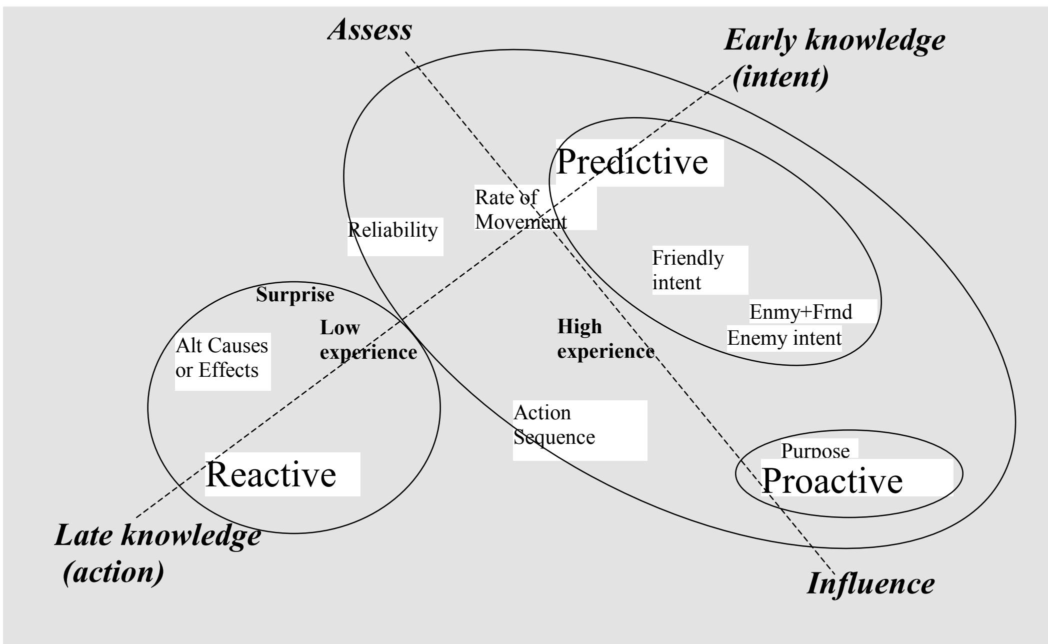

Figure 4. Proximity in this space represents degree of correlation among mental models (white boxes), time orientations (white boxes), and two variables (low/high experience and surprise by the enemy). Ovals show high-level structure derived by a hierarchical clustering algorithm. Italicized labels and dotted lines are a suggested two-dimensional interpretation of this space.

Table 2 shows the different profiles of mental model use that characterize the three time orientations. Being proactive was associated with thinking deeply about objectives, i.e., using mental models of higher-level *purpose*. The proactive time orientation was also more closely associated with mental models of the *enemy's intent* than were predictive or reactive orientations. These associations are consistent with (but not logically entailed by) the interpretation of *proactive* decision making as the attempt to shape the intent of others in accordance with one's will.

Table 2. Pearson correlations across incidents between proactive, predictive, and reactive time orientations and other mental models. Both statistically significant correlations and trends are italicized.

	Proactive	Predictive	Reactive
Purpose	*.557 * (p=.004)*	-.175	-.021
Enemy intent	*.435 * (p=.030)*	.188	.079
Friendly intent	*.336 (p=.101)*	*.510 * (p=.009)*	.021
Both e & f intent	.265	.263	-.253
Action sequence	.263	.026	-.169
Rate of movement	-.103	*.435 * (p=.030)*	-.253
Reliability	-.016	.257	.208
Alt. causes/effects	-.237	-.165	*.318 (p=.121)*

Predictive decision makers were more likely to develop mental models of *their own intent*, e.g., justifying their plans by considering relative force strength and opportunities afforded by terrain. Predictive decision makers were also more likely to use the *rate of movement* mental model, e.g., to anticipate their own or the enemy's future location (r = .435; p = .030). The use of *both* friendly and enemy intent models was about equally likely for predictive and proactive decisions.

Mental models of *reliability* were used both in the predictive orientation (to evaluate predictions ahead of time) and in the reactive orientation (to figure out why a prediction failed). *Alternative causes and effects* were considered most often in reactive modes, when decision makers tried to explain a failed expectation.

In sum, concepts in this domain appear to be organized into a set of mental models, including *purpose*, *intent*, *action sequence*, *alternative causes and effects*, and *reliability*. These models in turn are organized around a set of more fundamental principles pertaining to the time and manner in which uncertainty about other agents is reduced (the axes and clusters depicted in Figure 4). Reactive, predictive, and proactive time orientations represent increasingly influential interventions in another agent's decision cycle. Thus, moving horizontally from left to right in Figure 4 affects both how and when intervention takes place, and represents increasing *initiative*.

Initiative in this sense is correlated with experience. As Figure 4 indicates, when decision makers advance from low to high experience, they tend to move from the cluster of mental models associated with reacting to unexpected events, to the cluster containing predictive and proactive strategies. Figure 5 provides a more detailed look at the differences in mental model use between more and less experienced officers. In our sample of officers, command staff experience ranged from 0 to 64 months, with a median of 21 months. Figure 5 shows the mental models that were used at least 30% of the time by officers above the median level of experience and those that were used at least 30% of the time by officers below the median. Significant differences occur, as expected, at the extremes of high and low initiative. More experienced officers were twice as likely to consider mental models of *purpose* as less experienced participants (Figure 6; p = .056). Less experienced officers, however, were more likely to be surprised (p=.010). It remains now to consider how these mental models are used in action.

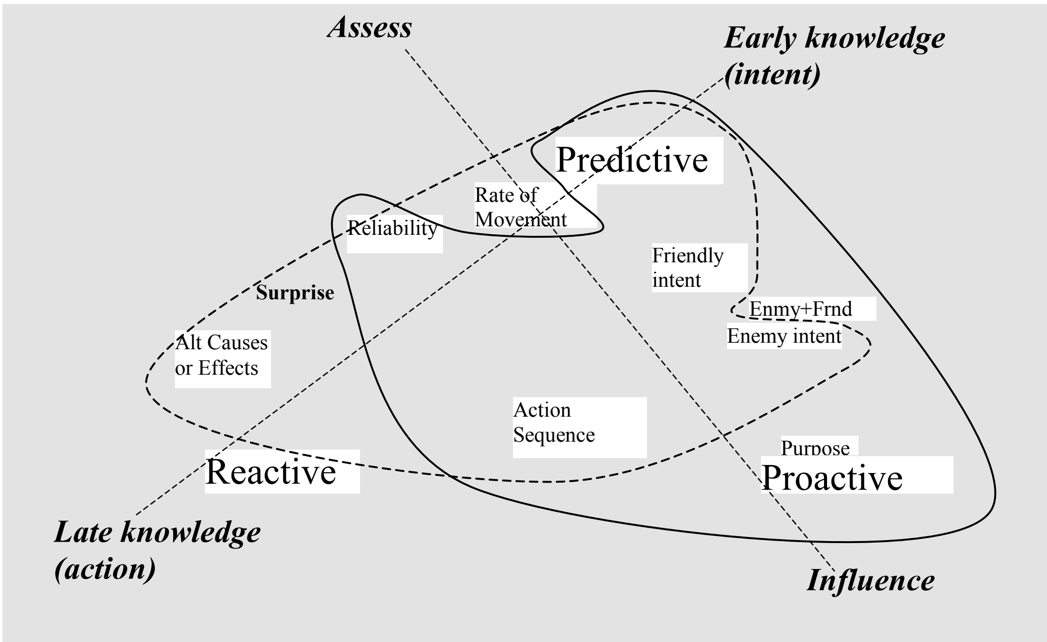

Figure 5. Mental models used in at least 30% of incidents by more experienced (solid line) and less experienced (dashed line) officers.

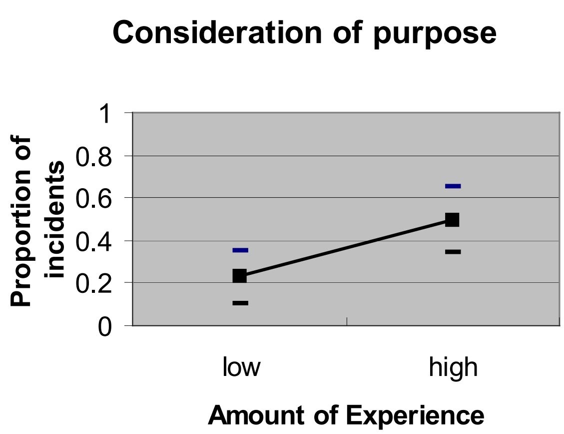

Figure 6. Tendency of experienced officers to consider high level purpose more often than less experienced officers.

CHAPTER 4
A THEORY OF CRITICAL THINKING ABOUT MENTAL MODELS

In successful recognition, perceptual inputs and goals rapidly converge within a decision maker's mind onto one, and only one, stable "intuitive" decision. The basis for decision making, more often than not, is recognition, and in ordinary circumstances, the recognitional responses of experienced decision makers are likely to be adequate (Klein, 1993). In more unusual situations, however, recognition needs to be supplemented by other processes. What are these processes, and how do they work?

Recognitional learning enables humans (and other animals) to escape the speed limit imposed by natural selection, with its glacially slow shaping of inherited behavioral responses to recurring environmental situations. Instead, recognitional learning permits the acquisition of adaptive responses to environmental conditions that recur with some regularity during a *single lifetime*, even when they have not appeared at all in the previous history of the species. On the other hand, recognitional learning itself takes many years to produce expertise in a particular domain (Ericsson, 1996); how long it takes is likely to depend on the extent of the environmental variability or novelty that must be mastered. *Critical thinking* provides a further gain in flexibility in changing or novel environments, where recognitional learning also turns out to be too slow. Critical thinking enables decision makers to find discriminative, adaptive responses to even finer-grained environmental variations, which have not appeared in the previous experience of the decision maker. It does so by building a relatively simple layer of attentional control over the recognitional processing that is already taking place.[6] The simplicity of the required attentional control processes (described below), along with their power, lends plausibility to the hypothesis that such a second-order capability could have evolved, and that specific skills drawing on that capability could be shaped by experience.[7]

Components of the Theory

The Recognition / Metacognition Model of critical thinking has three main components:

- Meta-recognitional processes

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[6] This hypothesis regarding the evolutionary origin of metacognitive control is consistent with the views of Campbell (1974), Simon (1962), Heylighen (1991), Turchin (1977) and others. Knowledge systems in general evolve through a process of variation and selection, which favors changes that improve the system's ability to maintain itself in the presence of environmental variability. The complexity of the system increases along with the variety of different situations it can distinguish and responses it can produce. This increase in complexity is self-limiting, since it magnifies the time required to learn the appropriate situation-response connections. A solution is to increase the variety of potential responses indirectly, by varying higher-level parameters – in short, to introduce a system that varies the constraints on the original lower-level system. This higher-level system itself adapts through variation and selection, and thus explores a vast space of lower-level configurations without disrupting the operation of the lower level system.

[7] The hypothesis that meta-recognitional strategies can be learned through experience is being tested by experiments with a computational implementation of the Recognition / Metacognition model. The implementation utilizes a connectionist architecture with a backpropagation learning algorithm, and employs temporal synchrony of firings for consistency of object reference in relational reasoning (Thompson, Cohen, & Shastri, 1997).

- Mental Models
- Argument structure

Metarecognitional Processes

Critical thinking includes *meta-recognitional* processes that monitor and regulate recognition. As shown in Figure 7, the Recognition / Metacognition model distinguishes three functions that these processes perform:

(1) The *Quick Test*, which is a rapid assessment of the value of taking more time for critical thinking versus acting immediately on the current recognitional response;

(2) *Critiquing* the current results of recognition in order to identify three kinds of uncertainty: incompleteness in situation understanding or plans, conflict of goals or evidence, ; and explicit or implicit assumptions;

(3) *Correcting* those problems by influencing the operation of the recognition system, by inhibiting recognitional responding, shifting attention, and making assumptions.

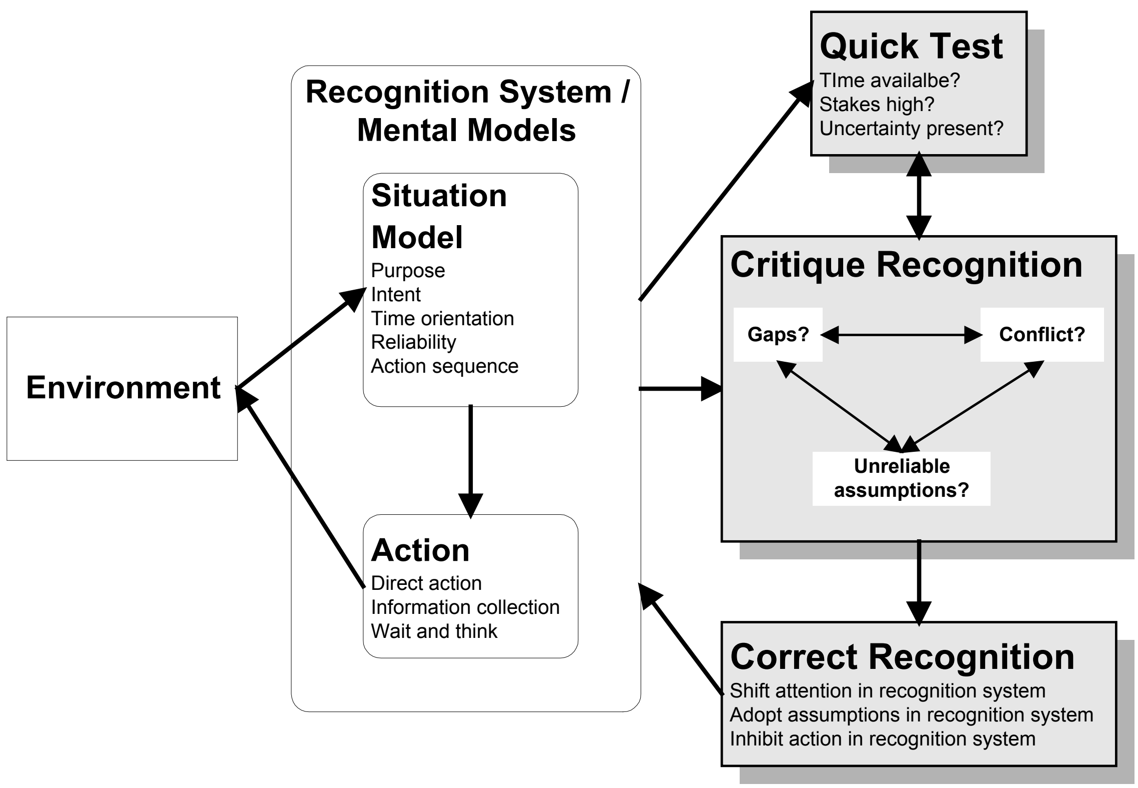

Figure 7. Basic components of the Recognition / Metacognition model. Shaded components are meta-recognitional, i.e., the reflective subsystem.

Meta-recognitional processes are general skill components that are effective across different tasks and domains. Their successful application, however, requires extensive domain-specific knowledge, such as mental models that describe causal relationships among events in the domain. We will discuss how meta-recognitional processes work in more detail later in this section and in Chapter 11. Previous descriptions of the R/M model may be found in Cohen, Freeman, and Wolf (1996) and Cohen, Freeman, and Thompson (1998; see also Cohen, Parasuraman, Serfaty, & Andes, 1997).

Mental Models

Mental models, which were discussed in Chapter 3, are sets of correlated concepts and the causal (or other) structural relationships among them. Many mental models are highly specific to a domain, but some types of models are generalizable at least to some degree. For example, a large number of domains utilize mental models of intent with elements corresponding to motive, opportunity, and capability; and the proactive / predictive / predictive-reactive structure of initiative that discussed in Chapter 3 is also widely relevant. In such domains, there is a distinction between: (i) mental models that support action based on predictions of future events (including the actions of other agents), (ii) mental models that support action designed to influence future events, and (iii) mental models of actions that are contingent on the specific future events that actually occur. Both domain specific and general mental models support meta-recognitional processes of verifying and improving situation understanding and plans. For example:

- Critiquing and correcting incompleteness: In predicting enemy plans, have I considered all the factors that might influence enemy intent? If I am unsure about a *prediction* of future enemy action, is there something I can do proactively to *influence* the enemy to act in a way that is advantageous to me? If my predictions, or my attempts to influence the enemy fail, what is my backup contingency plan?
- Critiquing and correcting conflict: Is the evidence that underlies my prediction of enemy actions consistent, or do some indicators point in opposing directions? Can I simultaneously attack where it will do the most harm to future enemy capabilities (i.e., be proactive), and attack where the enemy is currently the weakest (i.e., be predictive)? If I use artillery fires to reduce an enemy's strength prior to an attack, do I sacrifice the element of surprise? Which is more important in this particular case?
- Critiquing and correcting the reliability of assumptions: Do my predictions of enemy action or my plans depend on covert assumptions, for example, about enemy capabilities, the weather, or the passability of terrain? Have I assumed correctly that the enemy will panic in the face of a bold attack, rather than resist effectively? Have I assumed that I can implement a contingency plan or branch more quickly than is in fact possible?

Arguments

On the one hand, meta-recognitional skill is acquired in the process of gaining expertise in a particular domain. On the other hand, the skills that are in fact acquired need not be entirely domain-specific. We have already noted that meta-recognitional processes (identifying and correcting gaps, conflicts, and unreliable assumptions) are largely general across domains, and that some important mental models are also somewhat general. An additional source of generality is *argument structure*. Through experience in a domain, decision makers may learn to distinguish different *roles* that beliefs can play in any process of reasoning (e.g., the roles of *evidence*, *conclusion*, and *assumption*). By identifying the specific beliefs that play those roles in a particular case, decision makers can generalize the critiquing and correcting strategies that they have acquired in specific contexts.

A simplified version an argument structure (based on Toulmin, 1958) is shown in Figure 8. A *Claim* is any conclusion whose merits we are seeking to establish. It may be a assessment, e.g., about enemy intent, or part of a friendly plan, e.g., the time of an attack. The Claim is supported by *Grounds*, or evidence, e.g., considerations of likely enemy purpose, capabilities, and opportunities. Possible *Rebuttals* are condition under which the link between Grounds and Claim would not hold. Rebuttals are equivalent to implicit or explicit assumptions, that is, beliefs that are assumed true until shown to be false, and whose falsity would undermine the validity of the argument.

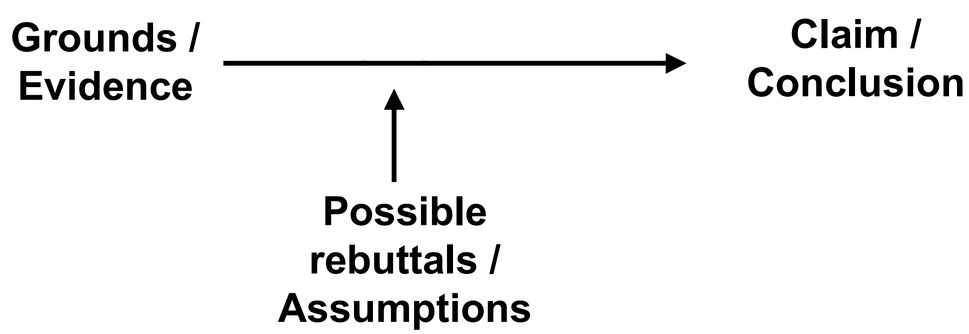

Figure 8. A simplified variant of Toulmin's model of argument. The structure can be read: Grounds, so Qualified Claim, unless Rebuttal, since Warrant, on account of Backing.

An argument is typically *based on*, but not identical with, an underlying knowledge representation or mental model. For example, observations or analyses of enemy capability may provide grounds for conclusions about intent, since it is one its causes. Similarly, conclusions about intent may provide grounds for conclusions about the effects, i.e., actions the enemy is likely to take to achieve the intent. However, evidence-conclusion relationships do not always run from cause to effect. For example, observations about enemy actions lead to inferences about the intent behind the actions. Inferences or information about the enemy's intent can lead to inferences about enemy capability. Distinguishing grounds from conclusion must be a real-time discrimination (Kuhn, Amsel, & O'Loughlin, 1988), because the same event may serve as evidence in one situation and as a conclusion in another. The relationship between grounds, conclusion, and assumptions on a particular occasion is an *argument*, which may or may not be convincing.

Critiquing and correcting in terms of arguments is a more general skill than critiquing and correcting in terms of domain-specific mental models. It can take more time and be less effective than the corresponding specialized skill. However, in relatively unfamiliar domains, or novel situations, it may be the only available approach to resolving uncertainty. Table 3 provides examples of specialized skills, on the one hand, and more general versions of those skills, on the other.

Table 3. Specialized meta-recognitional skills and general meta-recognitional skills compared to one another, in how they deal with incompleteness, conflict, and unreliability.

	Domain-specific skill (based on mental models)	**General skill (based on roles in argument structures)**
Identifying and resolving incompleteness	Enemy intent may be to attack in the south or the north. Let me compare enemy capabilities in the north and the south and look at current enemy actions.	There are no grounds either for or against this conclusion, so both the conclusion and its negation are possible. What kinds of evidence are relevant (either as causes or effects of the conclusion)?
Identifying and resolving conflict	Enemy engineer capability is better in the south, but leadership is superior in the north. Does the enemy really need engineers for the terrain in the north? Is the leadership in the south better than we have supposed?	There are grounds both for and against this conclusion, so neither the conclusion nor its negation appear possible. Therefore, some of the assumptions I used to interpret the evidence must be wrong? Which ones?
Identifying and resolving unreliable assumptions	I have assumed that engineers will serve in a specialized engineers unit, as they have in the past. Perhaps the enemy has decided to integrate engineers in with other units. Maybe that's why we observed no engineers in the north.	There is evidence for one conclusion, but there are conditions that would undermine the validity of the argument. The argument depends on generalizations that do not take into account the specifics of this situation. Conclusions may change as I acquire more detailed information.

Critical Thinking Processes

Critical thinking addresses these problems by removing one major limitation on recognitional learning: that the situation and the response retrieved to handle it must have been closely associated in the individual's previous experience. The mechanism that overcome this limitation involve relatively simple processes of controlled attention.[8] One important meta-recognitional correcting step involves shifting attention from cues in the situation to selected elements of the current recognitional conclusion. The result is activation of potentially relevant knowledge in long-term memory that has not played a role in the present argument because it is too distantly related to the situational cues. Activation of this new information may lead, via recognitional processes, to activation of still more indirectly related knowledge, to which attention may then be shifted, and so on.[9] Such attention shifting is equivalent to *posing queries* about the acceptability of the currently active situation model and plan (Shastri & Ajjanagadde, 1993; Thompson, Cohen & Shastri, 1997). A computational model of such processes is described in Chapters 10 and 11 below.

As-if reasoning can be regarded as a more directive variant of attention shifting: i.e., to *persistently* attend to a *hypothetical* or *counterfactual* action or event. Persistent attention to such a possibility is equivalent to assuming or imagining that it is true, and posing a query about what *would* happen if the hypothesized action or event were the case (Ellis, 1995). This strategy extends the reach of recognitional processing even further, by activating relevant knowledge that is not closely associated either with cues in the actual situation or with the recognitional conclusion.

The result of attention shifting strategies of either kind is usually to increase the amount of knowledge brought to bear on a problem (assuming that conclusions can be retained and integrated across cycles of attention shifting).[10] Attention shifting, however, operates in different ways and has different consequences in response to different types of uncertainty. Experienced decision makers learn meta-recognitional strategies that respond differently to different types of uncertainty. Moreover, the solution to one problem may (but need not) lead to the creation or discovery of new problems. Figure 9 summarizes a variety of ways in which critiquing and correcting interact. We will explain these interactions in the following sections.

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[8] The classic account of attentional control processes is in Atkinson & Shiffrin (1969), although more subtle models are now available.

[9] It is plausible, but speculative to distinguish attention from consciousness. According to one view, consciousness results from a positive feedback process which recruits major parts of the brain into resonating activation cycles (Ellis, 1995). This is consistent with view that consciousness requires the, and also with Shruti's use of temporal synchronization to unify activities in different parts of the brain (Chapter 10 below). Focused attention, on the other hand, involves querying a specific subset of the contents of perceptual or long term memory. Activation from this query may spread to other relevant contents, and return a signal to the queried node, creating a resonating cycle (Shastri & Ajjanagadde, 1993). Shifting attention, in order to query additional nodes, may result in recruitment of additional parts of the brain. Focal attention is thus one of the *causes* of consciousness.

[10] Priming and integration mechanisms were addressed in work on the Shruti system for this project. See Chapter 10.

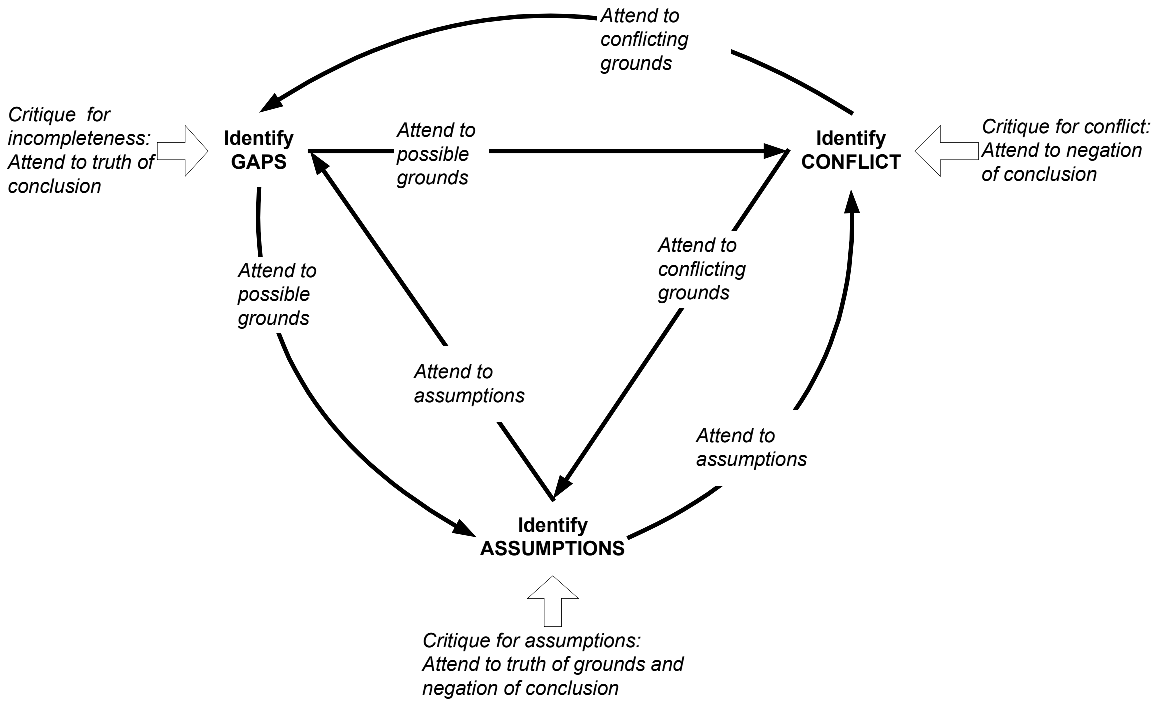

Figure 9. Cycles of critiquing and correcting in the Recognition / Metacognition model. Large arrows represent *critiquing* strategies, which are used to identify different types of uncertainty. Narrow arrows represent correcting steps designed to resolve particular types of uncertainty. In some cases, correction of one type of uncertainty leads to identification of another type of uncertainty.

<u>Critiquing and Correcting Incompleteness</u>

To identify and fill *gaps* in an argument (the case where more than one conclusion is consistent with the current evidence), attention shifts to one of the possible conclusions – in effect, querying its truth. The result is activation of an associated *mental model*, which indicates possible grounds for the conclusion. These grounds are the types of information that have been useful in the past in determining the truth or falsity of the attended conclusion. For example, in order to determine the *intent* of an enemy unit, it is useful to consider the *capabilities* of that unit, as well as its *opportunities*, *goals*, and *actions*.

Attention then shifts to one of the components of the activated mental model for which information is not currently active. For example, the decision maker decides to think about the *capabilities* of the enemy unit whose intent is uncertain. The result may be retrieval of relevant information in long-term memory about that component, or, if relevant information is not retrieved, a decision to initiate external data collection.

A more directive strategy for activating relevant knowledge in long-term memory is to temporarily assume that a conclusion is correct, by persistent attention to that possibility. This and subsequent shifts of attention may activate less immediately accessible information about the likely long-term consequences of an option, or about the less obvious implications of a hypothesis.

Knowledge activated by these attentional strategies may help narrow down the set of plausible conclusions by activating goals or beliefs that further constrain the solution. There are three possible outcomes, as shown in Figure 9: If newly activated knowledge eliminates all but one plausible conclusion, the problem is resolved. If filling gaps turns up constraints that *no* conclusion appears to satisfy, the result is a new problem, *conflict*. Finally, the newly discovered evidence may rest on shaky foundations, e.g., a statistical generalization that does not take into account particularities of the present situation. In this case, the result is another kind of problem, *unreliability of assumptions*.

Critiquing and Correcting Conflict

Correcting incompleteness by filling gaps in evidence is one method for identifying *conflict*. As we have just seen (Figure 9), newly retrieved or collected information may expose hitherto hidden conflict between a conclusion and existing goals or beliefs. Another, more directive strategy for identifying conflict is to temporarily assume (by persistent attention) that a conclusion is *wrong*, in effect tasking the recognition system to activate an account of how that could happen (Figure 9). This tactic heightens the salience of negative information about the conclusion, e.g., possible bad outcomes of an option or reasons why a hypothesis might not be the case. Awareness of this information may have previously been suppressed by stronger positive information.

Conflict among arguments (when there are grounds for both accepting and rejecting a conclusion) can be addressed by shifting attention to the grounds (e.g., sources of information or goals) that are responsible for the conflict. As a result of this shift in attention (and subsequent shifts to which it leads), assumptions underlying the argument may be exposed. It may be learned, for example, that (i) one or more conflicting sources of information are not as credible as previously supposed, (ii) one or more sources of information was misinterpreted in some way, (iii) one or more conflicting goals are not as important as previously supposed, or (iv) one or more options does not in fact conflict with a goal as previously thought. In this case, additional knowledge *removes* constraints on the recognitional conclusion, rather than adding constraints as in the case of filling gaps. Attention shifting reveals that what was previously thought to be a constraint on belief or action (e.g., a report from an information source, or a goal) was based on assumptions (Doyle, 1979; Cohen, 1986).

In the more directive version of this correcting step, the decision maker temporarily assumes (by persistent attention) that a specific source is not credible, or a specific goal is not important, etc., tasking the recognition system to account for how this could be. Such directive techniques can increase the chance that hitherto inactive knowledge in long-term memory about the relevant sources or goals will be retrieved.

There are three possible results of these correcting steps. First, the conflict is resolved if newly activated knowledge convincingly undermines the argument for one of the competing conclusions. For example, newly activated knowledge may establish that one of the conflicting information sources is not credible or that one of the conflicting goals is not important. Second, these correcting steps might undermine the reasons for both conclusions, thus leading back to the problem of gaps in arguments. Third, these correcting steps may lead to the identification of *unreliable assumptions*, if the decision maker must choose between current assumptions and new assumptions that would resolve the conflict (e.g., choose to regard a previously trusted source as untrustworthy).

Critiquing and Correcting Unreliable Assumptions

To address *unreliability*, a decision maker must first *identify* key assumptions underlying possible conclusions and then *evaluate* them. Identification of hidden assumptions is not trivial. We have just seen that conflict in evidence can, and should, be used as an indicator of an incorrect assumption in one or both of the conflicting arguments. Yet a decision maker may have a high degree of confidence in the initial recognitional response to a situation, and may be unaware of any opposing considerations, and yet that conclusion may turn out to depend on questionable assumptions (for example, that the present situation resembles previously experienced ones in crucial respects). In addition to conflict, instability of conclusions over time, or variability in the conclusions of different decision makers at the same time, are also symptoms that unreliable assumptions could be playing a role. However, (a) variability per se does not indicate *what* the problematic assumptions are, and (b) variability like conflict is not always available as an indicator.

In a group context, a strategy for identifying assumptions is for decision makers to articulate *reasons* for their divergent conclusions and then to compare these justifications. Openness to such a dialogue is, of course, a natural part of a healthy group decision making process (e.g., Helmreich & Foushee, 1993). When variability does not exist, because there is a single convincing conclusion, disagreement can be induced more artificially, by assigning some individuals the task of "red-teaming" the preferred conclusion or playing the role of devil's advocate. Each potential problem discovered in this way represents an assumption implicit in the favored solution, to the effect that the relevant problem will not materialize.

Skilled decision makers use attention-shifting strategies to simulate these group processes. No matter how confident they are in a particular conclusion, one powerful approach is to assume that the premises of the argument are correct, but that the conclusion itself is *incorrect*, in effect querying the recognition system for an explanation of a failure of a rule. If decision makers are persistent enough, an explanation for the falsity of the prediction or the failure of the plan will be generated. Decision makers may then imagine that this is not the correct explanation for the failure, and force the recognition system to activate another explanation, and so on. Each explanatory possibility activated in this way corresponds to an assumption underlying the original argument from premises to conclusion. If the decision maker wishes to accept the conclusion, the decision maker must be comfortable assuming that each possibility of failure is false.

Assumptions can sometimes be evaluated one by one as they are identified, by shifting attention in order to activate knowledge that bears on their plausibility. However, because of limitations on time, only a small number of assumptions can be dealt with directly in this way. Therefore, the mere fact that a conclusion depends on untested assumptions is not sufficient cause to reject it. In the novel situations where critical thinking is appropriate, some crucial information will inevitably not be available, and no conclusion will fit all the observations or goals perfectly. If gaps and conflicts are to be resolved at all in these cases, it will have to be by means of assumptions.

In fact, real-world decision makers often use an *assumption-based correcting strategy*. They attempt to fill gaps and resolve conflicts in a recognitional conclusion, by retrieving or collecting information if possible but by making assumptions where necessary, until they have a *complete* and *coherent* story. In effect, they ask themselves, “What is the best story I can tell to justify this inference or plan?” They then step back, take a look at the story they have created, and try to evaluate its plausibility *as a whole*. In particular, they ask, “How many truly different assumptions did I have to make to build this story? Are the assumptions I had to make credible in this situation?” If the assumptions are troubling, the decision maker may temporarily drop them, and start again with the gaps and/or conflict that the assumptions were intended to handle (Figure 9). The result may be a new story, supporting a different conclusion. The choice between competing hypotheses or actions is often made based on evaluation of the plausibility of the assumptions underlying competing stories (Pennington & Hastie, 1993).

As Figure 9 and the preceding discussion make clear, meta-recognitional processing is a highly iterative, open-ended, and flexible process. The solution to one type of problem (e.g., filling a gap) can lead to another type of problem (e. g., conflict), which prompts new correcting steps, leading to new problems (e.g., unreliable assumptions), and so on. In the course of this process, recognitional conclusions are improved and/or modified bit by bit through local decisions about what to do next, and an understanding of the strengths and weaknesses of alternative conclusions is developed at the same time. These improvements are accomplished across cycles of shifting attention that either activate long-term memory contents that lay beyond the reach of a single recognitional cycle or lead to external information collection. When further benefits are likely to be outweighed by the costs of additional delay, critical thinking stops, and the decision maker can act immediately on the current best solution to the problem.

Views of Decision Making

In most of these respects, meta-recognitional processing contrasts with formal analytical approaches to decision making. Typically, formal methods require a problem structuring stage which specifies in advance the inputs that will be used to model the problem (e.g., Watson & Buede, 1987). The required inputs are not related in any direct way to recognitional responding and the knowledge that it taps, yet decision makers must somehow make precise numerical assessments of variables such as the strength of evidence and importance of goals. Similarly, the steps required to generate outputs from the inputs are determined in advance by the choice of an analytical model. Although some iteration may take place, “thinking” is largely over (and a solution is available) as soon as, but not a moment before, the model is finished according to the prespecified blueprint. Finally, the output is typically an unrealizable statistical abstraction (e.g., “there is a 70% chance of enemy attack”; “the expected utility of option A is equal to 40”), rather than a coherent picture of the situation that can be visualized and planned for. Table 4 compares the view of thinking offered by the R / M model and by analytical and recognition-based models, respectively.

Table 4. Comparison of three paradigms for understanding decision making.

	Analytical Models	**Recognitional Models**	**Recognition / Metacognition Model**
Inputs	Identify all inputs in advance (exhaustive specification of hypotheses, cues, outcomes, goals)	Limited to previously experienced situations and associated responses	Activate knowledge about new hypotheses, options, cues, or goals as current ones are found wanting
Processing	Assign fixed, precise meanings to cues & mathematically aggregate by a set of predetermined steps	Rapid, intuitive, not easily explained or justified	Try to create complete, consistent, and reliable situation picture by dynamically modifying interpretation of cues & goals
Outputs	Unrealizable statistical aggregation	Concrete situation picture, but little insight into its strengths & weaknesses	A single concrete situation picture, with an understanding of its strengths and remaining weaknesses

The Recognition / Metacognition model is a *problem-solving* model. Unlike most problem solving approaches, however, the R / M model identifies *strategies that are explicitly framed in terms of uncertainty*, and specifies how search takes place in a problem space defined by different types and amounts of uncertainty. Each processing step may be determined by global selection of a strategy, or may be determined locally by the results of earlier steps. Both kinds of choice may be affected by persisting epistemic attitudes or individual cognitive styles.

The R / M model explains how experienced decision makers are able to *exploit their experience-based intuition* in a domain (as explained by pattern matching) and *at the same time handle uncertainty and novelty* without resorting to artificial and time-consuming "analytical" methods. Uncertainty is handled not by abstracting from concrete reality, e.g., to estimate probabilities, but by reflecting on recognitions. Metacognitive strategies in effect "annotate" the internal situation model or plan to highlight points of incompleteness, conflict, and unreliability, and then respond to these problems to improve the current model or help the recognitional system to find a better one. To quote Dreyfus (1997, p.28) again, metarecognition is "observation of one's intuitive practice-based behavior with an eye to challenging and perhaps improving intuition without replacing it…"

CHAPTER 5
A REAL-LIFE EXAMPLE OF CRITICAL THINKING AND INITIATIVE

As we have seen (Chapter 3), initiative is a matter of *timeliness*: acting early enough to influence another agent in accordance with one's own purposes. Yet, as we have also seen (Chapter 4), critical thinking takes more time than simple recognition. It is reasonable to ask, then, whether critical thinking is inconsistent with the tempo of decision making demanded by initiative. In fact, the opposite is the case. Rapid recognitional responding can, in some situations, take more time rather than less. It can trap a military decision maker in a reactive mode with respect to the enemy, or trap a business decision maker in a reactive mode with respect to competitors and customers. Seizing the initiative will often be impossible in the absence of critical thinking about innovative solutions that bypass standard procedures.

In the following section, we describe an actual incident through the eyes of a participant, and reanalyze it in the light of the model of initiative developed above. (Our factual description of the incident is based directly on the transcript of an interview obtained in research cited in Kaempf, Klein, Thordsen, and Wolf, 1996.) This incident is an excellent illustration of how critical thinking about mental models can be necessary to support initiative, and how the time cost of critical thinking can easily be dwarfed in comparison to the advantages of the proactive tactics to which it leads.

Silkworm Missile Scenario

Initial Recognitional Response

A U.S. naval officer was serving as the Anti-Air Warfare Coordinator (AAWC) on an Aegis cruiser in the Persian Gulf, when he received intelligence reports that an Iraqi Silkworm missile site had suddenly gone active. The site was a threat to a large number of U.S. surface ships assembled in the area at the start of the air war against Iraq. Unfortunately, no airborne strike aircraft were close enough to be used against the missile site. The first thing that occurred to the AAWC, i.e., his *recognitional response*, was the standard procedure for this situation: Ask the Tactical Operations Officer (TAO) on his own cruiser to call the Battle Force TAO and request that strike aircraft be launched from the carrier to destroy the newly activated missile site.

Quick test.

The AAWC was initially in a *reactive time orientation* with respect to the Iraqi missile site's turning on its fire control radar. Whatever he chose to do was designed to mitigate any advantage the enemy might derive from that surprise move. His *purpose*, however, quickly became *proactive* with respect to the enemy's launching a missile, an option that he wished to eliminate. The question, then, was: Will the standard procedure be effective and timely in destroying the missile site as quickly as possible? Rather than immediately carrying out the standard procedure, the officer paused momentarily to critically evaluate it.

Critiquing the Initial Recognitional Response

Find conflict.

One problem with the recognitional response came to mind immediately, based on a mental model of *team member reliability*. The officer recalled a previous experience when carrier staff failed to take into account updated information about target coordinates. *Resolve conflict by adopting an assumption:* Rather than immediately give up the initial recognitional response, the AAWC tried to repair it as well as he could. The standard procedure would be justified if the AAWC could assume that this situation was in crucial ways different from the previous one. *Evaluate assumption:* In fact, there was a difference: He was able to provide the required targeting information earlier now than he had on the previous occasion. Despite this difference, the AAWC believed that the magnitude of the previous error indicated a strong possibility that the deck-launched intercept would not be properly targeted. He was not comfortable with the assumption.

Fill gaps by retrieving information.

The AAWC was also concerned about the speed with which a missile strike could be implemented, so he decided to scrutinize the recognitional response further. He imagined that the standard procedure was adopted, stepped through the expected *action sequence* in his imagination, and looked for problems (Klein, 1993). In doing this, he drew on mental models not only of *action sequence*, but also *team member reliability* and *purpose*. He predicted that the Battle Force AAWC would pass the request to the Battle Force TAO, who would probably bring in the Commander, because the typical lieutenant commander standing TAO watch "didn't want to be responsible for…big decisions." If permission was granted by the commander, the Battle Force staff would then have to contact the carrier, initiating a new process that would itself take a number of minutes. Moreover, the process might take even longer than usual because the carrier was about to launch other aircraft. *Find conflict:* The AAWC's expectations regarding the standard procedure conflicted with the *purpose* of timely, proactive response to the missile site.

Resolve conflict by adopting an assumption.

Even now, the AAWC was not ready to abandon the initial recognitional response. To defend the standard procedure in the face of this problem, the AAWC tried to construct the best possible story; in effect, the AAWC imagined that the standard procedure was a success, and asked how that could be. The AAWC concluded that for the standard option to be acceptable, he would have to assume that the Iraqi missile site had switched on its fire control radar without the intent to launch a missile. *Evaluate the assumption:* While this was possible (for one thing, they had previously launched a missile without turning on their radar in advance), it was certainly not guaranteed. To assume the enemy would not fire meant adopting a *predictive* time orientation, which depends on assumptions about what the enemy will do, rather than a *proactive* orientation, which influences what the enemy can do. He was not comfortable with this assumption either. *Quick test*: The AAWC chose not to consider enemy intent any further. Taking more time to think critically about enemy intent was unnecessary in this situation. (This judgment contrasts sharply with the behavior of officers in non-wartime or low intensity conflict situations, where inferring hostile intent can play a major role in the decision to engage a target. These officers use critical thinking to fill gaps and resolve conflicts in an *enemy intent* mental model, and often consider *alternative possible causes and effects* of an unexpected and possibly hostile enemy action. The mental models that critical thinking focuses on vary with the circumstances. See Cohen et al., 1996.)

Resolve conflict by finding another option.

The Anti-Air Warfare Coordinator voiced misgivings to his own staff, including an Air Intercept Coordinator (AIC) whom he regarded as "outstanding." The AIC suggested another option just as the AAWC was thinking of it himself: An Armed Surface Reconnaissance (ASR) plane already in the air might be able to take out the missile site. *Quick Test:* This option also was subjected to critical scrutiny, since it was a departure from standard procedure. This option, too, was not without problems.

Critiquing the New Option

Fill gap by collecting information.

One problem was immediately apparent: Was the ASR well enough armed to carry out this unusual mission, and was it willing to do so? The AAWC and AIC contacted the ASR to find out, and the ASR crew responded that they could and would undertake the mission. *Find conflict:* A second problem had to do with the violation of standard operating procedures: A reconnaissance aircraft had never before been used under the control of an Anti-Air Warfare officer for a ground strike mission. *Resolve conflict by adopting assumption:* The AAWC chose to assume that he had the authority to retask the ASR, since he was the officer in control of the airspace. *Evaluate the assumption:* The AAWC was comfortable with this assumption. The Captain of his cruiser had established an atmosphere that encouraged initiative: "If I had a different kind of captain that had a different type of mentality…I might not have made that decision."

Find another conflict.

The normal procedure would be to refer the decision regarding use of the ASR to his own TAO. Again drawing on knowledge of *team member reliability*, however, the AAWC figured that his TAO "didn't make aggressive decisions…if it wasn't something that had happened before." *Resolve conflict by modifying the option:* Instead, he announced what he was going to do, and his TAO "went along with it." The AAWC adopted a *proactive* orientation with respect to his superior, influencing rather than soliciting his decision.

Find another conflict.

The TAO, nonetheless, called the Battle Force staff to inform them of the decision, and they said to wait. The TAO told the AAWC that Battle Force staff wanted to determine if any friendly troops were in the area of the Iraqi missile site. This created a new problem: The ASR had just radioed the AIC and AAWC that it was low on fuel and would have to strike the missile site immediately or else return to base. There was no time to wait for the Battle Force staff to close the loop. *Resolve conflict by finding another option:* The AAWC briefly considered waiting for the ASR's replacement, an S-3 aircraft, to become airborne. *Find conflict:* However this presented similar problems that, if anything, were worse than the problems with using the ASR: Taking control of the S-3 would require too much time. Moreover, the S-3 had more explicit restrictions on its use than the ASR, which would take even more time to work around. *Quick Test:* The AAWC did not think it worthwhile to further consider this option.

Resolve conflict by modifying the option.

The AAWC now considered the possibility of acting prior to receiving clearance from the Battle Force. He would again be adopting a *proactive* orientation toward a superior, by denying the Battle Force Commander the option of preventing use of the ASR. *Find conflict*: But were there friendlies in the area? *Resolve conflict by retrieving information:* In deciding whether to use the ASR without clearance, the AAWC drew on knowledge of the *task situation*. He thought it extremely unlikely that any friendly forces would be in the area of the missile site, since he had been sending attack missions into that area all day. *Continue to resolve conflict by collecting information:* Because the cost of an error was high, the AAWC chose to verity this further by calling staff on the battleship Missouri, who confirmed that no friendlies were in the area.

Continue to resolve conflict by adopting assumption.

It seemed reasonable to conclude that no friendlies were in the area, but why then was the Battle Force staff reluctant to approve use of the ASR? The AAWC drew again on knowledge of *team member reliability*. Based on past experience, the AAWC felt that the Battle Force staff was overly cautious in general. All the signs indicated that the Battle Force would eventually give its approval. He also concluded that if they did deny permission to send the ASR, that decision would be based on caution rather than on safety-related information. Acting prior to clearance was thus *predictive* with respect to his superior's eventual approval, but proactive with respect to his superior's real options. *Evaluate assumption*: The AAWC resolved the conflict by assuming that approval would eventually come, but accepting that he would have to "take the hit on being too aggressive" if permission were denied. He was comfortable with accepting this risk. By contrast, following the standard procedure required a predictive orientation to the enemy, based on assumptions he was far less comfortable with: that the enemy missile site would not fire, or that the carrier launch process would come off more accurately and quickly than before.

Taking Action

The AAWC told the TAO what he was going to do, then tasked the ASR to strike the missile site. The site was successfully destroyed. Clearance from the Battle Group Commander arrived shortly thereafter. The AAWC and TAO waited a few minutes, then reported the destruction of the missile site to the commander. They received commendation for their action, and use of the ASR in this way became a new standard operating procedure in the battle force. The Battle Force commander never knew that the AAWC had acted on his own initiative before receiving clearance.

Discussion

In this example, taking initiative with respect to the enemy required taking initiative within the organization, and both required critical thinking. Critical thinking that focused on mental models of *action sequence*, *team member reliability*, and *purpose* enabled the AAWC to identify problems with the standard procedure. In particular, he saw that it implied a predictive rather than a proactive stance in the face of an unexpected enemy action (turning on its radar), and thus did not sufficiently reduce uncertainty about enemy action in the future (firing a missile). The desire to be proactive toward the enemy, in turn, was the source of the time pressure that influenced the AAWC's subsequent decision making. In that decision making, he drew on critical thinking about mental models to decide (i) whether to communicate, (ii) how to coordinate without communication, and (iii) how to evaluate communications that did occur. These are, of course, the issues identified in the Introduction as characteristic of time-stressed, novel, and spatially distributed situations. The AAWC's way of handling these issues involved each of the three time orientations:

(1) *Should we communicate?* Through critical thinking, the AAWC decided not to wait for closed-loop communication with the Battle Force commander. Waiting would have entailed an unacceptable loss of initiative with respect to the enemy. Instead, he chose to be *proactive* both with respect to the enemy and with respect to the Battle Force commander (and his own TAO). Consistent with Figure 4, the key mental models in this critical thinking process were friendly *purpose* (to prevent damage to the battle group by the missile site), and shaping both *enemy intent* and *friendly intent* (i.e., eliminating options).

(2) *What will the others do?* On the other hand, the AAWC also used critical thinking to achieve as much coordination as possible despite the lack of full communication, through a *predictive* time orientation. For example, he predicted that the standard procedure would not accomplish a strike on the missile with the required accuracy or speed. He also predicted with some confidence that friendly forces would not be in the area of the target. He predicted that the TAO would go along with the decision presented to him, and that the Battle Force commander would ultimately approve the strike on the missile site. Again consistent with Figure 4, the key mental models were *friendly intent*, team member *reliability* and the *rate of movement* (i.e., likely duration) of a friendly *action sequence*.

(3) *How good is the information?* Finally, the AAWC used critical thinking to evaluate the information that was communicated to him and to *react* appropriately to it. For example, he considered different possible intents of the enemy in turning on the missile site radar. He interpreted the hesitation of the TAO and the Battle Force staff as indicators of habitual caution rather than as signs of actual disapproval or risk. By contrast, he assigned greater credibility to the opinions of the AIC and the staff of the battleship Missouri, both of whom he regarded as more likely to favor decisive action in regard to the enemy. Again consistent with Figure 4, the key mental models were *alternative causes and effects* and team member *reliability*.

By means of critical thinking about mental models, the AAWC was able to develop proactive tactics both toward the enemy and toward his own organization. In doing so, he developed a mutually supporting framework of proactive, predictive, and reactive orientations toward different aspects of the task. He invested a small amount of time thinking in order to buy much more time for action. The long-term result was improved adaptation to environmental variability *at the organization level*.

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