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# Naturalistic Decision Making and Macrocognition

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Chapter 1

# The Macrocognition Framework of Naturalistic Decision Making

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## Introduction

Naturalistic Decision Making (NDM), as a community of practice, has the goal of understanding cognitive work, especially as it is performed in complex sociotechnical contexts. In recent years, the concept of "macrognition" has emerged as a new and potential umbrella term to designate the broader paradigm that underlies NDM. In addition, the notion of macrocognition presents challenges and opportunities for both theory and empirical methodology. The present volume is a contribution to this literature, the seventh volume in the NDM series.

In this chapter we accomplish a number of things. First, we chart the history of NDM as a community of practice and then describe its stance concerning cognitive work and research methodology. Next, we chart the history of the concept of macrocognition and then show how NDM converges with it philosophically. Finally, we use these contexts to overview the chapters in this volume.

## Emergence of the NDM Community of Practice

NDM as a community of practice began with the first conference in 1989 in Dayton, Ohio. That first conference was kept small—only about 30 researchers were invited, based on their interests and activities. Many had been funded by the Basic Research Unit of the Army Research Institute. Judith Orasanu, who was then working in this unit, provided ARI funding to organize the 1989 meeting. The goal of the meeting was simply to assess whether these researchers did in fact have a common, and perhaps distinctive set of goals and methods, and whether those were in any way coherent—even though many of them were studying different domains for different reasons.

The 1989 meeting was intended as a workshop to allow sharing of recent results and interests, but it sparked demand for follow-on gatherings. The NDM community has met every two to three years since then, alternating between North American and European venues. Seven such meetings have been held to date. Thus far, each of the NDM meetings has generated a book describing the research and the ideas of the conference participants (Hoffman, 2007; Klein et al., 1993; Zsambok and Klein, 1997; Flin et al., 1997; Salas and Klein, 2001; Montgomery, Lipshitz and Brehmer, 2005).

How the NDM researchers have managed to maintain their community of practice is perhaps somewhat mysterious. There is no formal society, no officers, no dues, and no newsletters. At the end of each conference, all the attendees who are interested in helping with the next conference gather together to select a host and site. There are always several volunteers to organize the next conference. The community is sustained by common interests and by a desire to find out what the other researchers have been up to. There is of course a great deal of behind-the-scenes work focused on securing sponsorships that really make the meetings possible. Supporters have included the Office of Naval Research, the Army Research Institute, the Army Research Laboratory, the Human Effectiveness Directorate of the US Air Force, the National Aeronautics and Space Administration (NASA), the US Navy, and TNO Human Factors.

In addition to the NDM meetings, many NDM researchers gather every year as part of the Cognitive Ergonomics and Decision Making Technical Group within the Human Factors and Ergonomics Society, and at meetings on Situation Awareness.

## The Paradigm of Naturalistic Decision Making

In the 1980s, a number of researchers adopted a concept of decision making that seemed quite different from the standard "option generation and comparison" framework. Lipshitz (1993) tabulated nine different models of decision making that had been proposed by this emerging community of researchers over that decade. Two of the most widely cited models were Rasmussen's (1983, 1988) Skills/Rules/Knowledge account along with the "decision ladder," and Klein's (1989) Recognition-Primed Decision (RPD) model. The concept of decision making had often been defined in terms of a gamble: given two or more options, with certain information about the likelihood of each option to succeed, which is selected? However, the early NDM studies found that people (domain practitioners, consumers, managers, and so on) rarely made these kinds of decisions. Some have suggested the Klein, Calderwood, and Clinton-Cirocco (1986) study of firefighters marks the beginnings of NDM. Using a structured interview method, the researchers found that fire fighters do not evaluate options. They do not conduct anything like a "utility analysis" in which a list of options is generated, and each option is evaluated. More importantly, this is a domain in which decisions could not possibly be made using utility analysis. Thus, what purchase on reality was had by "normative" models that describe how rational decisions *should* be made? The house would burn down, or worse, people would die. In many domains, decision makers often have to cope with high-stakes decisions under time pressure where more than one plausible option does exist, but the decision makers use their experience to immediately identify the typical reaction. If they cannot see any negative consequence to adopting that action, they proceed with it, not bothering to generate additional options or to systematically compare alternatives. Thus, the metaphor of a decision as a gamble didn't seem to apply very often. If the metaphor of the decision as gamble failed to describe what practitioners usually encounter and usually do, NDM would abandon the metaphor and follow the phenomena.

NDM wanted to explore how domain practitioners make decisions in the "real world," under difficult conditions, in order to help them do a better job (Orasanu and Connolly, 1993). Such a goal statement should seem straightforward and yet it triggered a surprising amount of controversy. The lead article by Lipshitz et al. (2001) in a special issue on NDM in the *Journal of Behavioral Decision Making* was accompanied by skeptical commentaries from the Judgment and Decision Making community. Some questioned whether there was anything new about NDM that had not already been embraced by Behavioral Decision Making, and others doubted that NDM had much chance of succeeding. Those criticisms are orthogonal, of course, but were voiced with almost equal vigor and sometimes by the same people.

What is it that arouses such strong feelings, pro and con, for the NDM enterprise?

## Points of Contention

We see three points of contention: approach to subject-matter experts, approach to improving decision making, and approach to research. First, NDM researchers do not see domain practitioners as infallible, but nevertheless respect their dedication, skills, and knowledge. And researchers deeply appreciate any "face time" with experts. NDM researchers want to document practitioner abilities in order to make sure that the subtle skills they have are recognized, understood, and supported in training programs and in decision support systems. NDM researchers seek to understand the true work (for example, information needs and decision requirements). This stance towards the participants in research puts NDM in conflict with some other decision researchers for a number of reasons. Some argue that experts are not special in any way, or that "expertise" is a biased, elitist notion. Some researchers take a fundamental stance: The belief that people tend to follow economic (or "rational") models of costs and benefits when they make decisions. NDM also conflicts with the "heuristics and biases" approach to decision making–NDM sees the strengths in the heuristics, but it looks beyond superficial attributions of human limitations (Flach and Hoffman, 2003), and does not assume that experts are as prone to biases as the literature on heuristics and biases suggests, or even that bias is an inherent and inevitable feature of human decision making.

Second, the NDM stance on improving decision making is to help practitioners apply their expertise more effectively, and help non-experts achieve expertise faster. NDM researchers do not assume that the practitioner has to be force-fed a probability scaling task in order to avoid one or another of the dozens of biases that are believed to pervade human thought. This stance seems to conflict with the position of Behavioral Decision Making to formulate strategies and aids that can replace or fix unreliable human judgment, for example, by having them work through a Bayesian probability evaluation procedure.

Third, the NDM stance on studying decision making emphasizes cognitive field research and cognitive task analysis (Hoffman and Woods, 2000; Schraagen, Chipman, and Shalin, 2000). Today, we have a rather large palette of cognitive task analysis methods (Crandall, Klein, and Hoffman, 2006; Hoffman and Militello, 2008), including the Critical Decision Method, Concept Mapping, various forms of task and goal analysis, and various types of experimental methods such as the Macrocognitive Modeling Procedure (see Klein and Hoffman, this volume). NDM researchers sometimes use simulations, but these have to reflect key challenges of the tasks and engage practitioners in realistic dilemmas. One thing NDM research does *not* do is use artificial paradigms that can be run on college "subjects" in 50-minute sessions.

One thing NDM research usually *does* is rely on methods of structured interviewing and task retrospection. So the very nature of the investigations causes discomfort to some experimental psychologists. NDM deliberately looks for "messy" conditions such as ill-defined goals, high stakes, organizational constraints, time pressure. Such conditions are difficult to capture in the laboratory but certainly determine the types of decision strategies people use in the "real world."

The mission of NDM—to understand how people make decisions under difficult conditions, and how to help them do a better job—meant that researchers could not confine themselves to particular tried-and-true paradigms or stovepiped "fundamental mental operations." Instead, NDM researchers expanded their focus from decision making to cognitive functionalities such as sensemaking, planning, replanning, and related phenomena such as mental modeling and the formation, use, and repair of "common ground" by teams. For example, McLennan and Omodei (1996) have examined pre-decision processes that appear to be critical to success. Mica Endsley's (1995a; Endsley and Garland, 2000) work on situation awareness is central to much of the NDM research. So is David Woods' examination of resilience and disturbance management (Hollnagel and Woods, 1983, 2005) and Vicente's (1999) description of Cognitive Work Analysis methodology. The very notion that decisions are things that are "made" came into question (Hoffman and Yates, 2005).

Since the original 1989 workshop, the NDM community has expanded its mission to "understanding how people handle difficult cognitive demands of their work, and trying to help them do a better job." To have retained an exclusive focus on decision making would have lost sight of the phenomena that were being studied, and could have disenfranchised some NDM researchers, including the authors of this chapter. Thus, NDM does not seem to be just the study of decision making. Certainly no one ever saw benefit to actually limiting the scope of investigations to decision making. The focus of interest has been more directed by the real-world settings that NDM researchers explore and by the demands that these settings place on the people who are responsible for getting the job done, efficiently, effectively, and safely. As a result, some have wondered whether NDM should change its name.

As the NDM framework broadened, researchers came to realize that they were interested in the cognitive functions that were carried out in natural settings. "Naturalistic Decision Making" was evolving into "Naturalistic Cognition." The same kind of mission still applied, and the same cognitive field research and cognitive task analysis methods still applied. But it was time to recognize that the interests of the NDM community had expanded. It came to be generally understood that the designation of NDM made sense primarily in historical context—as a reminder of the initial successes in discovering how decisions are made under time pressure and uncertainty and the importance of studying decision making in real-world contexts—but no longer captured the spirit and mission of the movement.

## Origins of the Concept of Macrocognition

The line of discussion that led to the term "macrocognition" began in 1985 when at a NATO-sponsored conference on intelligent decision support systems for process control, Gunnar Johanssen distinguished micro- and macro- levels in an analysis of decision-making situations:

> Decision making is required on all levels of social life and in all work situations…The macro-operational situations are characterized by the need for decision making during such tasks as goal-setting, fault management, and planning in systems operations or maintenance of man–machine systems…The micro-operations situations involve decision making as an ingredient of control processes, either manual or supervisory, in man–machine systems. [pp. 328–31]

Although this is not quite the sense of macro–micro we rely on today in NDM, it is clearly pointing in the direction of looking at the phenomenology of cognitive work (see Klein et al., 2003).

Not surprising, given that David Woods was a participant in the 1985 conference and co-editor of the resultant volume (Hollnagel, Mancini, and Woods, 1985), the notion of macrocognition, and the distinction with microcognition was manifest in Woods and Roth's (1986) discussion of a hierarchy of decision-making situations—including organizational, macro-operational, and micro-operational levels, in reference to process control for nuclear power.

Ten years later, Pietro Cacciabue and Erik Hollnagel (1995) contrasted macrocognition with microcognition in order to present a view for human–machine systems design that would not take an information-processing approach. This alternative description is of cognitive functions that are performed in natural as opposed to laboratory settings:

> Micro-cognition is here used as a way of referring to the detailed theoretical accounts of how cognition takes place in the human mind…the focus is on "mechanisms of intelligence" per se, rather than the way the human mind works. Micro-cognition is concerned with the building of theories for specific phenomena and with correlating the details of the theories with available empirical and experimental evidence. Typical examples of micro-cognition are studies of human memory, of problem solving in confined environments (for example, the Towers of Hanoi), of learning and forgetting in specific tasks, of language understanding, and so on. Many of the problems that are investigated are "real," in the sense that they correspond to problems that one may find in real-life situations—at least by name. But when they are studied in terms of micro-cognition the emphasis is more on experimental control than on external validity…Macro-cognition refers to the study of the role of cognition in realistic tasks, that is in interacting with the environment. Macro-cognition only rarely looks at phenomena that take place exclusively within the human mind or without overt interaction. It is thus more concerned with human performance under actual working conditions than with controlled experiments. [pp. 57–8]

Cacciabue and Hollnagel argued that the forms taken by macrocognitive theories and microcognitive theories are different, with macrocognitive theories being unlike, for instance, information-processing flow diagrams or sets of procedural rules.

At this point in time the notion of macrocognition had two elements. One was what we might call the Johanssen-Woods assertion that cognitive work can only be understood through study at a number of levels or perspectives (see also Rasmussen, 1986). The other was the Cacciabue-Hollnagel assertion that the information-processing approach provides an incomplete and incorrect understanding of cognitive work.

In 2000, Klein et al. suggested the concept of macrocognition as an encompassing frame for studying the cognitive processes that emerged in complex settings. They attempted to encourage a dialog between laboratory and field researchers. Like Cacciabue and Hollnagel, Klein et al. defined macrocognition as the study of complex cognitive functions, including decision making, situation awareness, planning, problem detection, option generation, mental simulation, attention management, uncertainty management and expertise. In other words, it was dawning on people that macrocognition is what NDM is really about, after all.

## Expansion of the Notion of Macrocognition

Klein et al. (2003) saw macrocognition as a broader framework for NDM, more than the Johanssen notion of levels or perspectives, and more than the mere expansion of NDM to cover phenomena other than decision making. There are explanatory models such as the Recognition-Primed Decision-making model (RPD) (Klein, 1998), decision pre-priming (McLennan and Omodei, 1996), and levels of situation awareness (Endsley, 1995a). There are emergent functional phenomena such as sensemaking (Klein, Moon, and Hoffman, 2006a, b), and problem detection (Klein et al., 2005). Macrocognition is seen as the study of cognitive phenomena found in natural settings, especially (but not limited to) cognitive work conducted in complex sociotechnical contexts. The concept of macrocognition retains the essence of NDM, but with a broader mandate. Figure 1.1 describes the key macrocognitive functions listed by Klein et al. (2003): decision making, sensemaking, planning, adaptation/replanning, problem detection, and coordination. Some of these, such as problem detection, emerge in field settings, are rarely considered in controlled laboratory-based experiments, and would be unlikely to emerge in typical laboratory studies of cognition (for example, studies of how people solve pre-formulated puzzles would be unlikely to demonstrate the phenomenon of problem-finding).

Figure 1.1 also shows supporting processes such as maintaining common ground (for example, Klein et al., 2004), developing mental models (Gentner and Stevens, 1983), uncertainty management (Lipshitz and Strauss, 1996), using leverage points (Klein and Wolf, 1998), attention management, and mental simulation (Klein and Crandall, 1995). We differentiate these from the primary macrocognitive functions. In most cases, workers and supervisors are not immediately interested in performing the processes themselves—the supporting functions are a means to achieving the primary macrocognitive functions.

The macrocognitive functions and supporting processes are performed under conditions of time pressure, uncertainty, ill-defined and shifting goals, multiple team members, organizational constraints, high stakes, and reasonable amounts

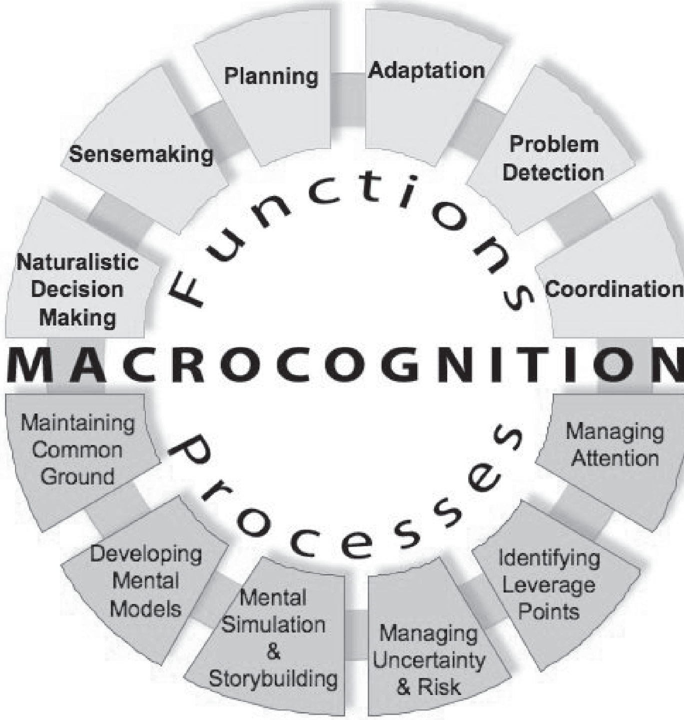


**Figure 1.1 Primary and supporting macrocognitive functions**
*Source*: Adapted from Klein et al. (2003).

of expertise—the same conditions that mark NDM. The primary macrocognitive functions are regularly found in cognitive field research. Macrocognitive functions need to be performed by individuals, by teams, by organizations, and by joint cognitive systems that coordinate people with technology. If we are going to understand cognitive work, and find ways to help practitioners and organizations, we need to learn how these functions are performed, the knowledge required, the information required, the reasoning strategies used, and the means of collaboration and cooperation.

## Contrasting Microcognition and Macrocognition

We define macrocognition as *the study of cognitive adaptations to complexity.* The macrocognitive functions and processes shown in Figure 1.1 are the most salient cognitive adaptations. Of course, lying behind the conceptual definition of macrocognition is a philosophy or view, and an attendant approach to research. Macrocognition can be thought of as a cluster of “isms”: naturalism, functionalism, and phenomenalism. On the other hand, microcognition seems to cluster other “isms”: experimentalism, formalism, and reductionism.

### *Reductionism versus Phenomenology of Cognitive Work*

In contrast to microcognition, which attempts to provide a reductionist, causal-chain account of behavior, macrocognition seeks to maintain a focus on the phenomena themselves. The macrocognition view is intended to spotlight something that seems apparent: In cognitive work the sorts of things that we might point to and call "mental operations"—everything from attention management during multi-tasking situations, to re-planning triggered by problem recognition, to goal and decision modification based on situation awareness—are all, always, parallel and always highly interacting. This certainly is a challenge to causal-chain explanations, including traditional information-processing flow models, hierarchies of procedural rules or conflict-free goals, and millisecond-level access to long-term memory. Decision making usually involves sensemaking and situation awareness; replanning depends on problem detection, and so on. Microcognitive analysis permits computer modeling, especially of well-specified or highly routinized tasks. However, the power of controlled investigation can be a liability in studying cognition under conditions of high stakes, context-rich tasks involving multiple participants and organizational constraints working with ill-defined and shifting goals.

### *Naturalism versus Experimentalism*

Experimental science relies on replication. This might be contrasted with the case study method or, as Jung, Piaget and others referred to it, the "clinical method." NDM research seems to deal a lot with case studies. For instance, the Critical Decision Method (CDM) procedure of scaffolded retrospection yields, in any single study or project, any number of highly detailed case studies from which researchers identify features such as decision requirements. NDM research also seems to thrive on story-telling, using particular cases to convey key points or phenomena revealed about the nature of cognitive work. Often, such cases are rare, or, for the practitioner, tough. Thus, NDM seems to hinge on the study of unique events, situations that cannot be easily replicated. But this is not to say that the core phenomena cannot be replicated, which they are, across cases.

Laboratory science seeks to select and manipulate the key variables that define the situations in which the unique events occur. One must be able to maintain the effects of certain "key" variables. At the same time, one must cope with those "other variables" by holding them constant. Or assuming that their effects are not important and that the interactions with the "key" variables are negligible and uninteresting, and can be glossed over by multiple replications (for example, averaging over large samples). Researchers need to be able to trigger the phenomenon of interest, making it appear and disappear upon command.

But what has this approach done for (or to) cognitive psychology?

Experimental psychology has yet to really recover from the critical claim of Newell in his classic paper, "You can't play 20 questions with nature and win" (1973), or take to heart the critical claim in James Jenkins' classic paper, "Remember that old theory of memory? Well, forget it!" (1974). Newell wondered whether the paradigm of hypothesis testing in the psychology laboratory ever really solves anything, since it seems to be the endless permutation of controls and counterbalancings on topics that come and go as fads; a never-ending game of beating problems to death with pet research paradigms, until people become bored and move on, only to have a subsequent generation re-discover the phenomena and re-invent the wheels. Jenkins (1978) wondered whether theories of learning were really that, or were just models of how particular people (usually, college students) adapt to specific constraints of materials and tasks (for example, memorizing lists of pairs of words) in specific (laboratory) contexts (small quiet room, with table chairs, pencil, paper). Although we saw aftershocks of the Jenkins and Newell papers on occasion (for example, Simon, 1980), cognitive psychology never adequately accommodated, although cognitive science certainly followed Newell's suggestion of trying to escape the problem by building cognitive architectures. Leading experimental psychology journals are still populated by studies of interest to fairly small groups of people who use particular micro-paradigms. Recognizing this state of affairs, George Miller (1989) encouraged psychologists to escape the "analytic pathology" of studying isolated cognitive processes, divorced from practical applications (see Staszewski, this volume).

The study of "real-world" cognition has always been of interest to psychology (see Münsterberg, 1912). We believe that what has led to these two paths—experimental cognitive psychology versus NDM—is the fact that cognitive psychology, and to a surprising extent even applied cognitive psychology, has been situated in the traditional academy. Experimental psychology has as its foundation, programs of studies, not individual experiments, that demonstrate phenomena, control important variables, and then determine causal relations. Such work takes considerable time. One challenge for applied research is that the timeframe for effective laboratory experimentation is vastly outstripped by the rate of change in the sociotechnical workplace, including change in technology and change in cognitive work. In contrast, NDM/Macrocognition are focussed on the world outside the academy. NDM emerged in the private sector, in government, and in sponsored research (in domains such as nuclear engineering, aviation safety, nursing, and so on). NDM research is, by definition, aimed at useful application. Thus, as a community, NDM has resonated strongly to the views of Jenkins and Newell, seeing this as part of the justification for a naturalistic-functionalistic approach to the empirical investigation of cognition.

What kinds of science can be accomplished using field research paradigms? A first part of the answer is that NDM researchers do perform controlled experiments, and NDM never advocated the abandonment of the academic laboratory. Cognitive field studies can involve the control of variables through selection and manipulation (see Klein et al., 2003; Hoffman and Coffey, 2004; Hoffman and Woods, 2000). One can hold variables constant, for example, studying reasoning in a group of individuals who qualify as experts versus a group who qualify as apprentices. One can manipulate variables, for example, number of interruptions while an operator is conducting cognitive work using a prototype of a decision aid. This being said, macrocognition is definitely more akin to the category of scientific investigation traditionally referred to as naturalism. It is often taught that the scientific method begins with observing phenomena and formulating questions. Such activities generate postulates about the phenomena of interest. These need to be tested by seeing the kinds of hypotheses they entail, and looking (somehow) to see how those entailments hold up (replicate), and hold up under other circumstances, to be sure that they are not limited to specific contexts, methods, or special types of participants or conditions. Macrocognitive field research particularly emphasizes the initial steps of formulating questions and observing phenomena, as well as the final step of seeking to generalize across contexts (or domains). In this way, researchers have identified phenomena and variables and relationships that were neglected by and would not have ever been manifested in laboratory investigations characteristic of mainstream cognitive psychology.

Controlled experimentation (or we might say, Popperian hypothesis falsification) is not a privileged path to causal analysis or understanding, and it is not an absolute requirement for any form of empirical enquiry to be dubbed "science" or "good science." Darwin, we might note, tested many hypotheses. In a more recent example, Peter and Rosemary Grant (Grant, 1986) conducted a natural experiment on finches in the Galapagos. The island that they studied, Daphne Major, was hit by a drought in 1977. As a result, one of the prime food sources for the finches became scarce. The finches had to resort to a secondary food source, a type of seed that could only be eaten by finches with fairly long beaks. Approximately 70 percent of the finches on the island died. But the next generation of finches had markedly longer beaks and were larger. The researchers would have had difficulty setting up this kind of experiment, and there was no experimental group (nothing was manipulated by the researcher) or control group (nothing could be held constant). Nevertheless, the findings are a striking demonstration of natural selection in just a single generation. The story continued in 1984–85 when the unusually rainy weather resulted in more small, soft seeds and fewer large, tough ones. Now it was the finches with smaller beaks that held an advantage and produced the most offspring. Must one try to take this sort of thing into the lab before one can believe that there is a cause–effect relation?

The most often-mentioned contrast case is astronomy. Astronomers cannot manipulate stars to test theories of internal stellar processes. But they can select groups of stars by some criterion (for example, red giants) and then falsify hypotheses about stellar processes (for example, red giants should all emit a preponderance of certain wavelengths of light). Macrocognitive research has repeatedly demonstrated and studied phenomena that would be difficult or impossible to capture in the laboratory. A good case in point involves the phenomenon of perceptual learning. While long recognized within psychology (see, for example, Gibson, 1969), the phenomenon is hard to study for a number of reasons. The most salient of these is that the acquisition of a perceptual skill takes time, for example, years of practice and experience to learn to interpret aerial photographs (Hoffman and Conway, 1990). It is hard to capture perceptual learning phenomena in the laboratory (see Fahle and Piggio, 2002). (One cannot fail to notice that laboratory studies of perceptual learning involve experiments in which college students view sets of static, simple stimuli, for example, line caricatures of faces, outlines of trees, and so on.) In his study of landmine detection (see Chapter 16, this volume), James Staszewski discovered how an expert used the landmine detection device in active perceptual exploration. From an understanding of the expert's exploration strategy and the patterns perceived through the dynamic exploration, Staszewski was able to develop a training program that significantly accelerated the achievement of perceptual expertise at landmine detection. Another way of putting this is that Staszewski was able to capture a perceptual learning phenomenon in the field setting.

When queried, NDM researchers and advocates of macrocognition are more likely to regard their work as "basic science" than applied science, without giving the matter much of a second thought. The research is aimed at revealing fundamental facts and regularities about cognitive work. We started out our discussion of the macro–micro distinction by noting the "isms": Macrocognition involves naturalism, functionalism, and phenomenalism; microcognition involves experimentalism, formalism, and reductionism. We conclude here by noting the most important "ism," one that that micro- and macrocognition share: *empiricism*.

All scientific methods and strategies have appropriate uses, strengths, and limitations. The concept of macrocognition is specifically chosen to create a distinction from microcognition, but it is also intended to facilitate connections with the microcognition community, as discussed in the next section.

## Bridging Macrocognition and Microcognition

Staszewski (this volume) rightly warns against presenting macrocognition and microcognition as competing or antagonistic frameworks. Klein et al. (2000) described a number of laboratory phenomena that were relevant to the macrocognitive agenda. Studies of categorization, particularly the distinction between taxonomic and thematic categories, have direct implications for the design of useful menus in human–computer interfaces. Studies of national differences in cognitive processes, such as tolerance for uncertainty and hypothetical reasoning, can inform individual and team training as well as computer interfaces. Research on polysemy (the way a single word evokes multiple related senses) shows that words are tools and their meanings evolve through changing use. The expansion of word usage suggests ways that context can be used to disambiguate meaning—a process that supports better design and use of multi-function interfaces.

Therefore, cognitive field studies identify phenomena of interest to macrocognitive models that can be tested in the laboratory; cognitive field studies also offer face validity assessment of laboratory findings and phenomena. Similarly, laboratory researchers generate findings that are of potential interest to macrocognitive investigations. We do not hold that either the laboratory or the field has a privileged position for originating discoveries (see Hoffman and Deffenbacher, 1993). The field setting obviously can serve as the test bed for gauging the practical implications of laboratory findings, and the laboratory can serve as a test bed for evaluating theories and hypotheses that emerge from field studies. One example of the synthesis of NDM and experimental psychology is in the emerging area of macrocognitive computational modeling. A number of investigators have been attempting to model macrocognitive phenomena such as Endsley's model of situation awareness (Gonzalez et al., 2006) and Klein's RPD model (Warwick and Hutton, 2007; Forsythe, 2003; Sokolowski, 2003). While these computational models have a long way to go, they are still very useful for revealing shortcomings in the macrocognitive models, limitations of computer modeling, and for stimulating us to elaborate our accounts more fully.

Another example, perhaps a surprising one, is the potential for fusion between NDM and Behavioral Decision Making (BDM). Kahneman (2003) has recently discussed the "System 1/System 2" framework. System 1 refers to forms of cognitive processing that are fast, automatic, effortless, implicit, and emotional—the kinds of processing strengthened through experience and highlighted in the NDM models of decision making discussed by Lipshitz (1993). System 2 refers to processing mechanisms that are slower, conscious, effortful, explicit, deliberate, logical, and serial. System 2 processing serves to monitor the intuitions generated from System 1. Within the RPD model, the pattern-matching process is an example of System 1, and the mental simulation serves as System 2 monitoring (see Hoffman and Militello, 2008, Ch. 9). The System 1/System 2 framework might form a bridge between NDM and BDM, a bridge that hopefully expands the horizons of both views.

Macrocognition researchers move back and forth from the field to the laboratory, using each setting as needed and as appropriate. More succinctly, *macrocognitive research involves bringing the lab into the world and bringing the world into the lab*. Thus, it encourages traditional laboratory researchers to spend more time observing the phenomena in natural settings.

Figure 1.2 is a Concept Map that summarizes some of the key ideas of macrocognition.

## Putting the Notion of Macrocognition to Work

The notion of macrocognition has uses, both in the practice of research and in advancing our theoretical understandings. First, because of its phenomenological nature, macrocognition may be a practical basis for dialog between practitioners such as system designers and cognitive researchers. Macrocognitive functions concern supervisors and workers—and the sponsors of the research who see a need for new tools and technologies. One can talk with practitioners about macrocognitive functions, and gain purchase on collaborative effort.

Second, macrognition may help us at the level of theory. For instance, macrocognition suggests an explanation of why some cognitive scientists have difficulty with the notion of "mental model" (for example, Hunt and Jossyln, 2007). It can be argued that the notion does not fit comfortably into information-processing views precisely because, as we can see in hindsight, it is actually a macrocognitive notion. The classic literature on mental models (Gentner and Stevens, 1983) points out that mental models (for example, a learner's understanding of how electricity works) involve such elementary phenomena as mental imagery and metaphorical understanding (for example, thinking of electrical circuits in terms of fluid flowing through pipes). Mental models link these to concepts and principles. Thus, a host of mental operations and elementary processes are involved all at once in mental model formation.

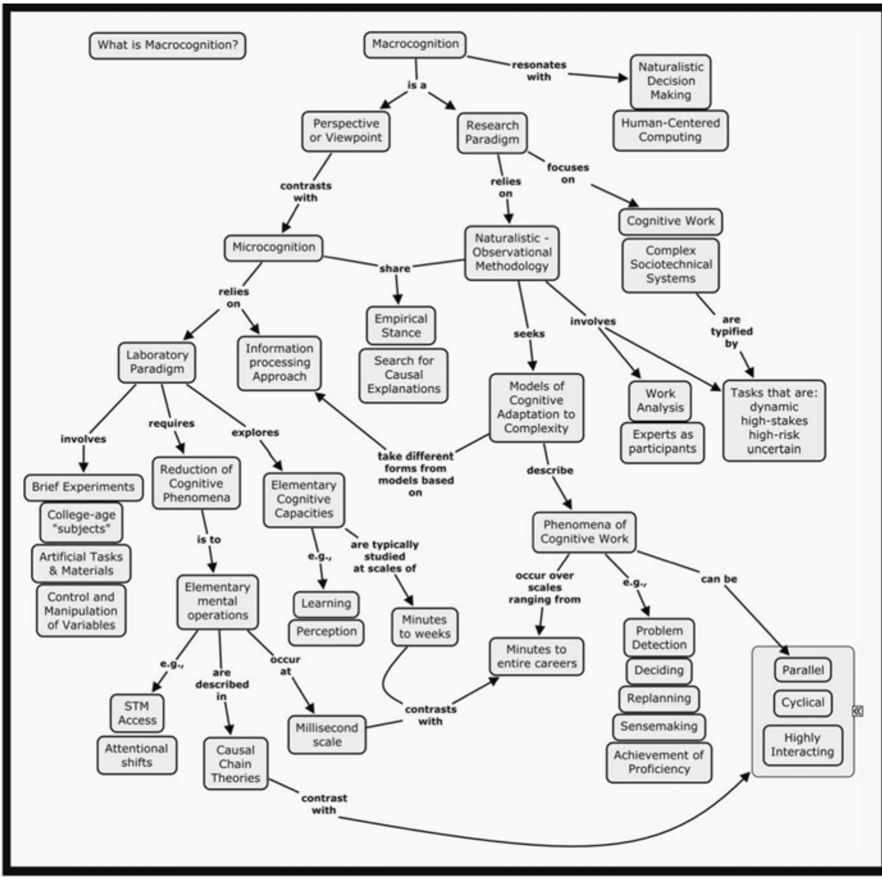


**Figure 1.2 A Concept Map about macrocognition**

The macro–micro distinction encourages us to make further discoveries about the core macrocognitive functions, and pursue the issue of how one can bridge between microcognitive and macrocognitive analysis. Just as the RPD model has changed the way people understand decision making and seek to support it, better models of sensemaking, problem detection, replanning and coordination might have an impact on how we view people performing complex tasks and how we seek to help them. By gaining a better understanding of macrocognitive functions we can provide an alternative to the conventional approaches to design and training and better support the needs of the practitioners—the people taking actions. Some scientists (for example, Flach, this volume) are counseling us to hold off until we are sure we have the right ontologies or metaphysical assumptions, and we look forward to further debate on all these matters. We hope to make progress by forging ahead in empirical study of macrocognitive functions, making mistakes along the way but continuing to learn how people manage to work successfully despite complexity.

Controversy is the lifeblood of scientific fields, and we believe that criticisms of NDM and macrocognition are important. But they should not overshadow the accomplishments of NDM. NDM researchers have developed new models of decision making that are a closer fit to the way people actually settle on courses of action than any previous account. These models have been found applicable many times in different settings. We have identified and described pre-decision processes (McLennan and Omodei, 1996). We have developed models of situation awareness (Endsley, 1995a) and sensemaking (Klein et al., 2006 a, b). We have described the role of common ground in team coordination (Klein et al., 2004). We have developed methods for measuring situation awareness (Endsley, 1995b). We have formulated a variety of system design approaches to support macrocognitive functions (Endsley et al., 2003; Crandall et al., 2006; Vicente, 1999). (A number of rich examples of success stories of cognitive systems engineering, many of which illustrate NDM, are recounted in Cooke and Durso, 2007.)

In gathering data, the field of NDM/Macrocognition is guided by curiosity about how experts are able to notice things that others cannot, and how experts are able to make decisions that would confound people with less experience (Klein and Hoffman, 1992). In addition, we are also seeking ways to help people gain expertise more quickly and take better advantage of the expertise they have. This applied perspective has helped to prioritize important variables that are worth studying, as opposed to variables that probably don't make much of a difference. The balance of learning more about natural cognition along with improving performance is an essential source of vitality for macrocognitive researchers. The models of macrocognitive functions are beginning to be used by practitioners for designing support systems, training programs, and organizational structures. Designers have to support uncertainty management, decision making, situation awareness, sensemaking, replanning, common ground and the other macrocognitive functions and processes. In working on these kinds of applications we have the opportunity to deepen and improve our models.

The present volume represents a contribution to this broader agenda.

## Overview of the Chapters in this Volume

This volume is organized into four parts. Part I focuses on the theoretical underpinnings of the naturalistic decision making approach and its extension into macrocognition. This introductory chapter presents the case from the proponents' point of view, whereas John Flach (Chapter 2) presents a critical view of the macrocognition concept. Flach is afraid that with the proliferation of concepts involving the word "cognition," we will not come any closer to a real understanding of the phenomenon. Inventing yet another kind of cognition or another kind of research method will lead us away from a unified theory of cognition. Knowing the name of something is different from knowing something. Flach agrees that the issues raised by the construct of macrocognition are important. However, macrocognition should keep in touch with mainline cognitive science. All cognition is *macro*. It is only the paradigms of science that are *micro*. Kathleen Mosier (Chapter 3) explores several myths that persist concerning decision processes in high technology environments, including the notions that expert intuitive judgment processes are sufficient in these environments, that analysis has no place in expert decision making in dynamic environments, and that "intuitive" displays can eliminate the need for analysis. Because decision makers in hybrid naturalistic environments are required to use both analytical and intuitive processing, decision-aiding systems should recognize and support this requirement. Mosier makes the case that high-tech decision environments are significantly different from purely naturalistic domains and that this difference impacts all macrocognitive functions.

Part II of this volume ("The Heartland of Macrocognition") focuses on research best exemplifying the concept of macrocognition. Gary Klein and Robert Hoffman (Chapter 4) explore some methods for gathering data, representing, and studying mental models. Mental modeling is a supporting process, especially critical for sensemaking. This chapter is basically an invitation to naturalistic empirical inquiry: If one were conducting cognitive task analysis (CTA) on experienced domain practitioners, for purposes such as cognitive systems engineering, what sorts of methods might be used to reveal mental models? Tom Ormerod, Emma Barrett, and Paul Taylor also explore the macrocognitive concept of sensemaking, particularly in criminal contexts (Chapter 5). They focus on three relatively ill-studied domains: understanding crime reports and scenes, monitoring and decision making during ongoing hostage-taking and barricade incidents, and following up suspicious insurance claims to evaluate whether fraud has been committed. The authors claim that what these domains have in common are an infinite number of possible scenarios which prohibits a rule-based response to an immediate and perceptually-based judgment; a focus on human action and reaction rather than the state of a physical process or plant, and the deceptive nature of the investigative domain. Interestingly, experts in the investigative domain are accustomed to generating alternative hypotheses. Experts appear able to adopt different inferential stances that allow them to evaluate multiple suspicion hypotheses against potential frameworks of guilt or innocence. Crichton, Lauche, and Flin (Chapter 6) describe a particular case study of incident management training in the oil and gas industry. As it happened, key team leaders of the Incident Management Team had participated in a full-scale simulated emergency exercise shortly before an actual incident (similar to the exercise) occurred. This provided a rare opportunity for comparing the transfer from training to actual experiences. It turned out that whereas training exercises generally put a lot of emphasis on the response phase (the first days after the incident), the actual incident was much more demanding in terms of how to deal with the prolonged recovery phase. During training, there was little opportunity to experience making decisions under stress, particularly pressures of time, uncertainty, and event novelty. In contrast, these pressures and challenges were experienced for many of the decisions that arose during the actual event, particularly during the recovery phase, which involved more knowledge-based decision making. As an aside to the definition of "macrocognition," it is interesting to note that Crichton and co-workers use the term "macrocognition" to refer to an "approach" to understanding incident management skills, rather than the macrocognitive functions themselves.

Laura Zimmerman does study one particular macrocognitive function, sensemaking, in the domain of law-enforcement decision making (Chapter 7). In her study, officers were interviewed after watching a video of an actual traffic stop and analysis revealed that, compared to inexperienced officers, experienced officers provide more detailed situation assessments, make more evaluative comments, and discuss officer cognitive processing. Novice officers provide more assessments of safety issues and procedures. Anna McHugh, Jennifer Smith, and Winston Sieck address the relatively novel issue of cultural variations in mental models of collaborative decision making (Chapter 8). Mental models are viewed here as macrocognitive processes that are critical for supporting the full spectrum of macrocognitive functions, including decision making. The specific aim of the current research was to uncover the salient disconnects in mental models of collaborative decision making among people from diverse cultures. This research comes at a time when we are experiencing a strong trend toward using multinational teams to tackle highly complex problems in both commercial and governmental settings. Addressing the disconnects in mental models is important for fostering hybrid cultures in multinational teams. The researchers interviewed 61 people from a variety of nations about their beliefs on how team decision-making practices actually occur in their home culture. Their findings indicate that despite some important differences in mental models of collaborative decision making across cultural groups, the basic set of core elements comprising these mental models seems to be shared. It is the means by which these various elements are carried out that varies. The authors weave a rich tapestry of elements that need to be considered when assembling multinational teams.

Mei-Hua Lin and Helen Altman Klein also address national differences in performing macrocognitive tasks, in particular, sensemaking (Chapter 9). Theirs is a literature review on laboratory studies dealing with holistic and analytic thinking. The analytic-holistic distinction consists of four dimensions that Lin and Klein subsequently discuss in terms of cultural variation: attention, causal attribution, tolerance for contradiction, and perception of change. Each of these dimensions shows a significant amount of cultural variation, between, for instance, Americans and Japanese. It is important to at least be aware of this cultural variation when working together with people from other countries. Susan Joslyn and David Jones present a cognitive task analysis of naval weather forecasting (Chapter 10). Forecasters are thought to be creating a mental representation of the current state of the atmosphere that includes both spatial and temporal components. This has been described as a mental model. By using verbal protocol analysis, they attempt to characterize the forecaster's mental model. Only one of the four forecasters, with over twenty years of experience, appeared to consolidate a mental model of the atmosphere and check it against other information sources. The other forecasters seemed to rely on incomplete rules of thumb. Perhaps creating and maintaining a complex mental representation such as this is a skill that develops with experience and well-developed domain-specific long-term knowledge structures to support it. Moreover, Joslyn and Jones found that information-gathering and model-evaluation processes had been reduced to a routine. Forecasters relied on a few tried-and-true procedures rather than creating new solutions specific to each situation. In addition, these forecasters relied on favored models and products suggesting selection based on habit and ease of access rather than on the weather problem of the day, or on superior relative performance of a computer model in the current situation. Although this inflexible approach is unlikely to produce the optimal decision in the abstract, it provided the forecasters with adequate answers and allowed them to get the job done in a timely fashion.

We now turn to two chapters in the health care domain. Laura Militello, Emily Patterson, Jason Saleem, Shilo Anders, and Steven Asch describe a study on improving the usability and effectiveness of computerized clinical reminders used in the ambulatory care unit of a Veterans Administration (VA) hospital (Chapter 11). They address a long-standing issue in the cognitive task analysis literature: how to overcome the barrier between human factors researchers and software designers. As the clinical reminder software was already fielded, a complete redesign was not feasible. The authors chose to present their recommendations as design seeds. The goal of this approach is to communicate the intent behind the recommendation and present whatever data is available regarding its feasibility and likelihood of success. Intent information is also aimed at reducing the likelihood that design ideas will be distorted due to miscommunication in the hand off between the researchers and the implementers. Simon Henderson discusses experiential learning in surgical teams (Chapter 12). The chapter describes the development and application of a process of "Team Self-Review" for surgical theater teams, and examines how the naturalistic approach adopted throughout the study has uncovered empirical support for the concept of macrocognition. The Team Self-Review consists of a Pre-brief and a Debrief. The Pre-brief is held at the beginning of a team "session" (that is, an operating list, case, training exercise or other event) and the Debrief is held at the end of the session. The Pre-brief aims to review and clarify the plan for the session ("What do we need to know? What are we going to do? What should we do if…?") and the debrief aims to assess and review team performance in the session that has just occurred ("How well did we do? What should we do differently in the future?"). The project has gathered a great deal of press and publicity, and its impact has been cited by the Chief Executive of the British National Health Service, as an example of successful organizational learning in the NHS.

Part II of this volume is concluded by a chapter on the macrocognitive functions in the air traffic control tower (Chapter 13). The air traffic control tower (ATCT) work domain involves a full spectrum of macrocognitive functions, including naturalistic decision making, sensemaking and situation awareness, planning and re-planning, problem detection, and coordination. These macrocognitive functions require the execution of processes that include the formation and use of mental models, the management of uncertainty, and, perhaps of foremost importance in the ATCT domain, the management of attention. Peter Moertl, Craig Bonaceto, Steven Estes, and Kevin Burns discuss three methods—cognitive modeling, critical incident analysis, and coordination analysis—that allow them to make predictions about the effects of procedural changes on air traffic controller performance.

Part III of this volume focuses on the relationship between micro- and macrocognitive approaches. Claire McAndrew, Adrian Banks, and Julie Gore describe how the microcognitive focus of the ACT-R model enables the specification of micro processes that exist both within and between a number of macrocognitive processes (Chapter 14). They focus on the theoretical validation of the Recognition-Primed Decision Making model. The success of their ACT-R model as a tool for validation is most markedly characterized by the agreement between ACT-R's trace outputs to the RPD models' descriptions. A detailed examination of the differences between the two models yields recommendations for how to improve the RPD model. For instance, in ACT-R, situation familiarity is assessed after the selection of relevant cues, whereas in the RPD model the question of "Is the situation familiar?" precedes the identification of relevant cues. Also, in instances whereby the situation is not viewed as familiar, the ACT-R model is more complete than the RPD model, which is underspecified in this case. In the end, the authors consider the micro–macro distinction as artificial and unnecessary, much as Flach does in Chapter 2. Rather, they propose, like Klein et al. (2003), that "the two types of description are complementary. Each serves its own purpose, and together they might provide a broader and more comprehensive view than either by itself."

Stephen Deutsch describes a micro-approach to a macro-phenomenon: a cognitive model of a captain's planning and decision-making processes (Chapter 15). Based on the 2 July 1994 windshear accident at Charlotte/Douglas International Airport, the model fostered new insights into aircrew decision making that were sources of human error contributing to the accident. In the Charlotte windshear threat situation, there was a straightforward plan for a microburst escape to be put in place, yet a creative action selection process was employed. Had the error been grounded in a skill- or rule-based decision, the exact execution of an alternate procedure would have been expected, yet the plan and its later execution were found to be a composite that drew on elements from three procedures. Whether as a conscious or non-conscious process, the cues presented in the evolving situation led to the construction of a compelling narrative and it was that narrative that dominated the process and drove the form of the actual plan. The plan as briefed was not working and unfortunately, the belated call for a microburst escape maneuver did not lead to a successful outcome.

The final chapter in Part III investigates whether information-processing models of expert skill are useful for designing instruction in the high-stakes domain of landmine detection (Chapter 16). Landmines are a major threat to military personnel engaged in combat and peacekeeping operations and also pose a multi-faceted humanitarian threat. Eliminating mines first involves detecting their locations. The task is hazardous because it involves fallible humans operating hand-held equipment in close proximity to hidden live ordnance. It appears that there are large skill differences, with most US soldiers' performance being dangerously low, while some heavily experienced operators produce more than 90 percent detection rates. James Staszewski has designed instruction in landmine detection based on the heavily experienced operators' knowledge content and organization. Results showed that training based on expert knowledge and techniques raised aggregate detection rates to 94–7 percent and produced six-fold gains in detection of the most difficult-to-find low-metal anti-personnel targets. The results of these and other training programs developed by Staszewski demonstrate the practical utility of expert models as blueprints for instructional design. The US Army's decision to adopt and use these training programs illustrates end-users' assessment of their practical value.

Finally, Part IV of this volume presents two chapters that deal with macrocognition from a cognitive systems engineering point of view. Rogier Woltjer, Kip Smith, and Erik Hollnagel deal with the timely problem of network-based command and control (Chapter 17). This chapter describes a method for generating ecological representations of spatial and temporal resource constraints in network-based command and control, and illustrates its application in a command and control microworld. The method uses goals-means task analysis to extract the essential variables that describe the behavior of a command and control team. It juxtaposes these variables in ecological state space representations illustrating constraints and regions for opportunities for action. This chapter discusses how state space representations may be used to aid decision making and improve control in network-based command and control settings. Examples show how state space plots of experimental data can aid in the description of behavior vis-à-vis constraints. Mark Neerincx and Jasper Lindenberg present a Cognitive Engineering (CE) framework to realize an adequate human-machine collaboration (HMC) performance, in which generic human-factors knowledge and HMC solutions are refined, contextualized, and tested within the application domain, as part of an iterative HMC development process (Chapter 18). Instead of one generic method for HMC design, they propose to establish *situated* cognitive engineering methods that comprise an increasing knowledge base on the most relevant human and machine factors for the concerning operations and technical design space in the different application domains. The CE framework incorporates regular meta-engineering activities to attune the CE methods and tools to the changing situational constraints. Two case studies show the development and application of such a set of methods and tools, respectively for space stations (that is, SUITE) and naval ships (that is, SEAMATE). The evaluations in the naval and space domains improved our understanding of the relevant macrocognitive functions, such as situation assessment during naval damage control and problem detection during payload operations in a space station.

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