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Macrocognition in Complex Team Problem Solving

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- **Track 4: Cognitive and Social Issues**
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ABSTRACT

Defense transformation has dictated that coalition operations, joint force actions and multinational response teams will all be integral to the force of the future. Therefore, a critical objective of C2 in the 21st Century will be to accomplish *Knowledge Interoperability*. Missions will be interconnected and interdependent, sociotechnical factors will increase, and cognitive work will be distributed among people and machines. This increases the need for teams to plan, think, decide, solve problems, and take action as integrated units. In this paper we describe a multi-disciplinary theoretical framework of macrocognition so as to support research in collaborative problem solving in C2. We define macrocognition as the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a-kind, collaborative problem solving. We build upon theoretical underpinnings from the cognitive and organizational sciences and integrate these with naturalistic decision making. We have two overarching goals with this effort. First, our short-term goal is to identify and define the key collaboration stages, and the associated major macrocognitive processes and sub-processes. Second, from this, our long-term goal is to develop a richer understanding of the varied concepts necessary to capture the complexities inherent in collaborative problem solving so as to eventually drive improved collaborative decision making and team collaboration tools.

Macrocognition in Complex Team Problem Solving

Defense Transformation has dictated that coalition operations, joint force actions and multinational response teams will all be a relevant part of the force of the future. As such, a critical objective of C2 in the 21st Century will be to accomplish *Knowledge Interoperability*. Missions will be interconnected and interdependent, sociotechnical systems will be ubiquitous, and cognitive work will be distributed among people and machines. From this we will see an increased need for teams to work together to plan, think, decide, solve problems, and take action as integrated units. These conditions require, now more than ever, collaboration and effective team decision making among all involved. Because of this prevalence of teams today, many are formed without much forethought and the expectation that only success can result from teamwork and team decision-making. The reality is that there is little guarantee of success, as many teams fail for any number of reasons. In this paper we present a multidisciplinary discussion of team decision making in dynamic environments to help the operational community better understand the cognitive components of complex collaborative problem solving, that is, macrocognition in teams.

Our earlier work (Warner, Letsky, Cowen, 2005) in understanding the macrocognitive processes in team collaboration has produced a preliminary conceptual model of team collaboration, which is illustrated in Figure 1. This model evolved over four years through the empirical research and technical workshops sponsored by the Office of Naval Research Collaboration and Knowledge Interoperability (CKI) program. Current empirical research suggests that teams solving complex, one-of-a-kind, time critical collaborative problems go through four stages of collaboration. The stages are *not always sequential* as they appear in Figure 1. Because team communication activity is very dynamic, the flow of communication can follow virtually any path. The cognitive processes within each stage are represented at two levels: *metacognitive,* which guides the overall problem solving process, and *macrocognitive*, which supports team member's activities (e.g. knowledge building, development of solution options, reaching agreement on a Course of Action) within the respective collaboration stage. In addition, there are various communication activities (i.e. verbal and non-verbal) for developing the metacognitive and macrocognitive processes. The specific definitions of each of the macrocognitive processes with the model is described in Warner, Letsky, Cowen, 2005 along with two empirical experiments on understanding the significant processes that impact team collaboration. One of the lessons learned from this research is the need for better operational definitions, from a cognitive science viewpoint, for each macrocognitive process. These definitions will permit better measurement of the macrocognitive processes during team collaboration. A second lesson learned is the need to understand the *contribution* and *consistency* of each macrocognitive process across different problem domains relevant to the C2 environment, which will provide a deeper understanding of how these processes impact team collaboration performance.

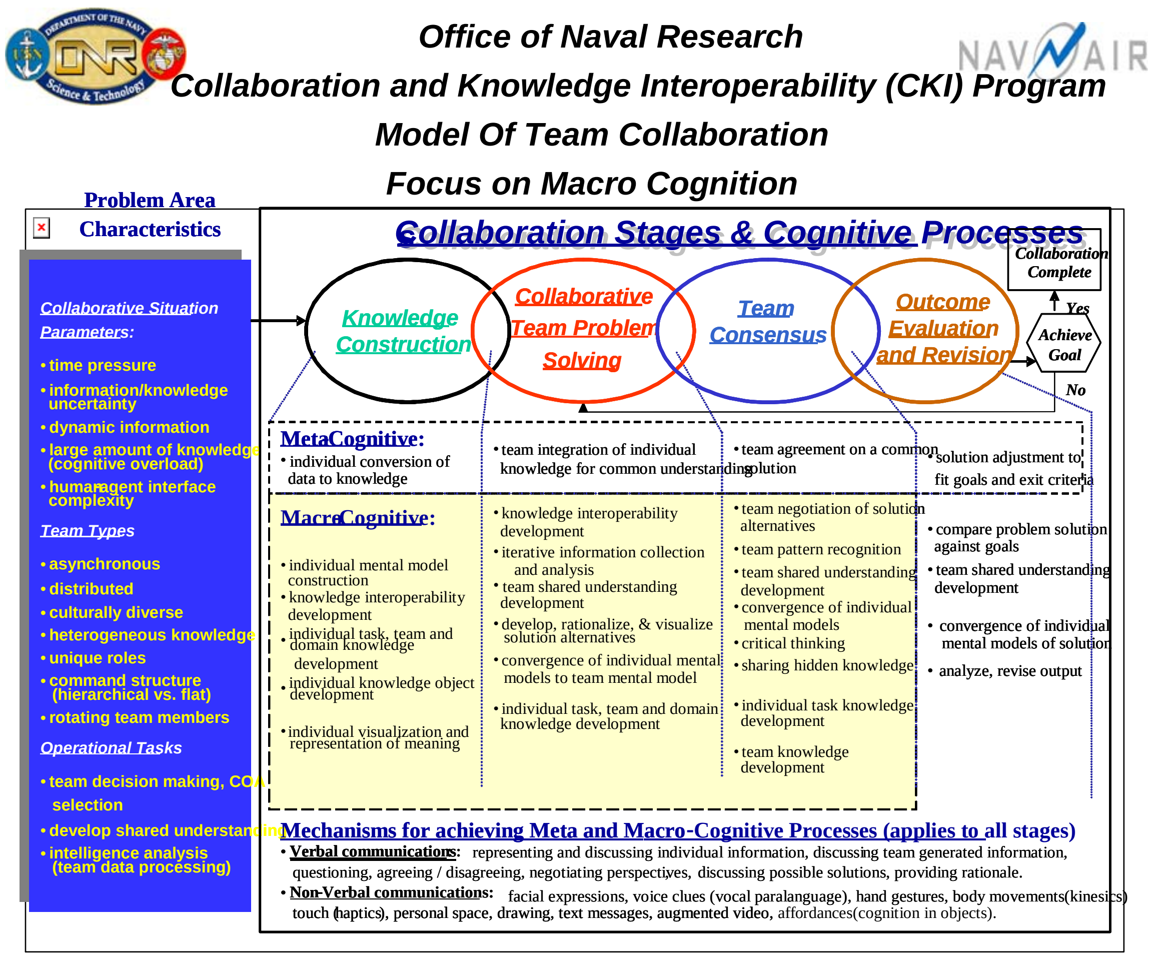

Figure1. *Model of Team Collaboration: Focus on Macrocognition*

This paper is our next step in further defining these key macrocognitive processes. We begin with a discussion of a taxonomy of processes related to macrocognition in teams in order to help research and practice in collaborative problem solving. In our first section we provide a brief overview of some of the scientific and operational issues associated with the study of this complex collaborative activity. Our second section provides a specific definition of macrocognition in comparison to cognitive engineering and naturalistic decision making. In our third section we briefly describe the stages of collaboration involved in macrocogntion. Our final section presents an initial set of major macrocognitive processes and sub-processes that support the various collaboration stages.

Problem Overview

Types and definitions of teams vary somewhat, from "interdependent collections of individuals who share responsibility for specific outcomes for their organizations" (Sundstrom, De Meuse, & Futrell, 1990, p. 120), to "two or more people who interact dynamically, interdependently and adaptively toward" a shared goal (Salas, Dickinson, Converse, &

Tannenbaum, 1992, p. 4). This paper focuses on problem solving teams, that is teams collaborating in short-term situations requiring relatively rapid action to be taken against specific missions. Such teams often posses a diverse membership, heterogeneous knowledge, unique roles, rotating members and a flat or hierarchical command structure. As such, they represent a particularly challenging form of team structure given that they possess a compressed developmental life-span and heterogeneous composition, the combination of which potentially exacerbates problems arising from team collaboration. Moreover, these teams function in an environment ("the wild") characterized by ill-structured and ambiguous situations, where consequences for error are severe and they rely on multiple sources of information.

Macrocognition in problem solving teams involves the study of individual and collective knowledge building and utilization of knowledge in the problem solving process. Macrocognitive processes emerge from interactions at the intra- and inter-team level, and via the interaction of humans and systems. As such, it is an inherently multidisciplinary scientific endeavor. A more thorough analysis of the cognitive and collaborative processes that distinguish effective team problem solving may be possible when studied using complex and dynamic task environments (e.g., Clancey, Sachs, Sierhuis, van Hoof, 1998). Only a limited amount of research has explicitly focused on analyzing the nature and causes of performance among groups interacting to solve complex problems (see Salas & Klein, 2001; Zsambok & Klein, 1997). We argue that the terminologies and their usage within and across disciplines need clarification. In particular, a classification of cognitive processes in a taxonomical format could be a useful indicator of class relationships. Our goal is to develop a coherent set of definitions in order to facilitate research and collaboration in macrocognition in teams.

In addition to the motivation to address these issues from a research/theoretical perspective there is also a strong requirements pull as a result of changes in defense policy. Defense Transformation has resulted in a focus on Network Centric Operations (connectivity) and a movement away from large systems and platforms to agile, quick-response strike groups. The Navy's S&T Community has responded in the form of a Navy Science and Technology Strategic Plan which was presented in a CNR informational brief to the Naval Research Advisory Committee (NRAC) in January of 2007. The plan outlines 13 focus areas which address key *Warfighting & Support Functions*. Three of these areas will depend on the ability of the Combat Team of the Future to meet mission requirements. Such teams will, in view of their mission, face extensive collaborative, problem solving situations (Figure 2).

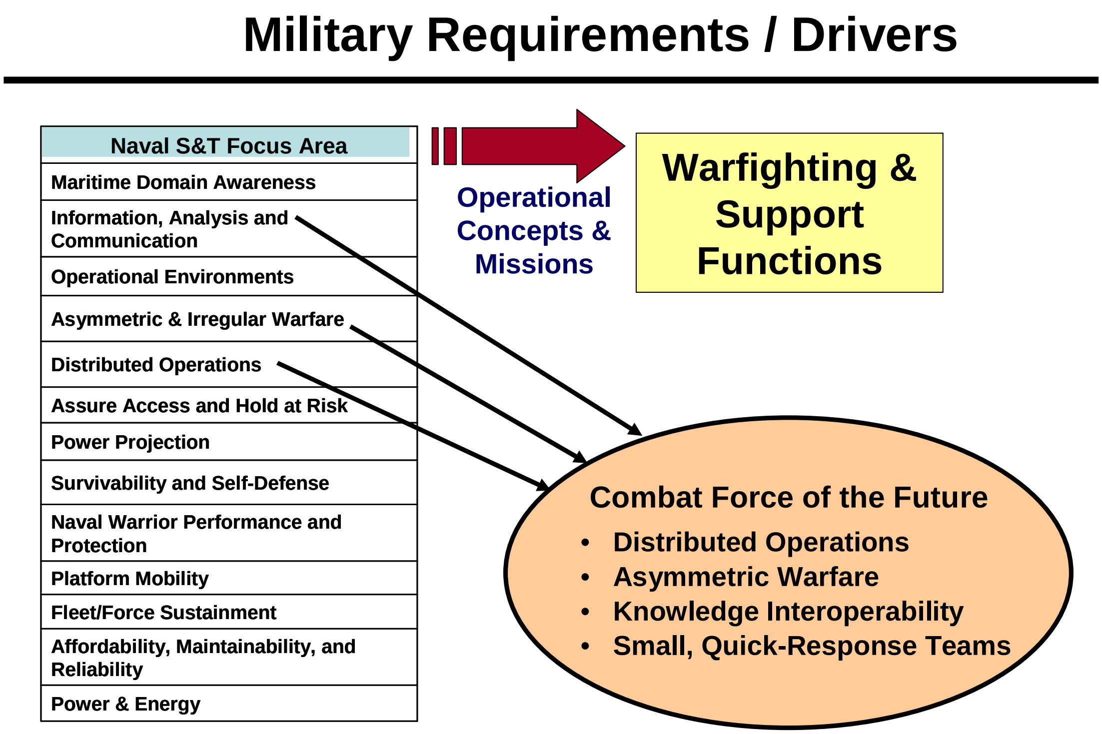

Figure 2. *Illustration of Requirements Pull*

In light of this requirements pull, we suggest that understanding the problem solving process, from problem conceptualization to solution generation and revision, represents a fundamental issue and a critical theoretical gap in our knowledge of teams in naturalistic contexts. In particular, team problem solving involves a substantial reflective component (higher order mental processes) in that successful problem resolution requires adequate knowledge construction, problem definition, collaborative team problem solving and generating consensus on the outcome (Klein & Pierce, 2001; Klein, Pliske, Crandall, & Woods, 1999; Warner, Letsky, & Cowen, 2005). Such stages are necessary, but not sufficient, factors in team problem-solving. What is mandatory is that this conceptualization is shared, that is, a team's comprehension of the critical problem components contains a substantial amount of overlap (e.g., Fiore & Schooler, 2004; Orasanu, 1994). But much of our understanding of collaborative problem solving is based upon a fractionalized conceptualization of its subcomponents across disciplines using similar and differing terminology without the requisite understanding of the integration of these components. Currently, a framework of collaborative problem solving is in development as part of the Navy's Collaboration and Knowledge Interoperability program (Letsky, Warner, Fiore & Smith, in development). This framework encompasses a number of the cognitive processes involved in effective collaboration and in this paper we use these to help guide our identification of pertinent macrocognitive constructs within and across these stages. We will describe the relevant major macrocognitive processes and sub-processes emerging from complex problem solving in collaborative environments and across disciplines.

Defining Macrocognition

Within the field of cognitive engineering, theorists have proposed the term "macrocognition" to describe how cognition emerges in natural environments. This line of thinking is essentially based upon the work of Cacciabue and Hollnagel (1995) who specifically noted: "Macrocognition refers to the study of the role of cognition in realistic tasks, that is, in interacting with the environment" (p. 57). Klein and colleagues have continued to argue that contextually bound cognitive processes (e.g., sense making, uncertainty management) must be studied in natural settings (Klein et al., 2003). These are environments in which complex and emergent cognitive processes arise (i.e., macrocognitive processes), as opposed to "micro-cognitive" processes described as cognition used in laboratory studies. We extend this theorizing and adopt the more recent thinking on *macrocognition in teams*. Here the term is used to capture cognition in collaborative contexts. In their theoretical and empirical analysis of collaborative problem solving, Warner, Letsky, and Cowen (2005) argue that *macrocognition in teams* encompasses both internalized and externalized processes, which occur during team interaction. Here we provide a more in-depth definition of how we are conceptualizing this complex cognitive and collaborative activity and we include a listing of the defining characteristics associated with macrocognition.

Macrocognition is defined as the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a-kind, collaborative problem solving. High-level is defined as the process of combining, visualizing, and aggregating information to resolve ambiguity in support of the discovery of new knowledge and relationships.

Internalized processes are those higher-level mental processes that occur at the individual or the team level, and which are not expressed through external means such as writing, speaking, gesture, and can only be measured indirectly via qualitative metrics (e.g., cognitive mapping, think aloud protocols, multi-dimensional scaling, etc.), or surrogate quantitative metrics (e.g., pupil size, galvanic skin response, fMRI, etc.). Nonetheless, these processes can become either fully or partially externalized when they are expressed in a form that relates to other individual's reference/interpretation systems (e.g. language, icons, gestures, boundary objects).

Externalized processes are those higher-level mental processes that occur at the individual or the team level, and which are associated only with actions that are observable and measurable in a consistent, reliable, repeatable manner or through the conventions of the subject domain having standardized meanings. Although the term macrocognition consists of some of the same characteristics embodied in the recent theories of human cognition, it brings these together along with several unique characteristics (see Table 1 for a listing of the macrocognitive characteristics present in collaborative teams.

Table 1. Characteristics of macrocognition in teams.

Unit of Analysis	*The unit of analysis includes both the individual team member and the whole team because of the unique macrocognitive processes operating at the individual and team level.*
Level of Analysis	*Cognitive activities are analyzed at a high level because of the limitations in using micro cognitive processes to explain higher order decision making mechanisms; additionally, it may be at this level that critical variance emerges, a variance important to differentiating good from poor performers.*
Measurement Focus	*Focus on both internalized and externalized mental processes employed by team members during complex, one-of-a-kind, collaborative problem solving.*
Method of Study	*Macro cognitive processes can be empirically studied in the lab and in operational field settings given domain rich collaborative problem solving scenarios.*
Nature of Occurrence	*Macro cognitive processes (i.e. internalized and externalized) occur during team member interaction (i.e. socially and collaboratively mediated) and are influenced by the artifacts in the environment.*
Dynamic Feature	*Macro cognitive processes develop and change over time.*
Environmental Context	*Macro cognitive processes are domain dependent and collaboration environment dependent (e.g. face-to-face versus asynchronous, distributed collaboration tools).*

Stages of Collaboration in Macrocognition and Taxonomy Constructs

We use the model illustrated in figure 1 as our stepping off point for this work (see Warner, Letsky, & Cowen, 2005). The model has initially been conceptualized as having a set of stages describing collaboration - *Knowledge Construction*, *Collaborative Team Problem Solving*, *Team Consensus*, and *Outcome Evaluation & Revision* (see descriptions below). We are using these stages to help guide our identification of pertinent macrocognitive constructs within and across these stages. The stages are not sequential but are very dynamic with the flow of communication following virtually any path.

- ***Knowledge Construction*** begins by identifying the relevant domain information required, selecting the required team members, setting up the communication environment necessary to address the problem, individual team members developing their own mental model of the problem, and developing individual and team task knowledge.
- ***Collaborative Team Problem Solving*** is where the majority of collaboration occurs among team members. The team's main objective in this stage is to develop viable solutions to the problem.
- ***Team Consensus*** is to achieve team agreement among several viable solution alternatives to the problem.
- ***Outcome Evaluation and Revision***. The main objective of this stage is to analyze, test and validate the agreed upon team solution against the goal requirement(s) and exit criteria. Included in this stage is an iteration loop for deriving other solutions for the problem if necessary.

Processes of Macrocognition

In this section we describe the major macrocognitive processes and sub-processes associated with these stages of collaboration. These definitions are meant to help the scientific and operational communities come to understand and better address the nature of complex problem solving. Also, as seen in Table 2, these initial set of constructs are illustrated. The shaded boxes indicate where these potentially lie within the collaboration stages described above. These constructs are viewed as either major macrocognitive processes or sub-processes. Major macrocognitive processes are shaded in the far left column whereas the sub-processes are shaded in the adjacent columns across the collaboration stages. The terms of data, information and knowledge used throughout the taxonomy are defined using the definition of Bellinger, Castro, and Mills (2004). *Data* represents a fact or statement of event without relation to other things. *Information* embodies the understanding of a relationship of some sort, possibly cause and effect. *Knowledge* represents a pattern that connects and generally provides a high level of predictability as what is described or what will happen next. *Understanding* is a cognitive, analytical and probabilistic process that takes current knowledge and synthesizes new knowledge from previously held knowledge. It is understanding that supports the transition from data, to information, to knowledge.

Table 2. Taxonomy constructs.

Major Macrocognitive Processes (Shaded) and Sub-Macrocogitive Processes	Collaboration Stages			
	Knowledge Construction	Team Problem Solving	Team Consensus	Evaluation and Revision
Individual Knowledge Building				
Iterative Information Collection				
Individual Task Knowledge Development				
Individual Mental Model Development				
Team Knowledge Building				
Pattern Recognition and Trend Analysis				
Team Mental Model Development				
Recognition of Expertise				
Sharing Unique Knowledge				
Uncertainty Resolution				
Knowledge Interoperability				
Developing Shared Problem Conceptualization				
Visualization and representation of meaning				
Building common ground				
Knowledge sharing and transfer				
Team Shared Understanding				
Team Consensus Development				
Critical thinking				
Mental simulation				
Intuitive Decision Making				
Iterative Information Collection				
Solution Option Generation				
Storyboarding				
Team Pattern Recognition				
Negotiation of Solution Alternatives				
Outcome Appraisal				
Feedback Interpretation				
Replanning				
Team Pattern Recognition				

Our first major macrocognitive process is **Individual Knowledge Building.** Individual knowledge building refers to creation of new cognitive artifacts as a result of the interpretation and synthesis of data. These artifacts should advance the current understanding of the individuals within a group to a point beyond their initial level of knowledge, and should be directed towards advancing the understanding of what is known of a topic or idea outside of the group (Scardamalia & Bereiter, 2003). Individual knowledge building is supported by the following sub-processes as defined by Warner, Letsky, Cowen, 2005. **Iterative information collection**, is the collection and analysis of information to build a foundation of understanding necessary to eventually come up with a solution; **Individual task knowledge development**, is individual team members asking for clarification of data or information, or responding to clarification requested by other team members; **Individual mental model development** is individual team members using available information and knowledge to develop their mental picture of the problem situation.

The second major macrocognitive process is **Team Knowledge Building**. A knowledge building community is defined by "a commitment among its members to invest their resources in the collective upgrading of knowledge" (Hewitt & Scardamali, 1998, p. 82). This process serves the development of "the collection of task and team related knowledge held by teammates and their collective understanding of the current situation" (Cooke, Salas, Cannon-Bowers, & Stout, 2000, p. 154; see also Cooke, Kiekel, Salas, Stout, Bowers, & Cannon-Bowers, 2003; and Cooke, Salas, Kiekel, & Bell, 2004). Stahl (2006) views team knowledge development as a process of accumulation whereby complex cognitive and linguistic artifacts are gradually and increasingly refined. Essentially, knowledge building and development involves a form of conceptual change and restructuring via questioning, criticism and evaluation that is inherent in the structure of conversations and debates since these force the participants to produce explanations, interpretations, and resolutions to problems (Brown & Palinscar, 1989). It can be thought of as treating new information as something problematic that needs to be explained (Chan, Burtis, & Bereiter, 1997). This is supported by the following sub-processes.

First, **pattern recognition** involves the perceptual processes used to identify the constellation of cues indicative of some environment or event. Pattern recognition is an awareness of "familiar states of the world" (Hayes, 1989, p. 55) and recognition can be seen as the "ability to discriminate among familiar classes of objects" (Gonzalez & Quesada, 2003, p. 287). Klein and Hoffman (1992) suggest that pattern recognition involves the detection of complex cue configurations which may or may not occur simultaneously. Related to this, we consider the process of **trend analysis** to be a form of pattern recognition that unfolds over time. In this instance the pattern consists of environmental cues that require integration across time for a realization of the critical problem. Handley (personal communication) views trend analysis as a description of "long-term overall movement of the time series data". Smallman (personal communication) views trend analysis as "the identification and monitoring of trends in multi-dimensional evidence evaluation space and the detection of deviations from, and similarity in, those trends over time." Concomitant to this is the process of **Uncertainty resolution.** Since the elimination of all uncertainty is a very unlikely event, Fleming (personal communication) prefers the term Uncertainty Reduction. Uncertainty reduction theory (URT) is a series of axioms which describe the relationships between uncertainty and communication factors in any dyadic exchange that are used to reduce uncertainty. Essentially, uncertainty reduction theory proposes that people are motivated to gather information about others to reduce uncertainty about them. This is followed by the process of **Team mental model development.** Mental models are "psychological representations of real, hypothetical, or imaginary situations" (Johnson-Laird, 1999, p. 525) or viewed as a "mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (Rouse & Morris, 1986, p. 360). Smith-Jentsch et al. (2000) defined teamwork mental model development as the construction of "an individual's understanding of the components of teamwork that are critical for effective team performance, as well as the relationships between those components" (p 180). Related to Team mental Model Development is the sub-process of **Knowledge Interoperability.** Knowledge Interoperability is the result of individual team members representing information or meaning in the form of a knowledge object, an artifact such as an icon, boundary object (Noseck, 2004) or coordinating representation (Alterman, 2001). The effect of such a representation is to make knowledge possessed by individual team members about a fact or event commonly understood (interoperable).

In this context, teams engage also in a **recognition of expertise -** most simply the ability of a team to correctly identify the expertise of its members (e.g. Hollenbeck, Colquitt, Ilgen, LePine, & Hedlund, 1998; Libby, Trotman, & Zimmer, 1987; LePine, Hollenbeck, Ilgen, & Hedlund, 1997), and can be seen as "a group's ability to accurately assess the expertise of its members" (Bonner, 2004, p. 278). More specifically, it transpires when teams and team leaders form a belief about team members' decision quality in the specific decision context and weights the decision inputs of individual team members according to his/her judgment of the individual team member's decision quality (i.e. the team leader's assessment of the team member's task relevant expertise) (Hollenbeck, Ilgen, Sego, Hedlund, Major, & Phillips, 1995). The next supporting process is **sharing hidden knowledge.** This involves unshared (hidden or uniquely-held) information which is considered to be decision-relevant information that is held by one (or more, but not all) group members and is not available to the other group members. Sharing hidden information is an exchange process where any information uniquely held by an individual is made available to all other group members. Further, the group must use this information in their option selection process.

The third major macrocognitive process is **Developing Shared Problem Conceptualization**, defined as the development of a problem space; where the problem solver encodes the salient aspects of the problem at hand such as the problem goal, the initial state, the operators (the actions that change one problem state into another), and the restrictions on the operators (Newell & Simon, 1972; Hayes, 1989). A problem representation includes: 1) a description of the given situation, 2) operators or actions for changing the situation, and 3) tests to determine whether the goal has been achieved (Simon, 1999). A problem representation has four components: 1) a represented world--a description of the problem to be solved; 2) a representing world--the set of elements to be used to depict the objects and relations in the represented world; 3) a set of rules that map elements of the representing world; 4) a process that uses the information in the representing world to solve the problem (Markman, 1999; Novick & Bassok, 2005). Problem conceptualization has also been expanded to the team level (e.g. Fiore & Schooler, 2004; Hinsz, Tindale, & Vollrath, 1997; Orasanu, 1994). In the context of teams, the problem conceptualization stage includes an aspect of sharedness, meaning that some level of overlap between team members' understanding of the essential problem characteristics is a mandatory factor that contributes to a team's ability to build representations that are effective in the generation of quality problem solutions (Fiore & Schooler, 2004). Shared problem conceptualization is supported by the following sub-processes.

First, **visualization and representation of meaning**, is described by Keel (personal communication) in terms of presenting information in pre-processed forms (e.g., pie charts, scatter graphs, line charts, etc.) so that the information is more coherent and easily accessible than in raw data form (Fayyad, Grinstein, & Wierse, 2001). This involves the amplification of cognition by representing abstract data with visual, interactive, and computer-supported representations (Card, Mackinlay, & Shneiderman, 1999). This enables the team in the process of **building common ground,** defined as "the sum of their mutual, common, or joint knowledge, beliefs, and suppositions" (Clark, 1996, p. 93). Most succinctly, common ground can be considered as "the things that we know about what is known by the person we are talking to" (Monk, 2003, p. 270). Others suggest that common ground consists of "the pertinent knowledge, beliefs, and assumptions that the involved parties share. (Klein et al., 2004, p. 92). Each team member has some knowledge of how the others' perspectives differ from his/her own. The process of establishing and maintaining this knowledge builds common ground (Carroll, 2006). Occurring with these is **knowledge sharing and transfer,** a process whereby information is given by one person and received by another. What is received is the information framed by the knowledge of the recipient. Although based on the knowledge of the initial person, the knowledge received cannot be identical as the process of interpretation is subjective and is framed by the recipient's existing knowledge. Knowledge-sharing intrinsically implies the generation of knowledge in the recipient. Knowledge-transfer is information that is passed to another person without generation of knowledge (Sharrat & Usoro, 2003; Miller 2002). These processes enable the team to develop **team shared understanding**, which is the synthesis of essential data, information or knowledge, held collectively by some (complementary understanding) and/or all (congruent understanding) team members working together to achieve a common task (Warner, Letsky, Cowen, 2005).

The fourth major macrocognitive process involves **Team Consensus Development**, According to Fleming (personal communication), this function "involves various forms of group judgment in which a group (or panel) of experts interacts in assessing an intervention and formulating findings by vote or other process of reaching general agreement." Individuals engaged in developing consensus have to operate under three general conditions (Flemming, personal communication): (1) the individuals involved share an understanding that a decision and subsequent action is required that relates the interests shared by the involved individuals and that time is a constraining factor; (2) the proposed options for the decision can be assessed based on bounded rationality; (3) coercion is not an acceptable means to reach consensus. The following sub-process of solution option generation and the **negotiation of solution alternatives** supports consensus development. **Solution option generation (**Handley, personal communication) is the process of generating a set of decision alternatives that satisfy the requirements of the task or goals of the situation (e.g., von Winterfeldt & Edwards, 1986, p.56; Butler & Scherer, 1997, p. 185). The **negotiation of solution alternatives** is described as a process wherein two or more individuals engage in a discussion with the intent of devising a solution to a shared problem. The main impetus behind negotiations is the desire to construct something new which neither individual (or participating group) could create on his/her own (Lewicki, Saunders and Minton, 1999). Throughout team negotiation, the sub-processes of **team pattern recognition** and **iterative information collection** (defined above) are important to enable the team to identify viable solution alternatives that meet problem goals. In developing solution options the sub-process of critical thinking is very important. **Critical thinking** or analytical thinking is the domain of the deliberate reasoning system in that the “deliberate system involves explicit reasoning” (Hogarth, 2005, p. 68). Deliberate reasoning is characterized by abstract thought, precision, and by the use of explicitly definable rules. Others suggest that critical thinking is the "correct assessing of statements" (Ennis, 1962, p. 81). Correct assessing entails "grasping the meaning of statements; judging ambiguities, assumptions or contradictions in reasoning; identifying necessary conclusions; assessing the adequacy of definitions; assessing the acceptability of alleged authorities" (Moore, 2004, p. 5). The next sub-process, **mental simulation** can involve either social phenomena, or systems, or a combination of the two. For example, it can be seen as the “ability to imagine people and objects consciously and to transform those people and objects through several transitions, finally picturing them in a different way than at the start” (Klein, 1998, p. 45). Additionally, it is viewed as a process in which mental models are used to match features of a situation with known similar situations to make inferences about likely future states of the system/situation or outcomes of proposed courses of action (Jones, Quoetone, Ferree, Magsig, & Bunting, 2003). Our next sub-process is **intuitive decision making.** Hogarth (2001) noted that the “essence of intuition or intuitive responses is that they are reached with little apparent effort, and typically without conscious awareness” (p. 14). Intuitive decisions are made with little or no conscious deliberation or effort. Klein (2005) suggested that, “when a team is faced with a decision event, they intuitively compare the event to the knowledge in the shared mental models. If the event can be understood by this comparison, the team implicitly knows the solution and is able to rapidly reach intuitive consensus” (p. 172). If the team cannot implicitly know a solution, iterative information collection (as defined above) is required by the team to derive the needed information to develop solution options.

As these sub-processes transpire, teams may engage in **storyboarding.** Fleming (personal communication) views storyboarding as “a multi-step structure used to focus any topic, and is used by groups or individuals to create a repeatable method for using idea theory to capture, apply and build consensus around what will happen as a result of examining the topic.” Handley views storyboarding in terms of capturing requirements and specifications for system design.

The fifth major macrocognitive process is **Outcome Appraisal.** Here the team evaluates the success of a selected solution option against the effectiveness of meeting their stated goals. In this situation teams may need to adapt or completely change their solution options if the option has been judged not to meet goals. This requires sub-processes associated with **team pattern recognition**, **feedback interpretation** as well as **replanning**. The sub-process of team pattern recognition supports solution option evaluation against problem goals. Some view replanning as task-specific, dynamic, and occurring on either individual or team levels. Cooke (personal communication) views replanning as primarily adaptive in nature in that “it is a response to a change in the environment.” In this way, replanning involves modifying an initial plan on the fly (Klein & Pierce, 2001). Others distinguish between large and small scale replanning. Small scale replanning involves relatively small scale adaptations of an abstract plan to the circumstances of task; this being the primary strength of human decision makers in comparison to machines (Clancey, 1995). Large scale replanning involves the modification, adjustment, or replacement of a plan either before or after it has been implemented (Klein et al., 1999). Feedback interpretation supports this process and it can be described as outcome, feedforward, or cognitive. Outcome feedback comprises information concerning changes in the environment after the decision action, decision outcomes or consequences. Feedforward feedback entails providing a model of the task to the decision maker before the task begins. Cognitive feedback occurs when information concerning relations in the environment, the decision makers perception of the relations in the environment, and between the environment and the decision makers perceptions. (Brehmer, 1990; Sengupta & Abdel-Hamid, 1993; Beroggi & Wallace, 1997; Gonzalez, 2005).

Conclusions

Much of the military research community is increasingly aware that *integrated interdisciplinary technology* is a critical success factor for the 21st Century warfighter. Nonetheless, more is required to enable the scientific and operational communities to achieve the type of coordination that this interdisciplinary focus demands. As scientists from differing disciplines begin to interact in coordinated exploration of complex military environments such as command and control, disciplinary boundaries may create artificial categories of thinking. These categories represent the unique ways that a particular discipline has attempted to address a problem or issue. Nonetheless, specific disciplines do not have a hold on a given problem and many different disciplines simultaneously investigated problems via their own unique approaches and methodologies. For this analysis we have relied upon the theoretical underpinnings of the cognitive and organizational sciences integrated with naturalistic decision making to develop a set of initial definitions associated with macrocognition in problem solving teams. Interdisciplinary contributions however bring challenges with terminology specifically with the explanation of key constructs and defining relationships among the identified macrocognitive processes. As such, we recommend that future research in this area be aware of potential conflicts and complexity to include:

Significance of the terminology:

- Terminology will often be domain specific
- Multiple meanings of terms will likely exist
- Multidisciplinary contributions add complexity to functional relationships
- Granularity of the processes must be defined (nesting of processes)

- A new Ontology may be needed

In addition to concerns with terminology three conclusions are posed as issues to be considered in future research:

- Macrocognition is an understudied construct within team cognition
- Macrocognition is a key factor in team performance in ad-hoc, problem solving teams
- Macrocognition consists of several macrocognitive processes consistently present in collaborative team activity

In this regard this effort lays a firmer foundation for macrocognitive research and the type of endeavors requiring input from scientists from a variety of disciplines. By presenting representative definitions of critical concepts, researchers from differing disciplines may be better able to coordinate their own collaborative efforts. Within this context we suggest that understanding the problem solving process, from problem conceptualization to solution generation, represents a fundamental issue and a critical theoretical gap in our knowledge of team collaboration. This brief review serves to begin laying the theoretical foundation for identifying the constructs supporting this complex collaborative activity.

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