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Team Collaboration for Command and Control:
A Critical Thinking Model

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Abstract

We define an initial framework for understanding, measuring, and managing one form of collaboration: team critical thinking. The framework will be used to understand how team members critique and refine team performance, develop measures of performance, and eventually to create training and decision aids that support this form of collaboration. The framework leverages recent research and theory concerning individual critical thinking, teamwork, and information-age warfare. A sample of measures is presented.

Introduction

Great attention has been paid to the advanced weapons, communications networks, and information systems used in modern battles and experiments. To make effective use of these resources, however, warfighters require effective collaboration tools and practices. In this sense, collaboration is a crucial element of information age warfare. Analyses of a recent Future Joint Forces (FJF) experiment suggest that warfighters recognize the importance of collaboration technologies, and clearly distinguish good technologies from bad (Freeman, et al., 2002). These data have led FJF leadership to argue that improving collaboration tools and their use may provide a better return on investment for DOD than more common hardware acquisition programs (Brooks, Institute for Defense Analysis, personal communication, March 2002).

However, systems in military experiments and the commercial sector illustrate that collaboration tools and practices are often awkwardly implemented and their use is poorly understood. A meta-analysis of laboratory studies comparing face-to-face collaboration with computer-mediated collaboration revealed that computer support for collaboration decreased group effectiveness, increased time to task completion, and decreased team member satisfaction (Baltes, Dickson, Sherman, Bauer, and LaGanke, 2002). A meta-analysis by Dennis and Wixom (2001) showed that decision quality was lower in virtual teams using collaboration technologies than for co-present teams, largely as a function of lower process facilitation in the virtual condition. There is clearly room for significant improvement in the development and use of collaboration techniques and the tools that support them.

To detect these faults and support collaboration better, we need to measure collaboration, refine the technologies and techniques, then measure and refine again and again. To develop valid, reliable, and useful measures, we must understand collaboration. However, collaboration has proved to be a very subtle phenomenon, even when tools are provided to constrain and shape it. Shirany, Tafti, and Affisco (1999) found that the success of collaboration techniques varies with task demands. They found, for example, that experimental teams using group support systems generated more ideas, while teams using basic email performed deeper analyses of the problems (as indicated by a greater proportion of inferences drawn). Maznevski and Chudoba (2000) found that effective teams addressed such issues by implementing strategies for selecting face-to-face or remote communication as a function of the task at hand, and by developing a rhythm of communications that interspersed face-to-face collaboration interspersed with remote communication.

The inherent complexity of collaboration has produced communities of research, under flags such as Situated Cognition and Computer Supported Cooperative Work. However, there is not yet a coherent body of theory concerning collaboration. There is, for example, no generally accepted mapping of team attributes to technology and tasks (Christensen and Fjermestad, 1997), and no solution to the smaller problem of fitting collaboration technology to collaborative tasks (Zigurs and Buckland, 1998). Accordingly, there is little to guide analysis of collaboration and its measurement generally, and little to inform its application within the domain command and control in particular. Yet, collaboration theory and measures are crucial if we are to achieve the full promise of information age warfare.

We are initiating a program of research to focus on one, crucial type of collaboration, which we call team collaboration in critical thinking (TC^2T). In this program, we are drawing on three relevant research threads:

Recent theory and fieldwork concerning individual and collaborative cognition in command and control and other information-intensive organizations has provided insights into the processes by which team members may interpret data to develop information, build understanding that informs decisions, and collaborate to ensure that information and knowledge are shared in support of synchronized action to shape events. Alberts, Garstka, Hayes, and Signori (2001) have developed a framework that clearly defines these (italicized) constructs as primitives of performance in information age warfare. Freeman, et al. (2000) conducted initial validation of a closely related model of knowledge management, based on field observations at a Marine intelligence operation and re-analyzed field data from an analysis of Virtual Information Center (VIC) at The Pacific Command (PACOM).

Research concerning critical thinking has validated a theory of how individual warfighters make decisions under uncertainty. According to the recognition-metacognition framework (Cohen, Freeman, and Thompson, 1998; Cohen and Freeman, 1997; Freeman, Cohen, and Thompson, 1998), expert warfighters (1) monitor for opportunities to critique their assessments and plans, (2) identify sources of uncertainty (specifically gaps, untested assumptions, and conflicting interpretations), and (3) reduce or shift that uncertainty by gathering information, testing assumptions, forming contingency plans, etc., before taking action.

Research conducted under ONR's A2C2 program and other Air Force Research Laboratories human engineering projects has produced a rich body of measures concerning the processes by which teams coordinate their activities explicitly, that is, through explicit communication, and implicitly, through reliance on shared information, shared interpretations of information patterns, and standardized responses to those patterns (MacMillan, Entin, & Serfaty, in press; Macmillan, et al., 2001; Miller, Price, Entin, & Rubineau, 2001; Moon, et al., 2000). In addition, this research has refined the methods of model-based measurement and model-based experimentation, in which experimental hypotheses are developed from models, measures are built to operationalize key variables, hypotheses are tested in models, then tested empirically, and the results are used to refine models for the next round of hypothesis generation, measure construction, and testing.

Our approach is to weave together these three research threads – collaborative cognition, individual critical thinking, and model-based measurement of team performance – to develop a model and validated measures that help us to understand team critical thinking, and eventually to predict and manage this form of collaboration.

The TC^{2}T Model

We leverage the work on collaborative cognition (above) by extending the framework proposed by Alberts, et al. (2001) to draft a TC2T model. That framework specifies that information age warfare involves events in three domains (represented in the diagram by three strata): the physical domain of actions and events; the information domain in which events are observed and communicated; and the cognitive domain in which the warfighter develops understanding in support of decisions that determine further actions. The flow is illustrated in the left portion of Figure 1.

Collaboration between warfighters is represented by overlap or intersections between two of these diagrams. Several points of intersection or linkage are possible (but not illustrated here). Shared (or linked) understanding represents common situation understanding and expectations. Coordinated decisions constitute plans. Coordinated actions denote synchronization. In Figure 1, we have overlaid a node and links to represent collaborative critical thinking, a special case of collaboration. Collaborative critical thinking resides partly in the information domain because it consists of practices, technologies, team architectures, and other enablers that support the sharing of information. It resides partly in the cognitive domain because the content that is shared and critiqued includes individual understanding and decisions as well as observations of effects[1].

To define the processes of collaborative critical thinking, we turn to the recognition-metacognition framework of critical thinking (above) proposed and validated by Cohen, et al. (1997, 1998) in studies of critical thinking by individual warfighters. Team members monitor the state of the mission and the team to discriminate those problems that are satisfactorily addressed with rapid, recognitional decision-making (c.f., Klein, 1993), from those that require more effortful (and time-consuming) critiques. Monitoring triggers a critique of understanding when (1) uncertainty is high, (2) stakes warrant high confidence or accuracy, and (3) time is available for a critique. That critique should uncover gaps in knowledge, conflicting interpretations of the evidence at hand, and/or untested assumptions. It may foster decisions and subsequent actions to passively wait out the development of the situation, or actively shape the battle to acquire information or advantage.

A collaborative extension of this model addresses a number of new issues. For example, it:

- Acknowledges and specifies the role of environmental enables to collaboration, such as technologies, team processes, and team architecture. These enablers make topics of TC^{2}T more (or less) salient and actionable;
- Addresses the ways in which team members raise and resolve issues deserving of critical thought across the team;
- Defines how team members coordinate their actions to resolve or shift uncertainty, by filling gaps in knowledge, resolving conflicting assessments, and testing or replacing assumptions and hypotheses;
- Define the ways in which teams disseminate the results of their collaboration and monitor their impact.
- Defines planning processes by which members identify the issues that should be monitored and the range of acceptable uncertainty or deviation from a norm;

Analytical and empirical studies under ONR's A2C2 research program and related Air

[1] The notion that *cognition* exists outside the mind of the individual stretches traditional definitions of the term. The case for interpreting cognition in this manner has been well argued by Hutchins (1995a), who demonstrated that cognitive acts are afforded and constrained by external entities and objects. Thus, shipboard navigation is seen as a cognitive process that results from coordination between a team of people and by their use of navigation instruments. Hollan et al., (2000) has elaborated this view, arguing that cognition unfolds not just by the manipulation of symbols within the mind of an individual, but through interpersonal exchanges and manipulation of objects.

Force Research Laboratories projects have produced a rich understanding of the relationship between team process, structures, and outcomes, and methods of measuring all of them. These measures address a host of processes relevant to collaboration including information sharing, information transfer via push and pull, specific measures of coordination communications, negotiation over shared assets, task delays due to resource contention, etc. The program has also produced useful measures of the effects of collaboration, such as level of synchronization in time and coordination of asset allocation relative to the threat (e.g., the value of munitions relative to the value of the threat). These and other measures from the literature form the foundation of a basic measurement system that addresses four issues:

- Collaboration Technology Measures of Performance (MOPs) address the impact of selected technologies on the occurrence and quality of TC^2T.
- TC^2T MOPs measure the occurrence, latency, and quality of collaborative critical thinking.
- C^2 MOPs assess the impact of TC^2T on team information management, shared understanding, coordination, and decision-making concerning the C^2 environment.
- Measures of Effectiveness (MOEs) tap the impact of TC^2T on battlefield events, team structure, and team process.

The relationship of the measures to the constructs in the draft model is illustrated in Figure 2. Representative measures are documented in Table 1.

Summary

In sum, we are developing a framework for understanding team collaboration in critical thinking. This work draws on several extant threads of research and is intended to produce useful measures of this phenomenon and, in time, tools for training and supporting the application of this skill in C^2 environments.

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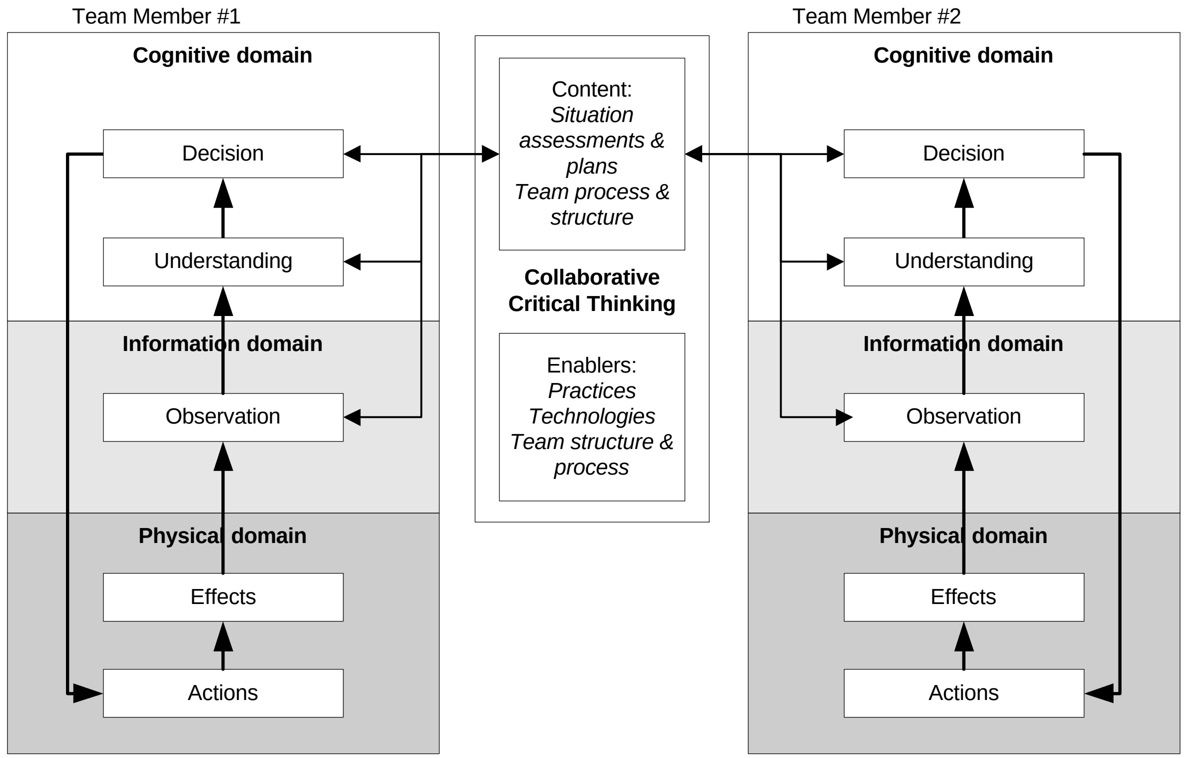

Figure 1: A preliminary model of Team Collaboration for Critical Thinking.

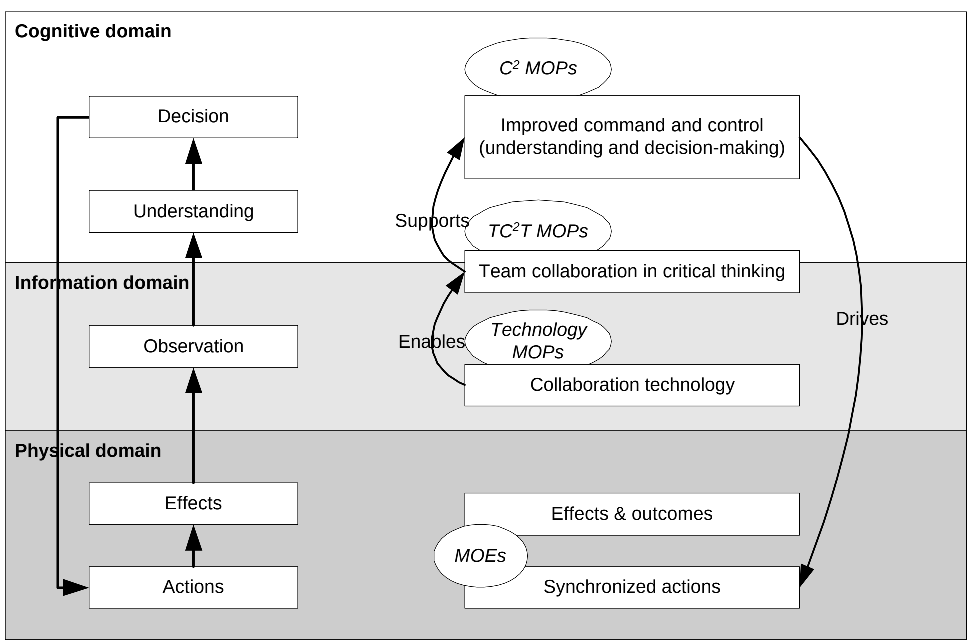

Figure 2: The relationship of four types of measures to the model.

Table 1: Representative measures

Type of measure	Measure	Definition	Source
Collaboration technology MOPs	Reach: Team connectivity	Interconnectivity of team members to each other ("Communities of interest") in Phase I report	Alberts, et al. (2001)
	Reach: Information connectivity	Interconnectivity of team members to information sources ("Information access") in Phase I report	
	Reach: Translation	Degree to which tool supports translation between representations, domains, and languages	
	Richness: Structured problem representation	Degree to which the tool requires structured representations of the problem at hand	Freeman, et al. (2000) (Phase I report)
	Richness: Deconfliction	Degree to which the tool supports coordination of activities via a shared workspace	
TC^2T MOPs	Planning for TC^2T	Collaboration communications (e.g., paraphrasing others, explicit statement of monitoring plans & critieria) during planning stage.	MacMillan, Entin, & Serfaty (in press)
	Monitoring	Number of critiques initiated concerning high priority issues	Cohen, Freeman, and Thompson (1998)
	Diagnosis	Number of gaps, conflicts, and untested assumptions identified	
	Action	Instances of probing own resources for data, testing enemy or environment for data, intentionally waiting out problem	
C^2 MOPs	Shared situation awareness	Degree to which team members share memory for current location of objects in the tactical picture	Endsley, 1988
	Shared predictions of future situation	Degree to which team members share predictions of the location of objects in the tactical picture	
	Shared situation assessment	Degree to which team members share assessments of the intent of entities of operational interest	Cohen, Freeman, and Thompson (1998)
	Mutual awareness of goals	Degree to which team members express shared goals	n.a.
	Mutual awareness of information needs	Degree to which team members anticipate the information needs of teammates	Freeman, Entin, et al. (2002); Entin & Entin (2000)
	Mutual awareness of next action(s)	Degree to which team members anticipate the actions of teammates	
	Mutual awareness of workload	Accuracy with which team members estimate the subjective workload of teammates	
MOEs	Synchronization: Allocation	Proportion of tasks executed without conflicts in resource allocation	Diedrich, et al., (2002)
	Synchronization: Execution	Proportion of tasks requiring coordination that are successfully executed	MacMillan, Entin, & Serfaty (in press)
	Synchronization: Precision	Lag in readiness for execution of synchronized events between first and last operator ready to act.	Diedrich, et al., (2002)
	Effects: Enemy losses	Proportion of targets or threats destroyed	Traditional
	Effects: Friendly losses	Proportion of friendly forces destroyed or lost	
	Effects: Delay in enemy ops	Latency in enemy maneuvers or actions (e.g., bombing targets) due to friendly actions	Traditional
	Effects: Team process	Average delay in task execution relative to optimal task execution schedule	MacMillan, Paley, et al. (2001)