**Introduction**

The ease with which a problem can be solved is influenced by many aspects of both the environment and the decision maker(s) (Jensen, 2002). As problems, technologies, and organizations become more complex, teamwork skills are increasingly important for effective problem solving. Working in distributed teams can pose unique challenges—requiring team member to make contributions to assessments and plans from different locations and at different times. Time and space hinder timely, critical dialogue over assessments and plans (Paulus, 2000) and, as such, are barriers to effective decision making. In particular, such distributed teams may be particularly vulnerable to social loafing (Latane, Williams, & Harkins, 1979) because the collectivist aspect of teams is diminished. Further, it becomes more difficult to assess individual contributions to the team in a timely and relevant manner due to such group phenomena as communications bottlenecks and failures as well as various forms of process loss (Steiner, 1972). Collaboration among asynchronous, distributed, culturally diverse teams is further complicated by the heterogeneous knowledge of specialists, hierarchical organizational structure, and (especially in the military) rotating team members.
Their vulnerabilities notwithstanding, teams are necessary. No individual has enough knowledge or cognitive capacity to fully address complex mission problems in real time. In these cases, a team effort is necessary to ensure that key information is gathered and considered, assumptions are revealed and tested, and plausible interpretations and plans are considered. Accordingly, the military relies on asynchronous, spatially distributed teams to analyze intelligence, develop courses of action, and perform many other tasks.

One strategy to better understand team collaboration, particularly collaboration to critique and refine intellectual products such as assessments and plans, is to begin by taking individual cognition as an analogue for intellectual collaboration. The empirical research literature shows that individuals succeed in solving complex problems in part through experience, which develops the capacity to recognize problems and retrieve solutions from memory (Klein, 1993), and in part by thinking critically about their understanding of the problem at hand and their solutions to it (Cohen, Freeman, et al., 1996, 1997, 1998).

The current research refers to the team analog of individual critical thinking as Collaborative Critical Thinking (CCT). Collaboratively critical teams encourage productive, timely, critical dialogue between team members – a process which should result in higher quality decisions that achieve greater rates of mission success.

This chapter discusses the initial development of the CCT construct and an attempt to develop training and a software tool to facilitate the use of CCT. We begin with a theoretical background that provides a framework for understanding CCT within an
existing structural model of collaboration (Warner, Letsky, and Cowen, in press; Warner & Wroblewski, 2004). Next we discuss the measures, feedback, tools, and training that make it possible for decision makers to develop CCT. We further discuss attempts at validating a polling application developed to enhance CCT: the Collaboration for ENhanced TEam Reasoning (CENTER) tool. Finally we discuss the fielding process for CENTER and conclude with a discussion of future plans for the tool and the training.

**Collaborative Critical Thinking Theory**

A fundamental challenge of military organizations is to operate decisively and synchronously in highly uncertain and dynamic settings. There is strong evidence that individuals succeed in these settings in part by thinking critically about the tasks before them; that is by critiquing their understanding of the situation, improving it, and adapting their decisions accordingly. CCT is the process by which individuals work as a team to apply this cognitive skill to the group level.

Prior to the current research, there has been little, if any, systematic development of theory to guide training, measuring, monitoring, and managing CCT. There are useful foundations for such theory, however, in recent research concerning individual critical thinking and team performance on information-intensive tasks.

A theory of how individual warfighters make decisions under uncertainty has been validated in research concerning individual critical thinking. The Recognition-Metacognition framework (Cohen, Freeman, et al., 1996, 1997, 1998) asserts that expert warfighters monitor for opportunities to critique their assessments and plans, identify sources of uncertainty (i.e., gaps, untested assumptions, and conflicting interpretations),
and reduce or shift that uncertainty by gathering information, testing assumptions, formulating contingency plans and other cognitive and material actions. The current work is extending this theory to team settings.

Research conducted under ONR’s program in Adaptive Architectures for Command and Control (A2C2) has formally modeled teams in decision-making settings in order to optimize collaboration (e.g., MacMillan, Entin, & Serfaty, 2002). This is achieved largely by concentrating – in as few individuals as possible – the information required to perform interdependent tasks (Vroom & Jago, 1988), while balancing this with the requirement to distribute task execution skills and responsibility widely enough to process large numbers of tasks in parallel. A2C2 has developed measures of collaboration; however, these measures are fairly gross in scale – describing the frequency and periodicity of coordination, but not the cause, content, or methods. The present work develops measures of finer granularity, while focusing on team member interactions that critique and refine assessments, plans, and team processes.

**The Context of Collaborative Critical Thinking**

Collaboration builds on the conceptualization of groups as information processors (Hinsz, Tindale, & Vollrath, 1997) where collaboration can be defined as a social process by which people exchange information and perspectives, create knowledge (Rawlings, 2000) and discuss and integrate the implications of these processes. More specifically, during collaboration, people with complementary skills interact to create assessments (shared understanding of events) and plans of action that are often more robust than would have been achieved by any individual alone.
The current work shares its focus on collaboration processes with recent research by Warner et al. (in press) and Warner and Wroblewski (2004). Warner and his colleagues propose that collaboration occurs in four stages:

1. Knowledge base construction – Identifies the human resources, information resources, and technological resources required for successful collaboration and mission execution;
2. Collaborative problem solving – Develops solutions to the problem at hand;
3. Consensus – to achieve team agreement on the common work products;
4. Outcome evaluation and revision – Analyzes, tests and validates the team solution against requirements and exit criteria.

Each stage of this model engages processes of metacognition, information processing, knowledge building, and communication.

Within this model of collaboration, the current research posits that CCT is relevant to all stages of the model (Figure 14.1), but is particularly relevant to three: Problem Solving, Evaluation and Revision, and Knowledge Base Construction. In problem solving and evaluation, team members must voice their reservations about their joint products, investigate the most serious of those deficiencies, and define actions to handle the risks they uncover. In knowledge base construction, team members engage in similar critical thinking interactions to define the team’s structure and processes. Thus, CCT can be seen as a global process that is available in all of the collaboration stages posited by Warner and colleagues.

[Insert Figure 14-1 near here – portrait]
**A Theory of Collaborative Critical Thinking**

CCT is the interaction between team members that manages uncertainty by revealing it, identifying its sources, and devising ways to test its depths or diminish it. The effect of managing uncertainty is to improve estimates of risk so that plans can be verified, made more robust to failure, or discarded.

CCT consists of four unique activities that each team member engages in: 1) *monitoring* interactions that alert other team members to the existence of uncertainty, 2) *assessment* interactions in which team members evaluate the opportunity (e.g., available time) and need (e.g., priority or stakes) to resolve the uncertainty, 3) *critiquing* interactions in which team members identify the source of uncertainty (i.e., *gaps* in knowledge (missing information), *conflicting interpretations* of the evidence at hand (e.g., alternative assessments or plans), and *untested assumptions* that shape the inferences from explicit knowledge; Cohen, Freeman, et al., 1996, 1997, 1998), and 4) devising *actions* that reduce uncertainty, at best, or that compensate for irresolvable uncertainty.

CCT can be used to handle any uncertainty that the team encounters; however, it is most frequently applied to two objects: the specific *mission* or problem at hand, and the team *processes* in achieving that mission or solving the problem. A focus on the mission involves critiquing *assessments* (e.g., of enemy intent, or the state of “friendly” forces) and critiquing *plans* (as is done in Course of Action development and assessment) that are instrumental in mission success. A focus on the team’s process involves a critique of *goals,*
the plans (or strategies) for achieving those goals, and the state of tasks that constitute the plan\(^1\). The behaviors that constitute CCT and their objects are represented in Table 14-1.

Table 14-1: Collaborative Critical Thinking behaviors defined and applied to two objects of analysis: team products and team process.

<table>
<thead>
<tr>
<th>Collaborative Critical Thinking (CCT)</th>
<th>Object of CCT</th>
<th>Team products</th>
<th>Team processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assessment</td>
<td>COA/Plan</td>
<td>Goals</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Detect instances in which critical thinking is needed due to high uncertainty and high stakes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assessment</td>
<td>Detect opportunities to handle uncertainty because time is available to think critically &amp; the problem is of sufficiently high priority (relative to other problems)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critiquing for gaps</td>
<td>Find gaps in information that lead to uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critiquing for assumptions</td>
<td>Find untested assumptions that lead to uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critiquing for ambiguity</td>
<td>Find ambiguous information that supports conflicting interpretations, a source of uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td>Determine what info or tests will resolve uncertainty, or what contingency plans will manage it, then implement them</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CCT is a success when it decisively tests theories or fills critical gaps in knowledge; that is, when it devises actions that produce useful results that reduce uncertainty. However, CCT is also a success when monitoring and assessment interactions increase awareness of uncertainty and its importance. For example, monitoring may uncover gaps in knowledge about the enemy’s true strength (order of battle) so that intelligence assets can be tasked to focus on this issue. A process that unveils uncertainty may counterbalance decision biases – such as representativeness, availability, and

\(^1\) While it is reasonable to think that teams might also focus on the structure of their organization (who communicates with whom, who controls which assets, etc.), in practice teams rarely adapt their structures on the fly to fit the problem at hand, and they rarely do so successfully (Hollenbeck, et al., 1999; Entin, et al., 2004). CCT might encourage rapid and successful adaptation of team structure; however, we have not focused on this application of CCT in the present work.
anchoring and adjustment (Tversky & Kahneman, 1974). These biases are adaptive by design, in that they enable people to decide and act in the face of uncertainty; however, in some circumstances they can be maladaptive.

Organizations often formalize CCT processes and the structures that support it. Military organizations define roles such as scout, air surveillance operator (e.g., the Air Control Officer (ACO) in an E2-C), and tactical intelligence analyst (e.g., imagery analysts). The warfighters who fill these roles serve a monitoring function. The procedures (implicit collaboration) and communication protocols they use are designed in part to handle new but unevaluated (uncertain) entities and events and to supply relevant and timely information to their teammates.

Assessment and critiques of mission information are to some extent built into the jobs of individuals (e.g., the ACO has procedures for evaluating unidentified entities), and to some extent addressed by interactions at the command level. For example, critical incident interviews in the TADMUS program provide some evidence that the Commanding Officer and Executive Officer in the Combat Information Center (CIC) revealed or negotiated conflicts in their assessments, and critiques of the intent of unidentified aircraft that were engaged in nominally threatening behaviors (Cohen, et al., 1998). Assessment and critique are more common and observable in team activities that unfold at a slower pace than CIC operations. Mission planning, for example, includes phases of Intelligence Preparation of the Battlefield, Course of Action (COA) generation, and COA evaluation that are designed to identify what is known, unknown, inferred and (to a lesser extent) assumed.
The selection and execution of actions to resolve uncertainty are often formulated as Standard Operating Procedure in tactical operations. For example, watchstanders in the CIC have a few, well understood actions with which to resolve uncertainty concerning track identity and intent. These include such things as radio queries, visual identification, and inference from kinematic information (e.g., the acceleration or turn rate of an aircraft. In less well-defined domains, such as Military Operations on Urban Terrain, intelligence analysis, and mission planning, decision makers have a vast range of techniques for gathering needed information, testing for information that discriminates between conflicting assessments, and testing assumptions. MOUT soldiers, for example, may test for the presence of enemies within a room by looking through the door, listening through walls, applying video cameras through windows and other holes, and observing the behavior of nearby civilians who may have observed the enemy’s entry to the room. The primary challenge in selecting actions is, of course, determining which actions will efficiently and reliably produce useful information, information that bears on the identified source of uncertainty.

Thus, the ability to exercise critical thinking credibly and productively is in part a function of domain expertise; CCT is not a process for novices. CCT leverages expert knowledge of what to monitor, how to assess opportunities and need for critical thinking, how to critique a solution (e.g., what information has not been considered, what assumptions have not been tested), and which actions resolve deficiencies in assessments and plans. Furthermore, although highly effective expert teams can make collaboration look easy, collaboration is not an innate skill. Individuals have been trained to exercise
better critical thinking processes and thus make better decisions – the effects of which were increased accuracy of their judgments about complex problems (Cohen, Freeman, and Thompson, 1998) and more appropriate language used to express them (Freeman, Thompson, and Cohen, 2000; Freeman, Cohen, and Thompson, 1998). There are strong indications that CCT can be trained; empirical research by Entin & Serfaty (1999) demonstrated that training to help teams reduce uncertainty about (or focus on) future goals and tasks produced better team performance and mission outcomes. The current research posits that even novice teams can learn interaction processes that facilitate CCT.

Finally, it is important to note that CCT is necessarily a cyclical process (Cohen, et al., 1996, 1997, 1998) (see Figure 14-2). Actions produce changes in the state of the perceived environment or knowledge about it. This informs monitoring – ideally reducing alerts concerning the presence of uncertainty. The process is also variable in its structure (as indicated by the shortcut around critiquing, in the figure). The function of assessment is to determine when to invest team effort in critiques, and when to act immediately. Assessment is, thus, a branching function that accommodates rapid, recognitional decision making (Klein, 1993) on the short path, and more deliberate analytic decision making on the other.

[Insert figure 14-2 near here – portrait]

**CENTER**

CENTER is a software system designed to improve team members’ collective knowledge and decisions by enhancing CCT. The CENTER tool (1) enables a leader to query members of the organization concerning the state of mission knowledge and
decisions, (2) elicits brief responses and summarizes them statistically, and (3) presents these measures to leaders with guidance concerning the issues on which leaders should focus their attention and that of members. In short, CENTER helps leaders to measure, monitor, and manage CCT about team knowledge and decisions.

**Measuring Knowledge**

One management adage states that “You can’t manage what you can’t measure.” Neither can you understand it, train it, or support it with job aids. The object of the current research is to understand CCT, to develop training that supports CCT, and to create tools that enable teams to manage CCT. To do this requires measures of the phenomenon.

CCT is a direct derivative of the literature on individual critical thinking, specifically the work of Cohen, et al. (1998; 1997), which empirically validated that individuals who engage in several specific critical thinking behaviors outperform others on tactical assessment, planning, and decision making tasks. CCT involves interaction between team members to reveal uncertainty concerning knowledge or decisions, identify the source(s) of this uncertainty, and devise ways to diminish or accommodate the uncertainty. These collaborative activities may help team members improve estimates of risk and refine plans to accomplish missions in the face of risk. Thus, to create measures of the state of CCT within a team, the current research focuses on measures of its impact on team products (e.g., mission plans) and processes (e.g., team synchronization).

Specifically, the definition of the space of behavior that must be measured can be described as the intersection of two dimensions of CCT (see Table 14-2) – the collaborative activities that constitute critical thinking (i.e., monitoring, assessment,
critiquing (for gaps, assumptions, and ambiguity), and action) and the objects to which it is applied (i.e., team products and processes). Taken together these measures provide a comprehensive assessment of collaboration effects.

Table 14-2: CENTER measures critical thinking activities applied to team products and processes.

<table>
<thead>
<tr>
<th>CCT Behavior</th>
<th>Team products</th>
<th>Team processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>A1</td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td>C2</td>
<td>T1</td>
</tr>
<tr>
<td>Assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critiquing for gaps</td>
<td>T3</td>
<td></td>
</tr>
<tr>
<td>Critiquing for assumptions</td>
<td>P4</td>
<td></td>
</tr>
<tr>
<td>Critiquing for ambiguity</td>
<td>A6</td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td>G6</td>
<td>T5</td>
</tr>
</tbody>
</table>

Measures within this space have been defined as ratings of agreement (strongly disagree to strongly agree) with assertions or probes (below) that can be customized [by adjusting the terminology in the brackets] for a given mission. For example, probes relevant to the marked cells in Table are:

A1: The team's assessment [of _____] is correct.

A6: The team is taking actions to resolve problems with the assessment [concerning _____].

C2: The team has time to critique and refine the plan [regarding _____].

P4: The team has identified key assumptions that have yet to be tested concerning its strategy [for _____].

G6: The actions of team members are consistent with the mission goals [concerning _____].

T1: Team members seek feedback on their tasks [concerning _____].
T3: The team is completing all tasks [concerning ____].

T5: Team members seek to resolve ambiguity in task assignments.

CENTER allows a leader or facilitator to select a subset of probes appropriate to the mission at hand, and customize them or use them in their generic form. The facilitator can then trigger the delivery of each probe to networked members of the team. Each probe appears in a small window in a member’s workspace (see Figure 14-3) with a rating scale and two buttons: one to add textual comments and one to send the response back to the facilitator. Each window disappears after a specified period, and a countdown reminds the team member of this.

[Insert Figure 14-3 near here – portrait]

In experimental research conducted at the University of South Florida, participants found these probes to be useful in a teamwork exercise and non-disruptive of taskwork if they occurred at least three minutes apart.

Monitoring Knowledge

CENTER converts responses to each probe into numeric values, and summarizes them as a mean and range (see Figure 14-4). Leaders or facilitators can view the numeric responses to all probes, or drill down to inspect the responses – both ratings and comments – to any one probe. In this way, leaders can monitor the organization’s state of collaborative critical thinking with respect to mission-specific issues.

[Insert figure 14-4 near here – portrait]
Managing Knowledge

CENTER helps leaders interpret measures of collaborative critical thinking and take action to improve it. It does so by analyzing distribution patterns in each response and presenting guidance to the leader. For example, assume that this probe – “The team has the information it needs to plan.” – is administered to the team well into a long, mission planning task. The distribution of responses across the team may have a high (positive) mean and low variance, indicating that there is near unanimous agreement with the probe statement. In this case, CENTER advises the leader as follows:

*The team members believe that they have the information they need to plan.*

Suggest that they move on. If there is a large team then probe for lone dissenters, if found, engage them, for example: "Would you like to add anything?"

If the responses across the team exhibit an average mean and high variance (indicating that some people agree with the probe while others disagree), CENTER returns the following guidance:

*The team members do not agree whether the team has the information it needs to plan.* Seek to understand why there is so little consensus. Tell those who disagreed with the probe: "Share your concerns regarding insufficient information needed for planning with the other team members. Tell them what information seems to be missing. See if they have that information." Tell the team members who agreed with the probe "Not all team members believe that there is enough information to plan. Find out what information is missing." Help the team quickly get the information it needs.
The facilitator can then send messages to the team members, or the facilitator can engage all or a subset of team members in an instant message session (see Figure 14-5) to facilitate more complete knowledge management.

[Insert figure 14-5 near here – portrait]

CENTER Validation Study

Data were collected to better understand CCT and the CENTER tool. Specifically, a study was designed and implemented to gather validity evidence for the CENTER tool. This study was fully described in Hess et al. 2006. What follows is a high-level description of the study, analyses, and the results and implications for future research, development, and use of the CENTER tool.

**Study:** A study was conducted at a large Southeastern university with 160 college students (30 Men; 130 Women) to assess the utility of 1) training developed to increase a team’s ability to practice CCT, and 2) the use of probes to facilitate team CCT during a team-based task. The seven experimental conditions are provided in Table 14-3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>No CCT training, No “control” training</td>
</tr>
<tr>
<td>“Control”/No probes</td>
<td>“Control” training only (no probes administered)</td>
</tr>
<tr>
<td>“Control”- Preplan Probes</td>
<td>“Control” training and probes were administered during the preplanning phase</td>
</tr>
<tr>
<td>“Control”- Task Probes</td>
<td>“Control” training and probes were administered during the</td>
</tr>
</tbody>
</table>
The probes, developed to facilitate critical thinking, are listed below. They were administered with the CENTER tool either during a pre-planning session (prior to actual task performance) or during the running of the task. It was hypothesized that administering the probes during the planning session would further stimulate critical thinking and thereby facilitate performance, whereas administering the probes during the performance of the task may overwhelm participants and lead to decreased performance. A probe was sent every three minutes until the 42 minute mark of the task. Participants responded to each probe on a 5-point Likert-type scale.

The 10 probes used in the experiment were:

1. The team has the information it needs to plan.
2. The team has a shared understanding of the situation.
3. The team is taking actions to resolve problems with the plan.
4. The team has clearly communicated its goals.
5. The team members are working towards the same goals.
6. The team has considered possible, alternative plans.
7. Alternative plans have been evaluated, according to team goals.
8. The team’s strategy for solving the problem is correct.

9. There is an opportunity to reassign tasks within the team.

10. The team has identified critical assumptions that have yet to be identified.

It was further hypothesized that both CCT Training and the use of the CENTER tool would result in better team performance than no training, “control” training, or no tool use, with the combination of CCT Training with the use of the CENTER tool resulting in the highest performance.

CCT Training: CCT training, fully described in Hess et al, 2006, was presented to the participants through a power point presentation. The presentation gave some background on what CCT is and why it is important. The concept of schemas was introduced to the participants; then two short exercises on recognizing schemas were performed by the participants. At the end of each exercise the experimenter provided an explanation.

“Control” Training: For the “Control” training, a different power point presentation was presented to the participants. In this scenario, the participants were to imagine themselves on vacation in the jungle in a foreign country (such as Mexico’s Yucatan Peninsula). The bus the participants were traveling on was hijacked, but they managed to escape. They were provided a list of materials that were with them and instructions on how to use the natural surroundings to their advantage (i.e. a rock as a hammer or a vine as a tourniquet). The participants were instructed to have a seat at the lab’s central round table and spend the next 10 minutes trying to determine the best course of action to survive in the jungle and eventually make it to safety. This training was used
because the setting gave it face validity (i.e., made it appear to be related to the simulation used for the experiment), without overtly training any behaviors related to CCT.

Once the appropriate training session had ended, all of the participants were informed that they would begin training for the “Artic Survival task.”

The Team’s Task: To assess team performance, teams participated in a computer simulation, or game, called Arctic Survival. The participants were told that the goal of the task was to use simulated “snow cats” and other resources to locate an unmanned aerial vehicle (UAV) and a lost team who is stranded somewhere in the Arctic. In this scenario there are three separate color-coded team members, red, blue, and purple. The administrator was blue. The participants were instructed to direct any questions during the running of the simulation to the blue snow cat.

The red and purple snow cats and resources were controlled by participants; these were the only snow cats able to complete the tasks of the scenario. Communication between the red and purple participants was accomplished through a messenger system built into the simulation. This was the participants’ only means of communication. Each red and purple team consisted of a snow cat, a medic, a technician, a scout, and a mechanic. All four could be put onto a snow cat and transported to various locations. In addition, each color coded team member (medic, technician, scout, and mechanic) started out with a certain amount of usable units. For example, the medic started out with 15 medic units. If a task required 3 medical units to complete, and the red medic was assigned to a task that indicated it needed 3 medical units, then after completing the task the red medic would have 12 medic points. This is similar for each of the other four color coded team members who each started with a
certain amount of points. Each team, red and purple, had the same personnel and each of these personnel had the same amount of points as their counterparts on the other team (i.e., red technician had 15 units, so purple technician had 15 units).

**Scoring:** Scoring was divided into three different areas. Objective scoring was accomplished by simply looking at the scores each team received in accordance with the simulation. Each team had an opportunity to score points on their tasks. The point system was follows:

**Point Allocation:**

- **300 points:** Find the unmanned aerial vehicle (UAV) or the lost team.
- **100 points:** Render Emergency assistance (-100 from both team members if emergency assistance is not rendered in the allotted time period)
- **50 points:** Assist with repair or medical requests
- **10 - 80 points:** Process seismic monitors

These tasks popped up at predetermined intervals and were relayed to the red and purple snow cats via the blue snow cat. The participants were told by satellite messages relayed from the blue snow cat how much time they had to complete each task. Some tasks popped up even before the time had expired for other task. If the participants successfully completed a task, they were awarded the above amount of points, depending on the task. If the participants were unable to complete the task in the given time, they were deducted that amount of points. An emergency could be neutralized by processing it with only part of the needed resources. In this case, the team is neither penalized nor rewarded and therefore
received 0 points for attending to that particular emergency. The running time for the DDD Arctic Survival task was 75 minutes.

Once the simulation task was completed, all the participants were instructed to sit at the round table in the center of the room for questions and debriefing. Participants were instructed that they could talk to others about the experiment, but to not mention specific details of their specific conditions. After all questions were answered we thanked the participants for lending us their time and informed them the experiment was over and they were free to go.

*Analyses and Results:* A full and thorough discussion of analysis and results can be found in Hess at al., 2006. For the purposes of this chapter, the discussion remains abstract. Analyses were performed at both the team and the individual level. Team level analyses were performed using Analyses of Variance (ANOVAs) to examine the performance of the teams in the different experimental conditions. A table with the performance scores and the sample size for each experimental condition is presented below.

Table 14-4. Summary of Means and Sample Size by Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean Score</th>
<th>STD</th>
<th>Subject N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>13.75</td>
<td>291.16</td>
<td>32</td>
</tr>
<tr>
<td>“Control” no probes</td>
<td>248.89</td>
<td>166.66</td>
<td>18</td>
</tr>
<tr>
<td>“Control” / preplanning probes</td>
<td>103.33</td>
<td>575.66</td>
<td>6</td>
</tr>
<tr>
<td>“Control” / task work probes</td>
<td>137.78</td>
<td>261.66</td>
<td>18</td>
</tr>
<tr>
<td>CCT no probes</td>
<td>407.50</td>
<td>352.16</td>
<td>32</td>
</tr>
</tbody>
</table>
In brief, the team-level analyses showed support for a positive effect of training (both the CCT and “Control”) on the team’s performance. Solely at the team level, the benefit of using of the CENTER tool was not apparent. Several possible explanations for these findings have been speculated. It may be that the population chosen for the study was inappropriate since CCT requires a level of expertise that college students have yet to achieve; or perhaps the disproportionate number of female participants influenced the outcome – it may be that these participants were exceptionally social in nature and this neutralized the effects of the probes on the team performance, whereas male participants, or other participants less social, may benefit more from the use of these probes. Further research is warranted to more fully understand these findings.

Because the data collected for this study were organized hierarchically, (e.g., individuals nested within teams) multilevel analyses were also performed. The team score variable remains the dependent variable. There were two Level-1 predictor-variables: IQ (measured by SAT or ACT), and the personality variable agreeableness. Agreeableness is a dimension of the Big 5, and generally reflects such attributes as: trust, straightforwardness, altruism, compliance, modesty, and tender-mindedness.

The multilevel analyses began with a baseline or null model that served as a comparison against which to compare other substantive model solutions. Models were compared using the deviance statistic. Deviance reflects the overall lack of fit of the model to the data. Models with lower overall deviance terms are preferred, all other things being
equal. Of course it is important not to add complexity to a model without ensuring the additional complexity significantly reduces overall deviance. This is easily examined as the deviance statistic for nested models is distributed as a chi-square. So the importance of the addition of a term to an equation (or other modification) can easily be checked by examining the decrease in overall deviance. The result of these multilevel analyses indicated that both individual-level variables (IQ and Agreeableness) contributed significantly to team performance.

A further strength of multilevel modeling is the ability to examine cross-level interactions. This allows the researcher to ask questions about the impact of variables at one level on variables at another level. To test for these effects, variables that reflect the product of level-2 by level-1 variables were computed. We were interested in whether there might exist cross-level interactions between level-2 variables (CCT training coded 0=no training, 1=training; probes coded 0=no probes, 1=received probes) and level-1 variables (IQ, agreeableness). The results of these analyses suggested both level-1 variables interact with both level-2 variables. This was seen by a significant reduction in model deviance for the models that include the respective interaction terms: IQ by CCT, IQ by probes, agreeableness by CCT, and agreeableness by probes. One interpretation is that the use of probes strengthens the relationship between individual-level variables (IQ and Agreeableness) and team performance.
**Fielding CENTER**

The CENTER tool was developed to benefit any team involved in a planning intensive situation. Some examples of the types of teams that should benefit include the following:

- *Intelligence analysis teams* gathering and interpreting data to infer adversary location, identity, capabilities, plans, and intent.
- *Operational planning teams* developing and evaluating courses of action.
- *Management consultants or board members* engaged in developing organizational strategy and policy.
- Any other *collaboration team* creating an intellectual product.

However, operational personnel (i.e., Marines and the Expeditionary Strike Group (ESG) 1 aboard the USS Tarawa) approached to discuss the tool’s possible use in their mission planning, and the benefits that the tool’s use would have on their mission performance agreed that the use of probes during mission planning would be too distracting. The correct place to use the CENTER tool is during *training* sessions to train teams how to use CCT in their jobs and missions. They all felt that CCT was an important skill for a team to have, and they saw the utility of the CENTER tool in training CCT, but they felt that training with the CENTER tool had to happen long before the team actually needs to use CCT. With this insight, and the supporting evidence from the earlier study, efforts are now focused more on finding opportunities to insert the CENTER tool into training situations, where teams have more time, and are more motivated, to develop their CCT skills and behaviors. For example, Aptima, Inc. has successfully incorporated
CENTER into After Action Review (AAR) and debrief processes that are being developed for the Army and the Air Force Research Lab.

**Conclusion**

By using macro-cognitive processes as a solid theoretical base to develop CENTER, the CENTER technology *measures* the state of knowledge within teams as well as team judgments about knowledge and decision making, and enables leaders to *monitor* and *manage* such knowledge. These capabilities are important to help leaders leverage the capabilities of modern information systems, by giving them insights into the use of information from these systems and judgments about it. Thus, CENTER may help to integrate data systems with social systems. Technologies such as this may be particularly important in distributed organizations, and in virtual organizations\(^2\), in which leaders cannot easily observe interactions – such as “buzz” about specific information or arguments over decisions – that convey the state of team knowledge. In these environments, technology is needed to make team knowledge state accessible.

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\(^2\) Virtual organizations are ad hoc alliances or opportunistic, temporary alliances of individuals from different formal organizations.
References


Rawlings, D. (2000). Collaborative leadership teams: Oxymoron or new paradigm?
Consulting Psychology Journal, 52, 151-162.


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Figure 14-1: A structural model of collaboration (Warner, Letsky, & Cowen, in press) to which collaborative critical thinking serves as a global resource.
Figure 14-2: Collaborative Critical Thinking consists of four types of team member interactions in a cyclical and adaptive process.
Figure 14-3: CENTER probes are simple, unobtrusive, and rapidly addressed.
Figure 14-4: Responses to CENTER probes are summarized as means and range.
Figure 5: CENTER’s Instant Message capability