ENHANCING TEAM PERFORMANCE IN TACTICAL ENVIRONMENTS: THE TEAM MODEL TRAINER

Phillip C. Duncan, John J. Burns, and Paul R. Frey
Search Technology
Atlanta, GA

Janis A. Cannon-Bowers and Joan Hall Johnston
Naval Air Warfare Center Training Systems Division
Orlando, FL

ABSTRACT

In order to solve complex decision problems, a ship's Combat Information Center (CIC) team members must develop the ability to manage information flow among themselves. This paper describes research conducted using a Multimedia training simulation, called the Team Model Trainer (TMT), that was designed to enhance knowledge of communication flow. Observations of and interviews with CIC training teams resulted in a description of team knowledge structures. Details about information flow regarding who says what, to whom, and when it is said were developed. This team knowledge structure, or mental model, became the training goal for individuals learning with the TMT. The TMT is a PC-based training device that employs an audio simulation of team member communications and a visual simulation of scenarios designed to shape the mental model of team role structures. Findings based on participation by Navy personnel suggest that TMT not only improves individual knowledge about other team member roles, but also improves team performance. Recommendations for application and future research include: a) providing opportunities to practice team communications, b) providing immediate feedback on performance, c) using a standalone PC-based system in conjunction with other team training, and d) developing strategies for measuring team mental models of complex knowledge structures.

About the Authors

Dr. Phillip C. Duncan is a Senior Staff Scientist. His work includes development of: an ITS for the NASA Space Shuttle; a hypermedia encyclopedia for designers; and an intelligent tutoring component of the Designer's Associate program. He received a Ph.D. in Cognitive Psychology and Instructional Science from Brigham Young University.

Dr. John Burns is a Staff Scientist. He has conducted behavioral research to develop training and simulation principles for the Navy’s Tactical Decision Making Under Stress (TADMUS) program. His professional interests include cognitive approaches to training complex knowledge, and the development of intelligent aiding to support decision makers. He received a Ph.D. in Psychology from the University of Massachusetts-Amherst.

Paul Frey is a Senior Staff Engineer. His responsibilities include research and development in human-computer interface, and computer-aided design. He has applied Multimedia technology to alternative methods for portraying large graphical displays on small computer screens. He received a B.S. and an M.S. degree in Electrical Engineering from Auburn University.

Dr. Janis A. Cannon-Bowers is a Senior Research Psychologist. She is co-principal investigator for the TADMUS program, and is responsible for research concerned with improving individual and team decision making in the Navy tactical environment. She received a Ph.D. in Industrial/Organization Psychology from the University of South Florida.

Dr. Joan Hall Johnston is a Research Psychologist. She is responsible for conducting research to develop training and simulation principles for the TADMUS program. She received a Ph.D. in Industrial/Organizational Psychology from the University of South Florida.

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INTRODUCTION

While tactical team performance can be defined in terms of discrete, observable behaviors, there is a growing consensus that improving tactical team performance involves changing how the team structures and uses knowledge (Cannon-Bowers & Salas, & Converse, 1993). A mental model, is particularly important because it is used to understand team actions and to predict future events (Rouse and Morris, 1986). Tactical teams use mental models to generate descriptions of the tactical situation, explanations about how the situation evolved, and predictions of likely future scenarios. The hypothesis of this research is that if training can be developed to improve the quality of mental models, then we should see subsequent improvement in team performance.

Over the last several years, we have worked toward an empirical test of this hypothesis. In order to establish the context for this effort, we first describe the tactical decision-making environment and current training for those who operate in that environment. Next, we describe the performance issues encountered by tactical teams and our assessment of the underlying cause of many of these issues. Then we describe an effort to provide training designed to enhance team performance. We conclude with recommendations for training and future research.

THE TACTICAL ENVIRONMENT AND TEAM TRAINING

Teams are integral to the modern command and control environment. In part, this can be attributed to the technological sophistication of the equipment. Modern Navy ships rely on state-of-the-art computer hardware that enables over-the-horizon detection and strike capabilities. The capability provided by this technology demands multiple operators working together.

A second factor that contributes to the complex nature of the team's task is the dynamic geopolitical situation. It is not atypical today for situations to arise that include multiple countries, each of which may have multiple agendas depending upon the time, place and other participants. The Combat Information Center (CIC) team must be cognizant of these intricacies, as well as technically competent at operating their equipment.

In the early stages of this research effort, these two factors became readily apparent and in fact, while the physical layout and staffing of the CIC vary as a function of ship class, these factors underlie six common characteristics of the typical CIC. We turn our attention now to a brief discussion of those six characteristics.

The Tactical Decision-Making Environment

(1) *Typically, many members in the team must coordinate their efforts*. Depending upon the type of ship, anywhere from six to more than 30 people work together in the CIC. In the more complex CIC, there are subteams that specialize in monitoring sensor information, and in making decisions about various types of craft (i.e., aircraft, surface craft, and subsurface craft). Through a process of sharing information, the CIC team must act in concert to access, understand, and synthesize the available information and sensor data.

(2) *Team members have specific task assignments, but share roles and responsibilities*. Each team member uses various types of equipment clustered together to form a station. A station typically consists of one or more computer displays, controls, and assorted communications equipment. Each member of the team has an individual task assignment, but the team works together to interpret the situation of the outside world.

(3) *The team makes decisions within a complex organizational context*. Team performance must be consistent with objectives and constraints external to the team. As we have indicated, the CIC team is often composed of subteams. It is also the case that

the CIC can be subsumed as a part of a larger organization. At the boundaries of these groups, teams, and organizations there are individuals who have dual membership. For example, the CIC is made up of groups that specialize in air warfare, surface warfare, and subsurface warfare. Each warfare commander must represent the warfare group to the CIC. In turn, the warfare commander must also represent the CIC to the warfare group.

(4) *The tactical situation is highly dynamic, unstable, and sometimes hostile*. As a result, situations and rules can change quickly and risks abound. In a busy environment such as the Northern Persian Gulf, at any given time there may be 300 or more tracks that the CIC team must try to identify. A high performance aircraft or missile can close on a surface ship in minutes. The types of decisions that should be made change as an unknown or hostile track approaches the ship.

(5) *Information which the tactical team receives is often incomplete, uncertain, or ambiguous*. More information is known about friendly tracks than hostile tracks, but hostile track information is more critical. Hostile tracks may actively prevent true information from being known, use identification frequencies to appear as commercial aircraft, avoid radar contact by flying underneath the radar, and actively jam the radar. There are more subtle methods of confusing the team: ignoring warnings, ignoring requests for identification, turning off transponders, and etc.

(6) *Demands on the tactical team vary in time and often conflict*. Shifting objectives and priorities, as well as the impossibility of satisfying all goals, result in no 'best' decision and perhaps many 'acceptable' decisions. For example, having a Combat Air Patrol (CAP) visually identify tracks is highly desirable, but is expensive in terms of resources. Often the 'acceptable' decision is to scramble the CAP in the few situations where there exists a high probability that the track is hostile.

While the focus of this research is on the air defense team in the CIC of Navy surface ships, we believe these six characteristics define an environment common to many tactical decision making teams. Their mission, to detect, identify, and take appropriate action for each track they monitor, can be hour upon hour of consistent routine. In these situations, the team's biggest challenge is fighting boredom. However, when things do heat up, seamless, efficient, and accurate coordination within the CIC team is essential to the ship's survival.

More often than not, CIC teams function smoothly, demonstrating mastery of sophisticated equipment and complex tactical situations. While this is due in part to a commitment to on-the-job training whenever and wherever possible, it is also due to formalized team training engaged in by the CIC team prior to ship commissioning.

In order to develop ideas about how we might improve CIC team training, we studied the kinds of errors teams make. Systematic observations of CIC teams were made as they progressed through training. The next section describes our approach to this effort and the results of our observations.

TEAM PERFORMANCE ISSUES

Our task was to develop training guidelines for improving team performance for Navy tactical teams. Therefore, the goal of this initial effort was to observe CIC training teams in order to determine teamwork skills that required specific training interventions.

Two CIC teams, each composed of about 30 people, were observed undergoing a two-week precommissioning training. The first crew was observed by a single investigator. The second crew was observed by a different investigator. The second set of observations was made to corroborate the results of the first set of observations, using multiple investigators to classify the resulting data independently.

For the first crew, four training scenarios were observed. Six training scenarios were observed for the second crew. Each scenario involved a different, fairly involved tactical situation. The training session began with a 30-minute briefing, followed by a 60 to 120 minute scenario, and concluded with a 30-minute debriefing. Two scenarios were conducted per day. Crews were evaluated by eight domain training experts. Each evaluator concentrated on a particular aspect of system operations. Crews also evaluated themselves by pointing out and discussing problems.

Detailed written notes were taken of training evaluators' comments as well as the crews' comments. Most of these comments were made during the debriefing, with a few noted during the actual training session. These written notes were later analyzed to identify instances of errors. These errors were then categorized using a simplified version of the error analysis methods in Rouse and Rouse (1983).

Table 1 summarizes the tactical team performance problems encountered during training. The problems

Features of Tactical Teams	Associated Performance Problems (frequency of occurrence)
Many team members	Communication problems (44%)
Shared tasks and shared models	Failure to predict and explain other's actions (27%)
Teams work within larger context	Coordination problems (8%)
Environment dynamic, unstable, potentially hostile	Inappropriate use of system resources (9%)
Conflicting demands	Conflicting and counterproductive performance (12%)

Table 1. Tactical Team Performance Problems

noted in this compilation do not include system problems (e.g., simulator peculiarities) which were frequent, but relatively minor. Further, problems of equipment usage (i.e., basic human factors problems), tended to be resolved during the exercises and not reported during the debriefings.

Many of the instances of problems noted in Table 1 represent evaluators' comments on multiple events. The classes of problems shown in this compilation represent diagnoses of problems rather than specific events that were always very context dependent.

The distribution of problems has been aggregated across crews. More detailed analysis of these data, broken down by crew are available in Rouse, Cannon-Bowers and Salas (1992). An assessment of the representativeness of these results, compared with NASA's Aviation Safety Reporting System for over 10,000 instances of aviation related incidents are also included in the above citation. The comparison is quite favorable, which lends a measure of credence to the results reported here.

Seventy-five distinct problems were detected through the debriefings of the two crews. The largest percentage were communications problems (44%). In 12 of these instances team members did not communicate when it was expected by other team members. In an additional 12 instances team members could not interpret or explain communications because they were not communicating in the expected way (i.e., using appropriate terminology). A lack of expected follow-up communications was noted in nine instances. The fact that there are communications problems is not surprising as there were about 30 people in the CIC.

The failure to predict and explain other's actions accounted for the next largest category of problems (27%). This type of error suggests a lack of planning such that team members had no expectations for what they would do in the particular situation that arose.

Eight percent of the errors were attributable to coordination problems (synchronized actions) among the team. These were situations where actions or messages were either too early or too late to be useful.

For nine percent of the total, the team used the ship's resources inappropriately. These system usage errors reflect both the complexity of the ship's systems and the dynamics of the external situation. The team used the equipment in configurations or modes that were not correct. These were not individual human factors problems that, as noted earlier, were not counted. Instead, these observations typically resulted from incidents where multiple people concurred in using the equipment in ways that did not match the needs of the moment.

The final 12% of the errors were times when the team took conflicting and counterproductive actions. In the CIC, demands on team members frequently conflict, so the members must negotiate compromises and tradeoffs. Some of these were unnecessary communications as team members attempted to determine what other members were doing or intended to do. In a few observations, no attempt was made to update others on their actions.

Cognitive Mechanisms Underlying Performance

Overall, this information suggested that the teams may have incorrect or inadequate performance models. There is a strong and growing trend in many fields, from behavioral science to systems engineering, to call these performance models mental models. They are referred to as mental models because they are often informal models that exist only in the mind of the team members (Klimoski and Mohammed, 1994).

The team mental model describes why the team exists and what team members do, explaining how the team operates, and predicting future team actions. The description of the team includes explaining the roles of team members, the relationships among the members, and typical sequences of events. The team model can also explain the function of team members with the ship's system and with other members of the team. Prince, Salas and Franz (1990) have documented the importance of teaching interaction skills to teams. In addition to functional interaction, team knowledge includes a rationale for the team's existence, what requirements the team fulfills, and general principles regarding team behavior.

Table 2 represents the team mental model in a team communication matrix. Based on interviews with expert CIC watchstanders, the matrix depicts optimal communication flow in terms of content and direction. The team members in the rows provide information to their teammates in the columns about the information contained in the cells of the matrix. For example, the TAO communicates information to the Anti-Air Warfare Coordinator (AAWC) about intelligence, the disposition of air assets, and the tactical situation.

Prescriptions for Mental Model-Based Training

The team training observations led to the development of a set of principles for delivering training. For example, the CIC team needs feedback about their performance individually, and as a team. They need to know if they can appropriately explain each others' actions and make predictions about future team actions. They need a review of actual scenario events to clarify any misinterpretations they may have had. Team training is not a mature science; we have only a few well accepted principles. However, implementing the few guidelines we do have would contribute significantly to training effectiveness (Campbell, 1988). We propose the seven team training principles listed below.

1) *In order to improve team member mental models and the overlap among them, training programs must be diagnosed and evaluated.*

	TAO	AAWC	TIC	IDS	EWS
TAO		♦Intelligence ♦Disposition of air assets ♦Tactical situation	♦Tactical situation ♦Intentions ♦Intelligence ♦Rules of engagement	♦Tactical situation ♦Intentions ♦Intelligence ♦Rules of engagement	♦Tactical situation ♦Intelligence
AAWC	♦Tactical situation ♦Actions performed♦ ♦Track info ♦Intentions ♦CAP status		♦Tactical situation	♦Track info	♦Tactical situation ♦CAP status
TIC	♦Track info ♦Equipment status	♦Track info ♦Actions performed		♦Track info ♦Actions performed	♦Track info ♦Equipment status
IDS	♦Track info	♦Track info	♦Track info ♦Actions performed		♦Track info
EWS	♦ESM info ♦Track info	♦ESM info ♦Track info	♦ESM info	♦ESM info	

Table 2. Team Communication Matrix

2) *Standardized measures of mental model progression are required to assess whether the goals of training are being met*.

3) *Team performance errors should be observed and recorded as a means to assess team members' mental models (in terms of quality, accuracy, completeness, overlap, etc.).*

4) *Team training must be designed systematically to meet the coordination requirements of the task (in terms of shared mental models*).

5) *Expert mental models and knowledge requirements need to be analyzed into specific components so that each may be trained and then integrated into total team performance*.

6) *Shared mental model development requires that feedback be provided in a timely manner during training*.

7) *Shared mental model development requires that feedback be relevant to the task and team*.

Now that we have described team training content and principles, we will now describe how team training was implemented. The next section describes an experimental platform for testing training approaches to develop team mental models.

PC-BASED TEAM TRAINING

Low fidelity simulations have been shown to be an acceptable training method for training air crew coordination skills (Prince & Salas, 1991). Similar skills are necessary for tactical teams responsible for AAW. The advantages of low fidelity simulations are their unique training opportunities, feasibility in use, and economy (Prince & Salas, 1991). A low-fidelity simulation elicited and allowed observation of crew coordination behaviors necessary for CIC teams (Stout, Cannon-Bowers, Salas, & Morgan, 1990).

Simulations typically focus on the equipment that a person is learning to use (e.g. a flight simulator simulates the cockpit). If the scope of the simulation could be enlarged to simulate both the equipment and the team itself, it could potentially be used for training teamwork skills. Such a simulator would have many advantages for the novice: a) the simulated team could be observed at the trainee's convenience, and the team's performance could be observed without influencing it; b) the team could be repeatedly observed until the trainee completely understood its interactions; c) any one of the team members' individual tasks could be learned by observing that particular team member; d) rare or infrequent events that are difficult or hazardous could be experienced without harm; and e) a subset of team actions could be performed to gradually increase the trainee's performance until mastery was achieved.

In accordance with these advantages, The Team Model Trainer (TMT) was developed to allow the individual to use a PC and interact with a simulated team to develop a team mental model. For instance, the IDS learns to explain and predict team actions by running a simulated scenario on a personal computer. Instead of live actions and messages, the computer delivers pre-scripted scenarios. Messages appear on the IDS's screen as events unwind in the scenario. If the IDS formulates the correct expectations about team performance, the IDS can react to the evolving situation. If not, the IDS soon finds out which expectations were inappropriate. The same is true of his explanations of team actions. In addition to experiencing the scenario in real-time, the IDS can replay the scenario after it was over to learn from mistakes.

Throughout the simulation scenario, the IDS hears voice recording of other team members in the CIC. The IDS has two choices about which voices to hear. The IDS may choose to passively listen to all of the team's voice recordings, or choose to listen to everyone except the IDS position. This second option is recommended as it allows the individual the opportunity to verbalize as the scenario plays.

The individual also has the option of turning the recording off completely. Sometimes when the individual encounters a new simulated event, it is confusing to hear all of the chatter from the team. The IDS can choose to play an event without sound, if the sound is too distracting. Playing the events with sound is recommended as it heightens the realism of the scenario.

TMT employs the training principles recommended earlier. Because it uses scripted scenarios, training is standardized. Each scenario runs exactly the same as the previous one. This allows the IDS to replay the same scenario again and again, focusing on those sequences which have been diifficult. TMT uses the standard evaluation measures already developed to organize feedback to the team member. Feedback is delivered in a standard format. With these standard evaluation measures the team member observes their own progress, and compares their performance with that of an expert.

EMPIRICAL EVALUATION OF TMT

We have attempted to utilize several measures in an effort to provide converging evidence of changes in mental models. Before we discuss these measures, a brief description of the experimental procedure we used is necessary.

Method

As part of a larger effort examining tactical decision making under stress, a methodology for measuring team performance has been developed (Hall, Dwyer, Cannon-Bowers, Salas, & Volpe, 1993). This methodology makes use of a PC-based, networked simulation that is a low fidelity replica of AAW component of the CIC: the Decision Making Evaluation Facility for Tactical Teams or DEFTT (Naval Underwater Systems Center, 1991). The methodology incorporated a pre-post design and includes an observational measurement tool designed to assess team processes that are critical to successful performance (the Anti-Air Warfare Team Observation Measure, hereafter called "process measure") (Johnston, Smith-Jentsch, & Cannon-Bowers, 1995). In addition there is a second observational measurement tool that assesses behavioral outcomes (the Anti-Air Warfare Team Performance Index, hereafter called "outcome measure") (Johnston et al., 1995). Essentially, the ATOM is designed to answer the question “Did the team demonstrate the kinds of behaviors associated with successful outcomes?”, while the ATPI is designed to answer the more scenario specific question of “How did the team do with respect to these specific events?” (see Johnston et al., 1995 for further detail).

In addition, the Team Communication Questionnaire (hereafter called "questionnaire") was designed to assess a team member’s understanding of what information they were to provide to other members of the team, and what information they could expect from other members of the team. Utilizing this methodology, we were able to evaluate four, ad-hoc, Navy CIC teams who received TMT training.

The procedure for evaluating the TMT was the same for all four experimental teams. Each team was given two hours of training on the use of the DEFTT simulation, and an additional hour of practice as a team. This practice was immediately followed by the first of two scenario runs in which the team acted as the AAW component of a CIC, and worked through a 30-minute exercise. Team performance during all scenario runs was videotaped to allow for off-line outcome and process measure scoring. Then, after training and the first scenario run, each team member filled out a questionnaire to capture their team models. Then each member received three hours of training with the TMT. Then, each team member responded to a second questionnaire (identical to the first). Finally, the team performed another standardized scenario which had been tested with several other teams, and was found to be structurally similar to the first scenario.

Results

As a first step in assessing TMT impact on mental models, we examined changes in questionnaire scores. The questionnaire was scored by comparing each individual’s answer with those of an expert. Errors of omission are instances where a team member should have communicated a certain type of information to another member, but did not. Errors of commission were instances where a team member indicated that information should be passed to a team member, but the information was extraneous. Because team members vary in the type of information they should pass to others, and who they communicate with, each member of the team was compared with the corresponding member of an expert team (IDS to IDS, TIC to TIC, etc.).

Individual questionnaire scores were combined for an average team score for each of the four teams pre and post TMT. Analysis of these scores revealed a significant increase in questionnaire score ($t(4) = 4.56$, $p < .05$). Table 3 shows the average pretest questionnaire score was 58.2 and the average posttest score was 67.4. (out of a possible 96). This constitutes almost a ten percent improvement in the team's mental models.

Noting the improvement in the teams’ understanding of what optimal communications should be, the next step was to examine potential, accompanying performance differences. To this end, we performed t-tests on the process and outcome scores pre- and post- TMT for the experimental teams. The process and outcome average scores for each of the four teams are presented in Table 3 along with the average mental model questionnaire scores (MODEL). While performance as measured by the outcome measure did not differ significantly pre to post, performance on the process measure did ($t(3) = 2.61$, $p < .1$).

	PROCESS		OUTCOME		MODEL	
Team	Pre	Post	Pre	Post	Pre	Post
1	66	80	11.0	15.0	59.6	69.0
2	53	52	8.5	15.5	61.2	69.0
3	58	63	8.5	12.5	55.8	70.4
4	55	56	12.0	12.0	56.2	61.2
Avg.	58	62.8	10.0	13.8	58.2	67.4

Table 3. Average Team Scores

Although control group data was not available for comparison, these results do suggest that improvement in team mental models and improvement in team process at least parallel one another. In order to explore the nature of this relationship, we decided to contrast the communication patterns of the experimental group with data from control groups taken during a later study. The control groups were four additional ad-hoc, Navy teams who received the same treatment as the experimental group except for the TMT training.

Table 4 presents the frequency of communications as number of relevant utterances pre- and post-training for the control teams and the experimental teams.

	Control		Experimental	
	Pre	Post	Pre	Post
Team 1	111	78	177	128
Team 2	97	65	140	100
Team 3	65	106	103	74
Team 4	94	53	161	123
Avg.	91.8	75.5	145.3	102.3

Table 4. Communications Frequency

A multi-level (training vs. no training) static groups within subjects ANOVA revealed a main effect of training ($F(1,6) = 7.93$, $p < .05$). Overall, control teams communicated less frequently than did experimental teams (average of 83.65 for control teams vs. 123.8 for the experimental teams). A second main effect of trials ($F(1,6) = 7.89$, $p < .05$, 118.5 vs. 91.13), however, was qualified by a significant interaction. Post hoc tests revealed that while the experimental teams significantly decreased communication frequency from trial one to trial two (pre and post TMT, $F(1,3) = 90.36$, $p < .01$), control teams did not.

Seeking to delve further into the possible impact of TMT on communication, we also looked at the frequency of questions asked. We reasoned that if TMT did improve team mental models, this should be reflected in team members being more apt to “push” information rather than having to be asked for information. A multi-level (training vs. no training) static groups within subjects ANOVA revealed a main effect of training ($F(1,6) = 6.0$, $p < .05$), as well as a significant main effect of trials ($F(1,6) = 10.66$, $p < .05$. Table 5 shows that control teams asked fewer questions than did their experimental counterparts.

	Control		Experimental	
	Pre	Post	Pre	Post
Team 1	20	12	56	39
Team 2	32	33	45	21
Team 3	35	31	42	41
Team 4	32	33	70	47
Avg.	29.8	27.3	53.3	37.0

Table 5. Frequency of Questions

However, the main effect of trials is qualified by a significant site by trials interaction ($F(1,6) = 5.73$, $p < .05$). The requisite comparisons revealed that while the experimental teams decreased in the frequency of questions ($F(1,3) = 9.35$, $p < .05$), the control teams did not.

These findings indicate that following the TMT, the experimental teams communicated significantly more with each other than did the control teams. One explanation is that experience with the TMT caused the team to discuss more details about the task, thus sharing their mental models. In addition, the experimental teams asked more questions of each other than did the control teams, again suggesting that practice with the TMT initiated more interactions. An explanation for reduction in communication following TMT in the experimental group could be that as the team’s communications become more efficient, their overall workload decreases, thus allowing them to devote more mental resources to other taskwork.

The data from the process measure suggest that the experimental group's coordination skills improved with TMT, and that their communications would have reflected this improvement. However, this is a hypothesis that needs to be tested with future analyses that include the data on control group performance, as well as questionnaire data. Other training interventions have demonstrated improved performance and decreased communications after implicit coordination training in teams (Entin, Serfaty, & Deckert; 1994). Further research could uncover the underlying mechanism for this improvement in team performance, (i.e., whether there is an accompanying improvement in the team’s mental models). If so, then the importance of mental model-based training would be underscored.

CONCLUSIONS AND FUTURE DIRECTIONS

The trends we found between mental model improvement and performance is that with a brief training intervention, teams could learn and use appropriate communication patterns. Debriefs with the team members strongly suggest that they feel that this type of communications training is needed. Some members have suggested that this training might be well suited to shipboard training. Others suggested that certain Navy schoolhouses should include this type of training in their regular curriculum.

The findings here are encouraging with respect to changes in performance and communications. However, more research needs to be conducted to demonstrate that improved mental models lead to improved performance.

A number of recommendations were derived from the current findings. First, teams should be provided with opportunities to practice team communications. Both the experimental and control teams we observed reduced their communication frequency as they practiced performance on a simulation with realistic scenarios. Secondly, we observed improvements in coordination skills.

Another training tactic which has wide applicability is the content and delivery of team feedback. Teams should receive more immediate feedback about their performance during training. With the TMT, teams received expert feedback, but it was often delayed until the end of a scenario event, sometimes up to 10 minutes, and it was completely under student control. Many team training sessions that we observed in other settings had delays of hours before feedback was provided, so the TMT feedback was more timely. There is probably a practical limit to how soon the feedback should appear without interfering with the flow of the scenario.

Thirdly, cost savings can be realized. PC-based simulators have several advantages over full-scope simulators, including cost efficiency, portability, privacy, and availability. There is probably an optimal combination of the use of the two types of simulators for training. PC-based simulators may be most effective training basic taskwork and teamwork skills, while full-scope simulators would afford teams realistic practice using those skills. Teams should practice together after individual team members have reached proficiency.

Finally, there is a need for further development of measures of complex knowledge structures, such as mental models. The instrument for assessing team models in this study was a questionnaire. There is a need to measure other types of mental models (situation, ship, system, task, and equipment), to measure them in near real-time (embedded in the training system), and to measure how team models change with time and training. Automatic recording of multiple aspects of team performance data enables the instruction to be more specific, timely, and cost effective.

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