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Measuring Team Knowledge: A Window to the Cognitive Underpinnings of Team Performance

[1]Nancy J. Cooke, [2]Preston A. Kiekel, [3]Eduardo Salas, [4]Rene'e Stout, [3]Clint Bowers, and [3]Janis Cannon-Bowers

[1]Arizona State University East, Mesa, AZ

[2]New Mexico State University, Las Cruces, NM

[3]University of Central Florida, Orlando, FL

[4]Rene'e Stout, Inc., Oviedo, FL

Abstract

This paper reports an effort aimed at developing and evaluating measures of taskwork and teamwork team knowledge for teams in which members differ in knowledge backgrounds. These measures are used in a study with 36 teams to explore the cognitive underpinnings of team performance variations due to cross training regime. We demonstrate that these measures are valid and provide team performance information that complements outcome and behavioral measures. Teams exposed to full cross training acquired more taskwork and teamwork knowledge than control teams or teams exposed to a conceptual version of cross training. Measures of team knowledge provide information regarding team task performance critical for system design and training programs.

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Team process behaviors such as communication, leadership behaviors, coordination, and planning have been linked theoretically and empirically to team performance (Foushee, 1984; Stout, Salas, & Carson, 1994; Zalesny, Salas, & Prince, 1995). Many interventions for improving team performance have targeted team process behavior (Braun, Bowers, Holmes, & Salas, 1993; Leedom & Simon, 1995; Prince, Chidester, Cannon-Bowers, & Bowers, 1992; Prince & Salas, 1993). Recently it has become clear that other factors that are more cognitive than behavioral in nature also play a role in team performance. An overall objective of the work presented here is to develop valid cognitive measures for teams.

Technological developments in the military and elsewhere have transformed highly repetitive manual tasks, requiring practiced motor skills, to tasks that require cognitive skills often related to overseeing new technology such as monitoring, planning, decision making, and design (Howell & Cooke, 1989). As a result, a full understanding of many tasks, at a level required to intervene via training or system design, requires an examination of their cognitive underpinnings. Additionally, the growing complexity of tasks frequently surpasses the cognitive capabilities of individuals and thus, necessitates a team approach, which simultaneously introduces an additional layer of cognitive requirements that are associated with the demands of working together effectively with others. Team members need to coordinate their activities with others who are working toward the same goal. Team tasks often call for the team to detect and recognize pertinent cues, make decisions, solve problems, remember relevant information, plan, acquire knowledge, and design solutions or products as an integrated unit. Therefore, an understanding of team cognition, or what some have called the new "social cognition" (Klimoski & Mohammed, 1994; Larson & Christensen, 1993; Nye & Brower, 1996), is critical to understanding team performance and intervening to prevent errors or improve productivity and effectiveness.

In this paper we intentionally restrict our focus to *team knowledge*. According to Salas, Dickinson, Converse, and Tannenbaum (1992), a team is "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/object/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership" (p. 4). Thus, based on this definition, a team is a special type of group (Hackman & Walton, 1986). Although there has been significant work on group cognition (e.g., Davis, Au, Hulbert, Chen, & Zarnoth, 1997; Hinsz, Tindale, & Vollrath, 1997; Stasser, Stewart, & Wittenbaum, 1995; Steiner, 1972; Thompson, Levine, & Messick, 1999; Wegner, 1986), our focus on teams as a type of group, presents special challenges for the measurement of *team* cognition. Specifically, the fact that team members are assigned distinct, though interdependent roles, raises issues regarding the concept of shared knowledge. The methods that we discuss in this paper address these and other issues.

There has also been significant theoretical work delineating cognitive constructs at the team level such as shared mental models and team situation awareness (Cannon-Bowers, Salas, & Converse 1993; Orasanu, 1990; Stout, Cannon-Bowers, & Salas, 1996) for which team knowledge is thought to be central (Cooke, Salas, Cannon-Bowers, & Stout, 2000). It is assumed that understanding these constructs will allow diagnosis of team performance, which is useful for training and design interventions. Also, the hypothesized relation between team cognition and team performance suggests that team performance can be predicted from an assessment of team cognition and perhaps apart from the performance context, thereby providing an alternative to assessment requiring teams to perform in suboptimal settings (e.g., with minimal training, in hazardous or high-risk environments).

Team knowledge is a component of team cognition that includes constructs such as shared mental models and team situation models. Parallel to research on individual expertise (e.g., Chase & Simon, 1973; Glaser & Chi, 1988), accounts of effective team performance highlight the importance of knowledge, or in this case, team knowledge. For instance, Cannon-Bowers and Salas (1997) have recently proposed a framework that integrates many aspects of team cognition in the form of teamwork competencies. They categorize competencies required for effective teamwork in terms of knowledge, skills, and attitudes that are either specific or generic to the task and specific or generic to the team (see also Stevens and Campion, 1994; 1999). Their distinction between teamwork and taskwork knowledge builds on the distinction made by Morgan, Glickman, Woodard, Blaiwes, and Salas (1986). The important role of team knowledge has also been empirically supported in several studies examining shared mental models and their relation to team performance (e.g., Marks, Zaccaro, & Mathieu, 2000; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). In general, team members with mental models that are accurate and more similar to one another tend to perform at higher levels compared to team members with dissimilar and inaccurate models. Another example, in which team knowledge plays a critical role in team performance, is team situation awareness or the team's understanding of a complex and dynamic situation at any one point in time. The team's ability to assess the situation is supposedly influenced by the fleeting knowledge of the situation that the team possesses or a "team situation model" (Cooke, Stout, & Salas, 1997; Stout, et al., 1996). Thus, like team cognition, we assume that the more specific measurement of team knowledge can enhance our understanding of team performance and the factors affecting it and provide diagnostic information for team training and design.

The measurement of team knowledge, however, is replete with questions and unresolved issues (Cooke, et al., 2000). For instance, Mohammed, Klimowski, & Rentsch (2000) note that there are a number of methods for measuring team mental models, each suited to different purposes. Further, in the few cases in which team knowledge has been measured, that measurement has focused primarily on team member similarity and to a lesser extent, overall accuracy (e.g., Langan-Fox, Code, & Langfield-Smith, 2000). This focus seems suboptimal for teams in which individuals have distinct, yet interdependent roles (Salas, Dickinson, Converse, & Tannenbaum, 1992) and thus, may share knowledge in the sense that it is *distributed among*, rather than *similar across* team members. Furthermore, measures have failed to distinguish taskwork and teamwork knowledge. Other limitations of team knowledge measurement are reviewed in Cooke, et al. (2000). In short, the reliable and valid measurement of constructs like team knowledge is a first, albeit nontrivial step toward advancing our understanding of team cognition.

Therefore, the objectives of this research were to 1) develop and evaluate measures of team knowledge relevant to taskwork and teamwork and suitable for teams in which knowledge is distributed across team members (i.e., they have heterogeneous backgrounds) and 2) to use these measures to better understand the cognitive underpinnings of team performance variations due to training strategy differences. Effective measures of team knowledge should correspond to performance differences among teams, but should also reveal knowledge differences that offer explanations for the success or failure of various training strategies. Cross training was the specific training strategy investigated in this experiment and is defined by Volpe, Cannon-Bowers, Salas, and Spector (1996) as a "strategy in which each team member is trained on the tasks, duties, and responsibilities of his or her fellow team members" (pp. 87). Cross training was selected because it has resulted in performance benefits in laboratory studies and these benefits are purportedly tied to the acquisition of taskwork and teamwork knowledge among members of heterogeneous teams.

Cross Training

Empirical evidence exists to support the effectiveness of cross training on team performance (Baker, 1991; Cannon-Bowers, Salas, Blickensderfer, & Bowers, 1998). Cross training has been thought to be effective because it promotes the shift from heterogeneous team members (i.e., who specialize in their own roles) to homogeneous members who understand the other roles as well. That is, there is an assumed shift from less to more IPK (interpositional knowledge). IPK is knowledge relevant to team positions other than one's own position. However, the state-of-the-art in team knowledge measurement has precluded direct evidence for these types of team knowledge changes with cross training. The single exception is work by Cannon-Bowers, et al. (1998). In this study three-person teams were cross-trained or not in the other positions for a command and control task. As a manipulation check, individuals completed a 33-item matching test that requested the type of information needed by the various positions to make decisions (i.e., IPK). Cross-trained teams exhibited higher levels of IPK than teams that were not cross trained.

The type of cross training that has been empirically demonstrated to be effective includes a substantial portion of hands-on practice on the tasks of other team members. Most commonly, team members are trained on the other positions to the same extent that they are trained on their own positions. Whereas, this kind of hands-on-cross-training is possible in the context of scaled tasks associated with simulations and laboratory experiments, it becomes expensive and highly time consuming as task complexity increases and approaches the complexity inherent in most “real world” tasks (e.g., consider cross training surgeon and nurse positions). For this reason, cross training is not widely used by most organizations. Additionally, while cross training may benefit individual performance through insights gained from different perspectives, Cannon-Bowers, et al. (1998) note that training on multiple complex and distinct positions may increase the possibility of individual proficiency decrements. In other words, assuming a limited capacity for skill acquisition, specialization and skill on the individual's own job is traded off for a broader range of skills associated with all jobs.

Blickensderfer, Stout, Cannon-Bowers, and Salas (1993) suggest that the same benefits of full cross training may be realized in training that is less intense, though focused on achieving an understanding of the positions and their interdependencies. They recommend using shared mental model theory to drive an abbreviated form of cross training with a focus on what actions other team members perform, as opposed to why or how they are performed. In a sense, this is more of a teamwork orientation, as opposed to the taskwork orientation of traditional cross training. Indeed the study by Volpe, et al. (1996) demonstrated that a 10 minute intervention targeting the roles and responsibilities of the other position on a two-person team resulted in significant performance benefits over no cross training.

Therefore, in this study, we compare a conceptual, abbreviated form of cross-training to full cross training. In full cross training team members proceed through the full-training program in each team position. The conceptual cross training is based on a shared mental models perspective and specifically targets the acquisition of teamwork IPK. It is hoped that conceptual training can achieve some or all of the same benefits of full cross training, while minimizing expense, training time, and possibilities of individual proficiency decrements. At the same time, the application of knowledge measures should provide a deeper look at the effects of these different training interventions on team knowledge.

Study Overview and Hypotheses

In this study four training conditions were compared: 1) FCT (full cross training), 2) CCT-35 (conceptual cross training for 35 minutes), 3) CCT-75 (conceptual cross training for 75 minutes), and 4) Control. The FCT condition required 75 minutes of training time, whereas the CCT condition by definition required less training time (i.e., 35 minutes). Therefore, in order to control for training time, participants in the CCT-75 condition spent time on the conceptual cross training material equivalent to time spent by FCT participants. In the Control condition, participants were trained only on their own role also over a 75-minute period to again control for time differences. Team performance and team knowledge (taskwork and teamwork) were measured. Different team knowledge metrics were developed to distinguish overall, positional, and IPK knowledge accuracy.

It was first hypothesized that to the extent that our taskwork and teamwork measures were valid, that they should predict team performance differences. We therefore, predict that teamwork knowledge accuracy and similarity indices should be positively correlated with team performance (Hypothesis 1). Further, to the extent that interpositional knowledge is important for effective performance on this task, this should be reflected in relatively strong correlations between IPK accuracy and team performance (Hypothesis 2).

From previous studies, we predict a benefit of cross training of any type over the control condition. We further predict that CCT-35 should have performance benefits over the Control condition, yet comparable to those of FCT, while requiring less training time (Hypothesis 3). Differences between CCT-35 and FCT conditions and the CCT-75 condition should indicate the degree to which training time as opposed to training content are responsible for any benefits of FCT over CCT-35.

Performance differences between training conditions should also be reflected in the knowledge measures. Interpositional knowledge accuracy should be greater for the cross-trained teams over the control teams (Hypothesis 4). Specifically, both the traditional and conceptual varieties of cross training should result in superior IPK over the control condition, however, because of the different foci, the former should result in superior taskwork knowledge, and the latter in superior teamwork knowledge (Hypothesis 5).

Method

Participants

A total of 108 undergraduate Psychology students at New Mexico State University voluntarily participated in this study as members of three-person teams for approximately 4 hours in exchange for $5.50 per hour. Data from three additional teams were collected, but not used due to audio and video recording problems. Participants included 57 males and 51 females ranging in age from 14 to 68 with a mean age of 22.5. Six teams were all males and five were all females and these were evenly distributed across the four conditions. There was no effect of gender composition on team performance ($F(3, 32) = 1.76$, $p = .17$, $\eta^2 = .14$). Twenty of the teams had two or more members who were acquainted, although these were distributed across the four conditions and degree of familiarity (no, some, or all members acquainted) was uncorrelated with performance ($r(34) = -.16$).

Design

Upon arrival, participants were each assigned to three-person teams (36 total) and within teams were assigned to one of three roles (intelligence officer, navigation officer, or pilot). The 36 teams were randomly assigned to one of the four conditions: 1) FCT: full cross training (75 minutes), 2) CCT-35: conceptual cross training (35 minutes), 3) CCT-75: time-controlled conceptual cross training (75 minutes), 4) Control: time control with no cross training (75 minutes). Each team participated in 2 missions and 2 segments per mission (always presented in the same order). Thus the experimental design was mixed with training as a between subjects factor and mission and segment as within subjects factors.

Synthetic Task

We conducted this study in the context of a synthetic team task environment, which like synthetic task contexts in general (Cooke, Rivera, Shope, & Caukwell, 1999; Cooke & Shope, under review) provides adequate experimental control, while at the same time preserves the cognitive fidelity of operational tasks. In order to allow generalizations to existing military team tasks, the synthetic task environment was modeled after typical Navy helicopter missions. Because the intent of the studies was to develop and evaluate measures of team knowledge, it was critical that the synthetic task rely heavily on various aspects of team knowledge (e.g., communication, team situation awareness, knowledge sharing) and that it involve interdependent team roles with respect to this knowledge. After several iterations with other tasks and some pilot testing, we settled on a helicopter rescue-and-relief mission that involved extensive pre-mission briefing and planning. We assume that although this synthetic task is based on a military task, because it requires individual and team cognition and behaviors relevant to other complex dynamic team tasks, results from this environment should generalize to similar team tasks. The synthetic task environment combined paper-based task materials such as maps and legends and mission statements with a PC-based helicopter flight simulation.

In this task, three team members were each assigned to one of three different roles: pilot, intelligence officer (IO), and navigation officer (NO), each specializing in different aspects of the mission and with access to different mission-relevant information. For instance, the pilot was trained to fly the simulated helicopter and activate weapons, whereas the NO was trained in various terrain and weather patterns and their constraints on the mission and the IO was trained on threat situations and how they constrain the mission. In order to successfully accomplish the mission, however, much of this information needed to be shared among team members.

There were two missions involved in this experiment. Each mission varied in its objective (i.e., rescue civilians, drop supplies at a location) and in the specific map locations and task materials used during the mission. The precise materials that were developed for the missions are reproduced in Cooke, Kiekel, and Rivera (2000). Each mission was composed of two main segments that differed in terms of cognitive and behavioral activities. The early Planning segment involved three tasks in sequence 1) the IO and NO plan a route under constraints (i.e., weather, terrain, and hostile situations) while the pilot continued with flight training, 2) the IO and NO brief the pilot who in turn incorporates additional constraints until all three reach consensus on a plan that is ultimately approved by the admiral (i.e., experimenter), 3) the three team members execute the planned route via an audio flight simulation in which the conditions along the route are stated, some of which require planning an alternative route. Once at the planned destination, the Flight segment commenced in which the mission-specific task was executed in the simulated helicopter. The Flight segment followed the Planning segment for both missions. During route-planning the experimenter intervened if the team was unable to locate a city on the map at the start or end point within the first minute of the segment. The three Planning segment tasks were completed when the team members said that they had finished (planning task 1) or when the correct route or alternative route had been identified (planning tasks 2 and 3). The Flight segment was complete when the team members said that the mission objectives had been achieved. Teams were limited to no more than 35 and 10 minutes for the Planning and Flight segments respectively. Teams were instructed that both accuracy and speed were important. For motivational purposes and as a performance benchmark, the experimenter recorded the completion time on the scoreboard, alongside the target times of fictitious high-performing teams.

There are several interesting features of this task. First, the Planning segment differs in several ways from the Flight segment in that the former requires careful, systematic, planning and decision making among team members, whereas the latter is much faster-paced requiring extensive team coordination and dynamic understanding of the situation (i.e., situation awareness). The task, as planned, is also information intensive. Team members are provided with role-specific background information in training and mission-specific information pertaining to each role during the mission. This information consists of topographical maps with symbols representing threats and weather conditions; rules about weapon usage and helicopter capabilities; terrain and weather constraints; map icons, their meaning, and their implications for the mission; helicopter control functions and interpretation of displays; specific mission and segment objectives; and roles and information associated with other team members. Although some (approximately 15%) of this information is provided to more than one team member, other (approximately 85%) information is uniquely distributed to individual team members. This creates interdependence and specifically, the need for knowledge sharing.

Measures

Team performance and team knowledge were measured in this study. Team knowledge measures were taken after training and prior to the first mission and after the second mission. They included measures of long-term team knowledge regarding the task and the team (i.e., taskwork and teamwork knowledge). Team process behavior, dynamic understanding of the task (i.e., situation awareness) and knowledge of video and computer games were also measured, but will not be discussed further due to various problems with these measures that made the results uninterpretable or uninteresting.

Team performance was measured in terms of mission completion rate or the proportion of the mission segments completed successfully divided by proportion of maximum allotted minutes used. For the Planning segment there were between 0 and 3 tasks (i.e., the three planning tasks) that could be successfully completed in a maximum of 35 minutes and in the Flight segment of each mission there was 1 task that could be completed in a maximum of 10 minutes. Thus performance scores could range from 0 to 100 (theoretically, all tasks completed in 1% of the time) with 3 (all tasks completed in one-third of the time) being a more reasonable maximum. Higher performance scores were indicative of more tasks completed per minute.

Taskwork knowledge measure. The teams' knowledge of taskwork was measured by having individuals provide relatedness ratings for pairs of 15 concepts (105 pairs): safe, avoid, thunderstorm, mesa, landing, rivers, altitude, whirlwind, drizzle, grease, speed, nuclear, fuel, refugees, and stealth. These concepts were primarily task cues that required particular courses of action or decisions by one or more team members. Relatedness ratings were entered using a Macintosh computer with Hypercard software that displayed each pair (pairs randomly presented and order of item within pair counterbalanced across participants) and required a rating of 1-5 (highly to slightly related) with a sixth discrete point for unrelated pairs.

The rating data were submitted to the Pathfinder network-scaling algorithm (Schvaneveldt, 1990) to generate node-link representations of each individual's taskwork knowledge in which nodes represent concepts and links represent relations between concepts. Four heterogeneous metrics were then developed to represent different types of team accuracy and similarity: 1) overall accuracy, 2) positional (own role) accuracy, 3) IPK (interpositional knowledge; accuracy in regard to the two roles other than your own) accuracy, and 4) intrateam similarity. The first metric reflects overall accuracy in that the individual results (in this case a Pathfinder network) were compared to an experimenter-generated referent network that represents the critical conceptual relations for an individual who is knowledgeable about all of the mission-relevant concepts. A Pathfinder-derived similarity value based on proportion of shared links between the individual team member and an overall referent networks was used to reflect degree of overall accuracy. These similarity values form the basis of all of the taskwork scores and can range from 0 (no shared links) to 1.0 (identical links) with intermediate values indicating intermediate degrees of similarity.

In the same way, referent networks were created to represent the conceptual knowledge associated with each of the three roles (Pilot, NO, IO). These role-specific referent networks contained a subset of the links present in the overall referent network. Positional accuracy, the second metric, was based on the similarity between a team member's network and the referent corresponding to his or her assigned role. IPK accuracy, the third metric, is intended to reflect the interpositional knowledge of team members or that knowledge about the task performed by the roles other than their own. It was the mean of the two Pathfinder-derived similarities between a team member's network and each of the referents representing the other two roles. For each of the first three metrics, the means across the three team members represented team-level measures of accuracy. Finally, the fourth metric, intrateam similarity, consists of the mean of the three pairwise similarities for the three team member networks (i.e., the mean dyad similarity). By averaging scores across team members, we assume that this form of aggregation best reflects the team's score.

Note that for this study referent network representations of taskwork knowledge were purposively constructed by experimenters who possessed expert knowledge about the task. Alternatively, referents can be constructed empirically by collecting expert ratings, averaging ratings and submitting the average to Pathfinder. Due to the small number of experts for this synthetic task domain, we chose the former approach. Also note that similarity is independent of accuracy in that a team with high intrateam similarity can either share accurate or inaccurate knowledge. Further, a team with low intrateam similarity may have members that differ in terms of their overall accuracy or may have three members with high positional accuracy scores.

Teamwork knowledge measure. The teams' knowledge of teamwork was captured in a questionnaire in which participants were required to identify the type of information passed between each pair of team members in a specific direction. Thus information was identified for exchanges 1) from the NO to the IO, 2) from the IO to the NO, 3) from the NO to the pilot, 4) from the pilot to the NO, 5) from the IO to the pilot, and 6) from the pilot to the IO. Information for each case was identified by circling 0-9 options in a list that included the terms weather, grease, planned route, hostile areas, in-flight directions, altitude, speed, and weapons to use.

Each participant's responses were compared to a key developed by the experimenters and then scored for accuracy. The key in this case was a list of correct terms associated with each of the six exchanges. The same three accuracy metrics (overall accuracy, positional accuracy, IPK accuracy) generated for taskwork knowledge were also generated for this teamwork measure. Teamwork positional accuracy was scored against a key that excluded the two team member exchanges that did not involve the position in question (e.g., the IO referent excluded pilot→NO and NO → pilot). Teamwork IPK accuracy was scored against a key that contained only the two team member exchanges that did not involve the position in question (e.g., the IO referent included only pilot→NO and NO → pilot). Thus, the same key or a subset of it (in the case of positional or IPK accuracy) was used to score the accuracy of every individual on every team.

Teamwork accuracy was composed of two components: 1) proportion circled responses correct: the total correct responses (number of circled responses that match the items in the key) divided by the total number of circled responses and 2) proportion items missed on key: the total number of key items not circled divided by the total number of responses on the key. Teamwork knowledge accuracy is the mean of the proportion of circled responses correct and 1 – the proportion of items missed on the key. Thus teamwork scores were mean proportions and could therefore range from 0 to 1.0 with higher values indicating greater accuracy. Intrateam similarity was computed by summing the cases in which each pair of team members agreed that an information flow response was either present or absent. The sum was then divided by the total possible to create a proportion of agreement (ranged from 0 to 1.0). The four metrics were averaged across team members to derive team scores.

Materials

Materials included paper-based task materials described above, including laminated maps that could be marked with erasable pens. In addition, the task incorporated scenarios from a PC-based helicopter flight and combat simulator (i.e., Novalogic's Comanche 2.0). An 8mm Sony video camera was used to record all parts of the mission except the hands-on pilot training. Training materials consisted of paper-based lists of rules, constraints, icons, and flight procedures, as well as a pilot training video created by the experimenters that demonstrated the controls used in the simulator. Measures were mostly presented on paper, although relatedness ratings were collected using a Hypercard-based rating program for the Macintosh. The complete set of task, training, and measurement materials can be found in Cooke, Kiekel, and Rivera (2000). [1]

Procedure

Groups of three participants who signed up for the same experimental session were randomly assigned to one of the three team positions (NO, IO, or Pilot). Participants were uninformed of their assigned position until after training and the first knowledge measurement session (though in the control condition with no cross training, the assigned role may have been obvious). Each team was randomly assigned to a training condition with the constraint that there be an equal number of teams in each of the four conditions. Each participant signed a consent form. Participants were told that they would be participating as a member of a three-person team to perform a simulated helicopter rescue-and-relief mission. They were told that the purpose of the experiment was to evaluate measures of team performance and to compare different team training methods. Then the three individuals were introduced to each other and were told that they would be participating in the study as a team. They each read an overview of the experiment. Training was then administered and differed depending on condition. However, in all conditions, each individual was given a brief description of the three team roles (4 bullets per role) to begin training.

In the Control condition, the role descriptions were followed by written training material pertaining to the participant's assigned role. This material contained rules, constraints, and information pertaining to the meaning of icons. The pilot’s material also consisted of written flight procedures and a brief video demonstrating controls of the simulator. The pilot also was given a check-flight after 15 minutes during which the experimenter tested the pilot on each of eight procedures (e.g., landing, flying backwards, locking-on weapons). Any procedures that were not carried out correctly were demonstrated by the experimenter and tested again until the pilot demonstrated competency for all procedures. After 20 minutes into training, all three team members were administered a role-appropriate training test (each had 10 multiple choice questions with four options each). The experimenter identified incorrect answers (i.e., feedback) and the individual was instructed to go back to the training material to find the correct answer (i.e., self-correction). After the second attempt, the experimenter corrected any incorrect answers (i.e., feedback) and told participants to continue reviewing the training material until 75 minutes of total training time had elapsed. The training test was basically a test of comprehension of the written training material. The training material and test had no direct overlap with the taskwork rating task or the teamwork questions.

In the FCT condition each participant was trained as described above for 25 minutes in each of the three positions. The order in which the positions were learned varied for each team member and was also counterbalanced across teams. Each part consisted of presentation of the role-oriented training material, a check-flight for the Pilot at 15 minutes, the role-appropriate training test at 20 minutes with feedback followed by self correction and additional feedback, and then review for the remainder of the 25 minutes. Total FCT time was 75 minutes.

In the CCT-35 condition, the conceptual training material followed the role descriptions. The conceptual material included 1) a diagram analyzing the team task (i.e., a task analysis diagram), 2) the same task analysis diagram with team member responsible for that part of the task indicated, and 3) a diagram pertaining to information that was shared between team member pairs (i.e., information flow diagram). The information contained in the third diagram was directly relevant to the later teamwork questions. After these diagrams were reviewed, participants were given the role-appropriate training material for their assigned role (same material as given in the other conditions). Again, the check-flight for the pilot was given at 15 minutes into training and at 20 minutes the role-appropriate training test was administered with feedback-self correction-feedback. Participants reviewed the training material for the remainder of 35 minutes. The CCT-75 training condition was identical to CCT-35, except that participants reviewed their material for a full 75 minutes of training. Therefore all training conditions took 75 minutes, except for CCT-35 that required only 35 minutes.

Once training was complete, each participant completed the taskwork relatedness ratings, followed by the teamwork questionnaire. At this point participants were informed of their roles on the team and given name tags, which displayed the role label. All participants then read an overview of the missions. Missions proceeded as described in the section on the synthetic task with a 10-minute break between. After Mission 2 had been completed, the taskwork ratings and teamwork questionnaire were competed for a second time. Then a demographic questionnaire was administered and participants were each debriefed and compensated.

Results

Nine variables were analyzed, for two time periods each, with the performance measure being further measured at two segments per mission. We chose not to try to reduce the variables with scaling techniques, because each variable was intended to measure a distinct construct of interest. Furthermore, factor analysis techniques are only stable with large samples. Tabachnick and Fidell (1996, p. 640) recommend 300 cases as ideal, but 150 cases as acceptable, if several factors have high loading variables.

Means, standard deviations, minimums, and maximums are found in Table 1. The values are calculated for each segment, mission, and training condition. Table 2 shows correlations among all eight knowledge measures during both sessions, and the performance measure in both missions at both segments, as well as averaged across segments.

Predictive Validity of Knowledge Measures

In order to examine the predictive validity of the knowledge measures, correlations were computed between team performance (i.e., completion rate) for Mission 2 and knowledge measures taken at elicitation Session 2 across all conditions. Mission 1 performance and Session 1 knowledge were assumed to be less stable, because the teams were only beginning to learn the task. Improvements in performance across missions and teamwork knowledge across sessions (presented in what follows) support this assumption. The teams' unfamiliarity with this rather complex task was expected to lead to inconsistent data, as different teams learned the task at different rates. Indeed, knowledge-performance correlations were uniformly low (ranging from -.14 to .17). This is not particularly interesting, because we were more interested in team behavior after their understanding of the task had stabilized.

Correlations for the later mission and knowledge session are presented in Table 3. In support of Hypothesis 1 regarding a positive correlation between knowledge and performance, the measures of the teams' knowledge of taskwork and teamwork at Session 2 are generally correlated with completion rate of Mission 2. Teams with greater overall knowledge accuracy, positional knowledge accuracy, IPK accuracy, and intrateam similarity tended to have higher completion rates than those with lower accuracy and similarity. These correlations are reliably greater than zero for all measures except the two teamwork metrics of IPK accuracy and intrateam similarity. Thus, Hypothesis 2 regarding a correlation between IPK accuracy and performance received mixed support with taskwork IPK, but not teamwork IPK, correlating positively with performance. In addition, taskwork and teamwork knowledge measures correlated significantly with each other across all four metrics (*r* overall = .43, *r* positional =.55, *r* IPK=.37, and *r* similarity =.36, see Table 2).

A multiple regression analysis with all eight knowledge metrics taken (four taskwork and four teamwork) at Session 2 as predictors are together predictive of team completion rate in Mission 2 (F (8, 27) = 2.68, p =.03, *Adjusted* R^2 =.28). Beta coefficients, *t* values and significance levels for each of the eight predictors are reported in Table 3. Partial correlations for each of the eight knowledge predictors are also presented in Table 3. Tolerances in this model ranged from .11 to .42, so colinearity is not a major concern. Examination of the individual coefficients indicates that taskwork positional accuracy and intrateam similarity are the best predictors of team performance. Teams with high positional accuracy and lower intrateam similarity in terms of taskwork knowledge (i.e., teams with members who are specialized in terms of taskwork knowledge associated with their individual role) tend to be the better performing teams.

The intrateam similarity variable is a suppressor for positional accuracy. The zero order correlation between taskwork similarity and performance (r = .35) is the opposite valence from the partial correlation (pr = -.37). Also, the zero-order correlation is lower than its indirect zero-order correlation through positional knowledge (*r_Sim-Position* * *r_Position-Perf* = .67*.57 = .38 > .35). Since the relationship between similarity and positional knowledge has a large impact on similarity's zero-order correlation with performance, the partial correlation should be thought of as the more accurate relationship between similarity and performance (Cohen & Cohen, 1983, p. 96).

Effect of Training Strategy on Performance.

In order to address whether training strategy effects team performance, a Training (4) x Mission (2) x Segment (2) mixed analysis of variance was conducted with completion rate as the dependent variable. Contrary to Hypothesis 3 regarding superiority of cross training conditions over the control condition, Results indicated no reliable main effect of training strategy on completion rate (F (3,32)=1.18, p =.33, η^2=.1)[2], however, there were significant main effects of mission and segment.

Specifically, teams improved across conditions from the first (mean completion rate = .52) to the second mission (*M*=.69; F (1,32)=12.21, p =.001, η^2=.28) and did better on average on the three slower-paced, planning mission segment (*M*=.69), relative to the more dynamic flight part of the task (*M*=.52; F (1,32) = 4.99, p =.03, η^2=.13). None of the two-way interactions reached statistical significance (all three n.s. *p*'s > .2, η^2's < .13). However, there was a marginally significant three-way interaction (F (3,32) = 2.64, p = .07, η^2=.20) of mission, session, and training condition for completion rate.

Simple effect post hoc tests were conducted to determine how the training differences in improvement between missions, differed across segments. For the planning segment of the mission, FCT teams improved from M = .65 to M = 1.07 (t (32) = 2.67, p = .011), with no other training conditions showing detectable improvement (all n.s. *p*'s > .05). However, the flight segment, it was Control-trained teams that showed improvement from Mission 1 (M = .29) to Mission 2 (M = .68, t(32) = 2.51, p = .017), while no other training conditions showed any detectable improvement between missions (all n.s. *p*'s > .11) (see Figure 1). In sum, and contrary to predictions, the CCT-35 training condition did not result in better performance than the control. In fact training strategy effects were minimal and slightly favored FCT. Additional analyses were conducted on knowledge measures to explore the effects of training strategy on knowledge.

Diagnostic Information in Knowledge Measures

Taskwork relatedness ratings. A Training (4) x Session (2) analysis of variance was conducted using each of the four taskwork knowledge metrics (overall accuracy, positional accuracy, IPK accuracy, and intrateam similarity) as dependent measures.

Results of these analyses revealed training condition main effects for all metrics (overall accuracy: F (3, 32) = 13.27, p < .001, η^2=.55; positional accuracy: F (3, 32) = 5.31, p =.004, η^2=.33; IPK accuracy: F (3, 32) = 27.62, p <.001, η^2=.72; and intrateam similarity: F (3, 32) = 13.61, p < .001, η^2=.56. Although there was no general change between the two knowledge elicitation sessions for any of the four metrics (all p's > .1, all η^2's < .09), sessions did interact with training condition for measures of overall (F (3, 32) = 5.21, p = .005, η^2=.33) and IPK accuracy (F (3, 32) = 5.1, p =.005, η^2=.32). There was no such interaction for similarity or positional knowledge (both n.s. p's > .1, η^2's < .09).

Post hoc comparisons revealed that the main effects of training strategy on taskwork knowledge support the superiority of the FCT condition in terms of taskwork knowledge (all pairwise comparisons yielded p < .01), but not CCT (all pairwise comparisons yielded p > .23). Figure 2 illustrates the training strategy effect on taskwork knowledge averaged across the two sessions. These results provide only partial support for Hypothesis 4, which predicts a general IPK advantage for all forms of cross training. Conceptual cross training resulted in no benefits of IPK over the control condition. In addition, results support Hypothesis 5, which predicts a specific advantage of the FCT condition in terms of taskwork IPK.

In addition, post hoc simple effect comparisons indicated that, for the first session, the only detectable differences were that FCT-trained teams were superior in terms of overall and IPK accuracy to other teams (all p's < .001). There were no other detectable differences in the first session (all n.s. p's > .05). For session 2, FCT teams still showed detectable superiority over other teams on overall and IPK accuracy (all p's < .001). However, the Control teams with 75 minutes of no cross training also significantly surpassed the two conceptual cross training conditions (i.e., CCT-35, and CCT-75) on these measures (all p's < .02). Again, there were no detectable differences between CCT-35 and CCT-75 (t(32) = -.007, p = .571). In sum, conceptual cross training resulted in no gains in taskwork knowledge over the control condition.

Teamwork questionnaire. A Training (4) x Session (2) analysis of variance on each of the four metrics (overall accuracy, positional accuracy, IPK accuracy, and intrateam similarity) derived from the teamwork questionnaire scores indicated training strategy effects for overall accuracy (F (3, 32) = 3.25, p = .035, η^2 = .23) and IPK accuracy (F (3, 32) = 5.22, p = .005, η^2 = .33), but none for similarity, nor for positional knowledge (both n.s. F's < 1). There were also some general changes in teamwork knowledge between the two elicitation sessions. Across conditions overall accuracy increased (on average .60 to .64: F (1, 32) = 10.64, p = .003, η^2 = .25), as did IPK accuracy (.46 to .50: F (1, 32) = 6.69, p = .014, η^2 = .17). Positional accuracy increased only trivially, by half as much as the IPK or overall accuracy (.66 to .68: F(1, 32) = 3.12, p = .087, η^2 = .09). Intrateam similarity, however, did not change. No interactions were detected between training condition and elicitation session.

Post hoc comparisons revealed that for overall accuracy and IPK accuracy, FCT was superior to all other conditions (all p's < .027), including CCT-35, with no other detectable differences among conditions (all n.s. p's > .24). Figure 3 illustrates the training strategy effect on teamwork knowledge (averaged across both sessions) reflected in the overall and IPK accuracy metrics. These differences mirror those found for taskwork knowledge and so partially support Hypothesis 4 regarding general IPK advantages of cross training, but are contrary to the hypothesized superiority of conceptual cross training in terms of teamwork knowledge (i.e., Hypothesis 5).

Indirect influence of training strategy on performance. Even though training strategy had negligible direct impact on performance (i.e. only through a weak three-way interaction), it is possible that training strategy impacted performance indirectly by way of influencing knowledge. Therefore, we further explored the data to determine whether training strategy had an indirect impact on performance and whether this indirect impact was greater or weaker than the independent effect of knowledge. Direct effects of training strategy on performance were not of interest in this analysis. To examine the effects of training strategy on knowledge and ultimately, performance, we partitioned the variance of the two overall knowledge measures, into that which was attributable to training strategy, and that which was orthogonal to training strategy.

First, we computed two ANOVA models examining the effect of training strategy on overall taskwork accuracy, and overall teamwork accuracy (both Session 2). For each of these models, we retained the predicted values and the residuals. As with any linear model, the criterion Y is equal to $\hat{Y} + e$, where $\hat{Y}$ is a linear combination of the predictors, and e is orthogonal to $\hat{Y}$. Conventional multiple-predictor analyses (e.g. ANCOVA) calculate the set of e's among all predictors, and discard the set of predictors' $\hat{Y}$'s to each other. In this case, we were not interested in training strategy's direct effects on performance. We were, however, interested in a) that part of knowledge that could be accounted for by training strategy (i.e. $\hat{Y}$ from the ANOVA), and b) that part of knowledge that was orthogonal to training strategy (i.e. e from the ANOVA). By taking $\hat{Y}$ and e from the two ANOVA equations predicting overall knowledge from training strategy, the variance of these two knowledge variables was partitioned into that attributable to training strategy and that not attributable to training strategy.

The results comprised the four predictors in a regression equation in which Mission 2 performance was predicted. Using a backward variable selection procedure, two of these four predictors were retained: teamwork-accuracy-through-training-strategy and taskwork-accuracy-not-through-training-strategy. This model was significant ($F(2, 33) = 4.21$, $p = .024$, $R^2 = .20$), with the teamwork-through-training variable having a Beta coefficient of .35 ($t(33) = 2.27$, $p = .03$) and the taskwork-not-through-training variable having a marginally significant Beta coefficient of .28 ($t(33) = 1.8$, $p = .08$). Thus, it appears that training strategy does influence performance, mainly through the acquisition of teamwork knowledge.

Because training strategy (i.e., cross training) was directed at interpositional knowledge the same type of analysis was done for taskwork IPK and teamwork IPK, separating variance attributable to training strategy and not attributable to training strategy for each. Only teamwork-IPK-through-training survived the backward selection procedure ($F(1, 34) = 5.62$, $p = .024$, $R^2 = .14$) and had a Beta coefficient of .38 ($t(34) = 2.37$, $p = .02$). Again, training strategy's effect on performance appears to be an indirect effect through its impact on knowledge, in this case teamwork IPK.

Discussion

The purpose of this research was twofold: 1) to develop and evaluate measures of team knowledge that reflect team member heterogeneity, and 2) to use these measures to better understand the cognitive underpinnings of team performance variations associated with training regime. The first objective was accomplished through the development of measures of taskwork (relatedness ratings) and teamwork (questionnaire) knowledge that were capable of reflecting positional and interpositional knowledge of team members.

Knowledge measures were generally predictive of later team performance and indicated that the highest scoring teams had knowledge that was more accurate overall and in regard to specific team positions. It should be noted that in the absence of manipulative control over knowledge itself, we are not able to determine whether knowledge affects performance, or if alternatively, teams learn from their performance experiences.

When the influence of other knowledge metrics are partialled out, the best independent predictors of team performance are positional taskwork knowledge and intrateam similarity of taskwork knowledge. Specifically, high performing teams tend to be those with members who have accurate taskwork knowledge about their own roles and are dissimilar to each other in the structure of this knowledge. This interesting profile of low intrateam similarity, coupled with high positional accuracy, reflects "shared knowledge" in terms of division of responsibility among the roles, as opposed to shared knowledge in terms of similarity or overlap. This specialization of team members may be important for high performance in this task or at least in the early stages of acquisition of this task. In general, this case demonstrates that these heterogeneous metrics are valuable in facilitating such distinctions.

Further, the teamwork knowledge measure revealed improvement in team knowledge accuracy over time, another indication of the validity of this measure. Interestingly, the taskwork knowledge measure showed no change over the two sessions. Based on these results and results from similar studies (e.g., Cooke, Kiekel, & Helm,

2001) it appears that some measures (e.g., of teamwork knowledge) seem to be sensitive to intrateam knowledge changes that occur with task experience, and others (e.g., of taskwork knowledge) seem more sensitive to interteam differences. One possibility is that taskwork knowledge develops early, but differences across teams are diagnostic, whereas teamwork knowledge requires task experience to develop and differs less across teams. Also, the rating measure by virtue of the fact that it is a relatively indirect elicitation method, may be better at revealing more subtle knowledge distinctions compared to more direct measures such as the teamwork questionnaire. These differences among knowledge elicitation methods parallel those found at the individual level and generally support the differential access hypothesis, the proposal that different knowledge elicitation methods access different types of knowledge, (Hoffman, Shadbolt, Burton, & Klein, 1995).

In sum, the taskwork and teamwork measures that were developed were related to team performance under some circumstances, supporting their predictive validity. Also, the results of these measures suggest interesting patterns of knowledge and knowledge acquisition associated with team performance on this task. Although the measures used here included materials specific to the team task used in this study, they can be adapted to a different task with adequate understanding of the taskwork and teamwork information required for effective team performance. In addition, the metrics that were used to assess positional and interpositional accuracy can also be adapted for other tasks given knowledge of positional knowledge requirements.

The second objective of this research, to use the measures to better understand the cognitive underpinnings of team performance variations associated with training regime was accomplished in the context of an experiment comparing cross training techniques. Although the team performance measure (i.e., mission completion rate) only weakly differentiated the conditions in favor of the traditional full cross training condition, the knowledge measures painted a very strong and clear picture of team knowledge in these conditions. Team knowledge was greatest for the teams that were trained under the full cross training condition. This was true for both taskwork knowledge and teamwork knowledge, contrary to the hypothesized benefit of the conceptual version of cross training on teamwork knowledge. These results not only support the validity of the knowledge measures in their ability to differentiate training conditions, but they also serve to clarify the cognitive effects of training strategy.

Specifically, the results associated with the knowledge measures indicate that having taskwork and teamwork knowledge is predictive of performance and FCT teams have more of each than teams in any other training condition. In addition, FCT teams have more interpositional knowledge of taskwork and teamwork that is typically associated with cross training. Curiously, CCT teams who were trained directly in interpositional teamwork knowledge were nonetheless, surpassed by FCT teams in this regard. This finding, combined with the acquisition of teamwork knowledge over sessions, suggests that teamwork knowledge requires task experience to develop and this natural acquisition process may actually suffer from early attempts at directly training interpositional teamwork information, as was done in the CCT condition.

However, because FCT teams also surpass Control teams in terms of teamwork IPK, there must have been a benefit of the FCT program (which emphasized interpositional taskwork knowledge) to the acquisition of teamwork knowledge. In fact, the regression analysis of the partitioned variance suggests that it is the acquisition of teamwork knowledge through training that most influenced performance. Perhaps, early acquisition of taskwork knowledge is critical for the development of later teamwork IPK and it may be difficult to acquire or maintain teamwork IPK, devoid of taskwork knowledge. In support of this is the fact that overall accuracy on taskwork knowledge in Session 1 is correlated with IPK accuracy on teamwork knowledge in Session 2 (r (34) = .41). A medical analogy is trying to explain to the nurse what information the surgeon needs without providing an understanding of what it is that the surgeon does. Overall, this result provides an explanation for the knowledge benefits of the FCT training condition that focused largely on taskwork, relative to the CCT conditions that focused primarily on teamwork. The FCT teams acquired early taskwork knowledge, which then facilitated later acquisition of teamwork knowledge. Teams without early taskwork background (i.e., CCT teams and control teams) were unable to acquire teamwork knowledge. If indeed, the FCT condition benefited from an early focus on taskwork IPK, future modifications of FCT might also focus on taskwork information.

One other, less interesting possibility for FCT knowledge superiority should be noted. That is, FCT teams could have acquired more knowledge in general because these teams spent more "motivated time" in training than teams in other conditions. Recall that Control and CCT-75 teams reviewed the same training material for at least half of the training session, whereas FCT teams spent the same amount of time engaged in training on new material. However, motivation does not completely account for FCT superiority. CCT-35 teams spent 35 minutes of "motivated time" in training. Thus the knowledge benefit of FCT over CCT-35 must have to do with the training material, which focused on taskwork IPK for 75 minutes in the former and teamwork IPK for 35 minutes in the latter. At the least, these results suggest that one cannot "short-cut" cross training by focusing solely on teamwork IPK.

Interestingly, although the FCT teams were more knowledgeable in terms of taskwork and teamwork, they did not perform much better than other teams who did not have this knowledge. The knowledge results showing that positional taskwork accuracy and intrateam taskwork similarity were the best independent predictors of performance may shed some light on this. That is, the FCT training was successful in terms of acquisition of interpositional information, but this information was not as valuable for performance on this task (at least at this level of skill), as was positional taskwork knowledge. Indeed, according to the analysis of partitioned variance, overall taskwork knowledge acquired through training strategy was not as predictive of performance as overall taskwork knowledge not attributed to training strategy. Although positional taskwork knowledge was also acquired by FCT teams, the interpositional information about other roles may have hindered or interfered with this to some extent, limiting their ability to specialize in their role-specific taskwork knowledge. This cannot be the entire story, however, because control teams trained only on their roles did not pick up positional knowledge as well as FCT teams. It appears that FCT training facilitates both positional and interpositional taskwork knowledge acquisition, with positional knowledge being the most relevant to high performance, though perhaps weakened by the simultaneous acquisition of interpositional taskwork knowledge.

In summary, these tentative findings suggest interesting hypotheses about the relations between knowledge, training strategy, and effective team performance in this synthetic task:

1. Taskwork knowledge, especially that which is specialized by individual role, is more predictive of performance than teamwork knowledge.
2. Teamwork knowledge develops with task experience, and thus may suffer from premature attempts at cross training, but appears to be facilitated by prior cross training in taskwork knowledge.
3. The teamwork knowledge acquired through full cross training is most relevant to performance.
4. The specialization of taskwork knowledge apparently associated with superior team performance in this study may be at odds with the objectives of full cross training.

These hypotheses demonstrate the utility of examining the knowledge patterns underlying team performance. Although the hypotheses require additional empirical testing, there are ultimately important implications for the design of training programs. Specifically, these results suggest that full cross training may have had a greater effect on performance in this task if role-specific taskwork knowledge had been trained, followed by cross training in teamwork knowledge, while minimizing cross training in taskwork knowledge.

In general, the relationship between team knowledge and team performance, coupled with valid measures of team knowledge, has implications for assessing training requirements. Additional research along these lines can help identify 1) patterns of positional and interpositional teamwork and taskwork knowledge required for effective team performance in a task domain, and 2) the training regime best suited to meet those requirements. For instance, the knowledge measures described in this paper could be used as part of a cognitive task analysis of a targeted team task. Results could reveal the degree to which team members of effective teams have knowledge that is overlapping or unique, as well as the specific aspects of that knowledge that are overlapping or unique. In this way, a knowledge profile could be generated for the task that identified for each type of knowledge the degree to which team members of effective teams were specialized. This knowledge profile of the task could then drive cross training or team composition requirements. Further, the emphasis on taskwork or teamwork could also be based on this form of analysis.

Finally, this study suffered from a number of limitations. In particular, the weak effects of training strategy on performance could be attributed to a need for specialization in this task. However, it is also possible that training strategy effects suffered from low statistical power, an insensitive performance measure, a motivational confound or a combination of these. In addition, some of the interteam variance may have been reduced by limiting teams to a single gender composition or by keeping intrateam familiarity constant. Finally, these results pertain to a single synthetic task and we assume that they generalize to the target domain of Navy helicopter missions and possibly to other tasks that involve similar forms of team planning and decision making. Although we see no reason that the knowledge measures should not apply to other similar task environments, the specific knowledge profile (e.g., positional accuracy on taskwork knowledge best predicts performance) is likely to be specific to the task and domain.

In conclusion, team knowledge measures for teams with heterogeneous knowledge backgrounds were developed and succeeded in predicting team performance in a single experiment. Empirical results demonstrated that full-cross training was superior to other training regimes at establishing a variety of types of teamwork and taskwork knowledge. A detailed examination of the data from the knowledge measures provided some interesting hypotheses regarding knowledge, training strategy, and team performance in this task context and in general, demonstrated the advantages of examining the cognitive underpinnings of team performance in this way. Taskwork and teamwork knowledge measures like these can provide a deep look into the effects of training programs, technological interventions, and group factors by exploring their effects not only on outcome measures, but also on the nature of team knowledge underlying those outcomes. Such knowledge-based explanations for team performance afford knowledge-based interventions by which team performance can be modified.

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Author Note

Nancy Cooke is in the Applied Psychology Program at Arizona State University, East, 7001 E. Williams Field Road, Mesa, AZ 85212 and can be reached at 480-727-1331 or ncooke@asu.edu.

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Footnotes

[1]Contact Nancy Cooke in the Applied Psychology Program at Arizona State University, East, 7001 E. Williams Field Road, Mesa, AZ 85212 (480-727-1331 or ncooke@asu.edu) for more information on the materials used in this study.

[2] All post hoc tests were conducted with no α correction; however, effect size (η^2) is displayed to compensate for this.

Table 1
Descriptive Statistics for Performance and Knowledge Measures

Variable	Mission	Segment	Condition	Mean	SD	Min	Max
Performance	1	s1-s3	FCT	0.652	0.503	0	1.364
			Control	0.814	0.491	0	1.364
			CCT-35	0.533	0.347	0	1.071
			CCT-75	0.503	0.356	0	1.035
		s4	FCT	0.551	0.363	0.25	1.429
			Control	0.291	0.284	0	0.8
			CCT-35	0.499	0.36	0	1
			CCT-75	0.341	0.241	0	0.8
	2	s1-s3	FCT	1.066	0.551	0.4	2.093
			Control	0.68	0.328	0.333	1.2
			CCT-35	0.482	0.359	0	1.071
			CCT-75	0.82	0.683	0	2.143
		s4	FCT	0.643	0.293	0	1.071
			Control	0.682	0.307	0.25	1.071
			CCT-35	0.582	0.347	0	1.071
			CCT-75	0.596	0.345	0	1
Teamwork Overall	1	-	FCT	0.643	0.047	0.592	0.727
			Control	0.599	0.046	0.533	0.681
			CCT-35	0.58	0.032	0.526	0.636
			CCT-75	0.581	0.064	0.475	0.649
	2	-	FCT	0.672	0.047	0.57	0.732
			Control	0.614	0.056	0.529	0.683
			CCT-35	0.621	0.078	0.445	0.703
			CCT-75	0.637	0.054	0.543	0.718
Teamwork Positional	1	-	FCT	0.684	0.035	0.635	0.733
			Control	0.656	0.038	0.589	0.721
			CCT-35	0.658	0.035	0.603	0.709
			CCT-75	0.646	0.047	0.572	0.702
	2	-	FCT	0.688	0.041	0.6	0.727
			Control	0.667	0.063	0.577	0.749
			CCT-35	0.686	0.054	0.578	0.76
			CCT-75	0.669	0.063	0.588	0.747
Teamwork IPK	1	-	FCT	0.525	0.102	0.352	0.671
			Control	0.433	0.068	0.333	0.523
			CCT-35	0.413	0.05	0.361	0.5
			CCT-75	0.457	0.101	0.31	0.653
	2	-	FCT	0.578	0.085	0.435	0.667
			Control	0.469	0.061	0.361	0.593
			CCT-35	0.459	0.066	0.384	0.569
			CCT-75	0.49	0.113	0.292	0.625
Teamwork Similarity	1	-	FCT	0.691	0.052	0.58	0.741
			Control	0.647	0.075	0.556	0.765
			CCT-35	0.634	0.076	0.543	0.765
			CCT-75	0.657	0.073	0.58	0.815
	2	-	FCT	0.667	0.063	0.568	0.753
			Control	0.635	0.085	0.494	0.716
			CCT-35	0.631	0.075	0.531	0.741
			CCT-75	0.643	0.122	0.42	0.741

Table 1 (continued)

Taskwork Overall	1	-	FCT	0.414	0.054	0.334	0.492
			Control	0.294	0.036	0.25	0.346
			CCT-35	0.327	0.042	0.27	0.394
			CCT-75	0.33	0.09	0.222	0.506
	2	-	FCT	0.406	0.027	0.372	0.447
			Control	0.348	0.031	0.285	0.389
			CCT-35	0.3	0.034	0.236	0.349
			CCT-75	0.293	0.034	0.244	0.341
Taskwork Positional	1	-	FCT	0.338	0.048	0.269	0.405
			Control	0.262	0.047	0.172	0.33
			CCT-35	0.283	0.041	0.218	0.371
			CCT-75	0.25	0.06	0.161	0.346
	2	-	FCT	0.306	0.038	0.268	0.39
			Control	0.255	0.034	0.172	0.291
			CCT-35	0.258	0.041	0.206	0.331
			CCT-75	0.264	0.049	0.176	0.307
Taskwork IPK	1	-	FCT	0.328	0.036	0.294	0.393
			Control	0.219	0.047	0.154	0.283
			CCT-35	0.237	0.02	0.207	0.272
			CCT-75	0.221	0.029	0.187	0.257
	2	-	FCT	0.314	0.02	0.282	0.343
			Control	0.262	0.032	0.2	0.315
			CCT-35	0.225	0.032	0.17	0.281
			CCT-75	0.231	0.024	0.194	0.272
Taskwork Similarity	1	-	FCT	0.353	0.071	0.234	0.481
			Control	0.222	0.042	0.157	0.282
			CCT-35	0.272	0.069	0.148	0.382
			CCT-75	0.228	0.061	0.115	0.312
	2	-	FCT	0.343	0.043	0.274	0.407
			Control	0.263	0.05	0.198	0.33
			CCT-35	0.238	0.047	0.169	0.287
			CCT-75	0.231	0.055	0.132	0.277

Note. FCT = full cross training, CCT-35 = Conceptual cross training for 35 minutes, CCT-75 = Conceptual cross training controlled for training time at 75 minutes. For all cells N = 9.

Table 2

Correlations Among all Knowledge and Performance Measures

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1. M1 PERF	***1.00***	0.09	0.15	0.05	0.17	0.08	0.12	0.01	-0.14	*0.36*	-0.05	0.03	-0.05	0.15	0.16	0.13	0.17	0.17
2. TM OV1	0.09	***1.00***	***0.84***	***0.51***	***0.56***	*0.41*	*0.40*	***0.42***	*0.38*	0.14	*0.39*	0.29	*0.38*	***0.42***	***0.44***	0.27	***0.48***	*0.34*
3. TM POS1	0.15	***0.84***	***1.00***	0.16	***0.57***	*0.37*	*0.41*	0.32	*0.36*	0.28	*0.34*	*0.37*	0.27	*0.37*	*0.36*	*0.35*	0.29	0.23
4. TM IPK1	0.05	***0.51***	0.16	*1.00*	0.06	0.21	0.30	***0.42***	0.32	0.02	0.25	0.01	***0.47***	0.25	0.19	0.05	*0.39*	0.21
5. TM SIM1	0.17	***0.56***	***0.57***	0.06	***1.00***	0.14	0.18	0.17	-0.06	0.27	***0.42***	***0.44***	0.16	***0.44***	*0.33*	0.17	0.26	0.19
6. TSK OV1	0.08	*0.41*	*0.37*	0.21	0.14	***1.00***	*0.61*	***0.74***	***0.70***	***0.48***	***0.46***	*0.35*	*0.41*	0.24	***0.55***	***0.63***	***0.54***	***0.57***
7. TSK POS1	0.12	*0.40*	*0.41*	0.30	0.18	***0.61***	***1.00***	***0.67***	***0.63***	*0.40*	***0.44***	*0.40*	***0.46***	0.09	***0.47***	***0.63***	*0.36*	*0.39*
8. TSK IPK1	0.01	***0.42***	0.32	***0.42***	0.17	***0.74***	***0.67***	***1.00***	***0.78***	0.33	*0.37*	0.27	*0.38*	0.15	***0.64***	***0.51***	***0.69***	***0.68***
9. TSK SIM1	-0.14	*0.38*	*0.36*	0.32	-0.06	***0.70***	***0.63***	***0.78***	***1.00***	0.19	0.25	0.18	***0.45***	0.14	***0.42***	***0.45***	***0.42***	***0.53***
10. M2 PERF	*0.36*	0.14	0.28	0.02	0.27	***0.48***	*0.40*	0.33	0.19	***1.00***	*0.36*	*0.33*	0.15	0.25	***0.42***	***0.56***	***0.43***	*0.35*
11. TM OV2	-0.05	*0.39*	*0.34*	0.25	***0.42***	***0.46***	***0.44***	*0.37*	0.25	*0.36*	***1.00***	***0.81***	***0.49***	***0.57***	***0.43***	***0.51***	*0.39*	***0.45***
12. TM POS2	0.03	0.29	*0.37*	0.01	***0.44***	*0.35*	*0.40*	0.27	0.18	0.33	***0.81***	***1.00***	0.04	***0.66***	0.29	***0.55***	0.20	*0.40*
13. TM IPK2	-0.05	*0.38*	0.27	***0.47***	0.16	*0.41*	***0.46***	*0.38*	***0.45***	0.15	***0.49***	0.04	***1.00***	0.09	*0.35*	0.18	*0.37*	0.20
14. TM SIM2	0.15	***0.42***	*0.37*	0.25	***0.44***	0.24	0.09	0.15	0.14	0.25	***0.57***	***0.66***	0.09	***1.00***	0.17	0.30	0.30	*0.36*
15. TSK OV2	0.16	***0.44***	*0.36*	0.19	*0.33*	***0.55***	***0.47***	***0.64***	***0.42***	***0.42***	***0.43***	0.29	*0.35*	0.17	**1.00**	***0.55***	***0.86***	***0.83***
16. TSK POS2	0.13	0.27	*0.35*	0.05	0.17	***0.63***	***0.63***	***0.51***	***0.45***	***0.56***	***0.51***	***0.55***	0.18	0.30	***0.55***	***1.00***	***0.51***	***0.67***
17. TSK IPK 2	0.17	***0.48***	0.29	*0.39*	0.26	***0.54***	*0.36*	***0.69***	***0.42***	***0.43***	*0.39*	0.20	*0.37*	0.30	***0.86***	***0.51***	***1.00***	***0.82***
18. TSK SIM2	0.17	*0.34*	0.23	0.21	0.19	***0.57***	*0.39*	***0.68***	***0.53***	*0.35*	***0.45***	*0.40*	0.20	*0.36*	***0.83***	***0.67***	***0.82***	***1.00***

Note. M1 PERF = Mission 1 Performance, M2 PERF = Mission 2 Performance, TM = Teamwork Knowledge, TSK = Taskwork Knowledge, OV1 = Overall Accuracy Session 1, OV2 = Overall Accuracy Session 2, POS 1=Positional Accuracy Session 1, POS2= Positional Accuracy Session 2, IPK1 = Interpositional Knowledge Accuracy Session 1, IPK2 = Interpositional Knowledge Accuracy

Session2, SIM1= Intrateam Similarity Session1, SIM2 = Intrateam Similarity Session 2. The degrees of freedom for all cells = 34.

Correlations in italics are significant at p<.05 and those in bold italics at bold p<.01.

Table 3

Multiple Regression Model Results Knowledge Metrics at Session 2 as Predictors of Mission 2 Completion Rate

Team Knowledge Measure	**Zero-order correlation (df=34)**	**Partial correlation**	**Beta**	**t**	**p-value**
TASKWORK RELATEDNESS RATINGS					
Overall Accuracy	.42*	.17	.32	.90	.37
Positional Accuracy	.57*	.49	.64	2.89	.008
IPK Accuracy	.43*	.20	.37	1.04	.31
Intrateam Similarity	.35*	-.37	-.69	-2.05	.05
TEAMWORK QUESTIONNAIRE					
Overall Accuracy	.36*	.09	.20	.49	.63
Positional Accuracy	.33*	-.08	-.18	-.42	.68
IPK Accuracy	.15	-.14	-.18	.75	.46
Intrateam Similarity	.25	.14	.17	.73	.47

Note. * $p < .05$.

Figure Captions

Figure 1. Effects of training condition, segment, and mission on completion rate (proportion completed per proportion time to complete).

Figure 2. Mean effects of training condition on taskwork knowledge across the two sessions.

Figure 3. Mean effects of training condition on teamwork knowledge (overall and IPK metrics only) across the two sessions.

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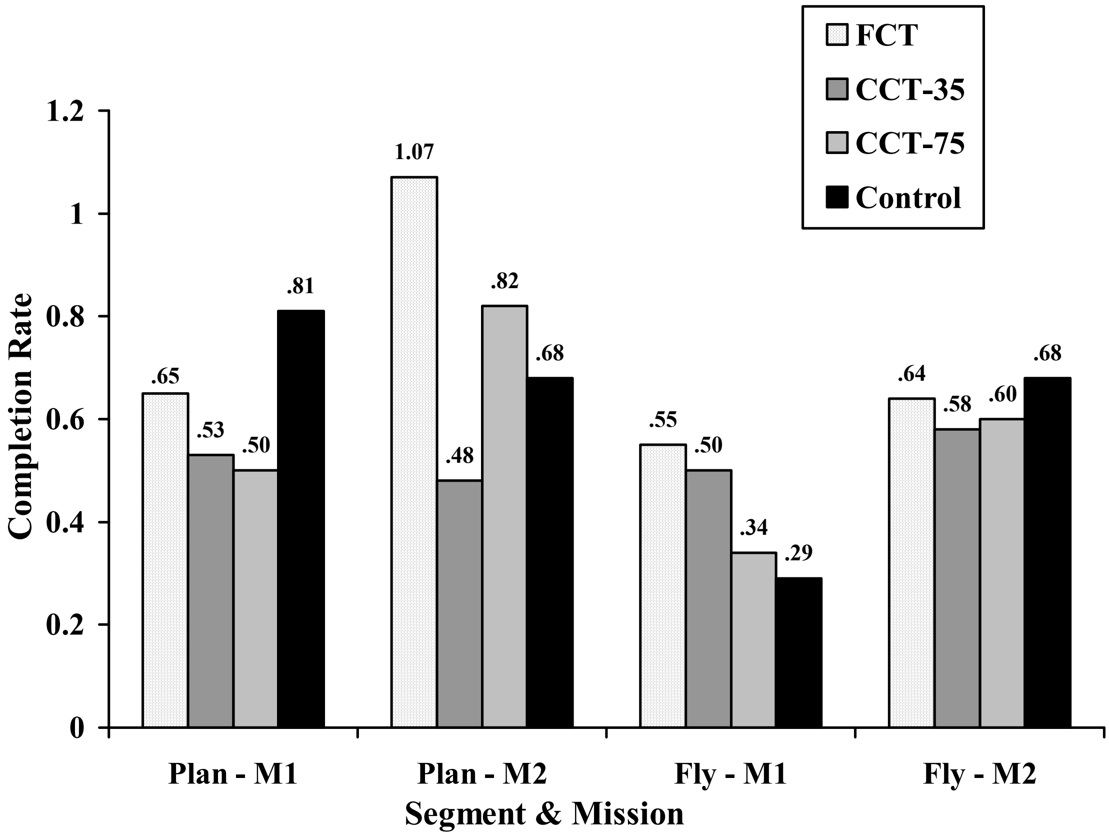
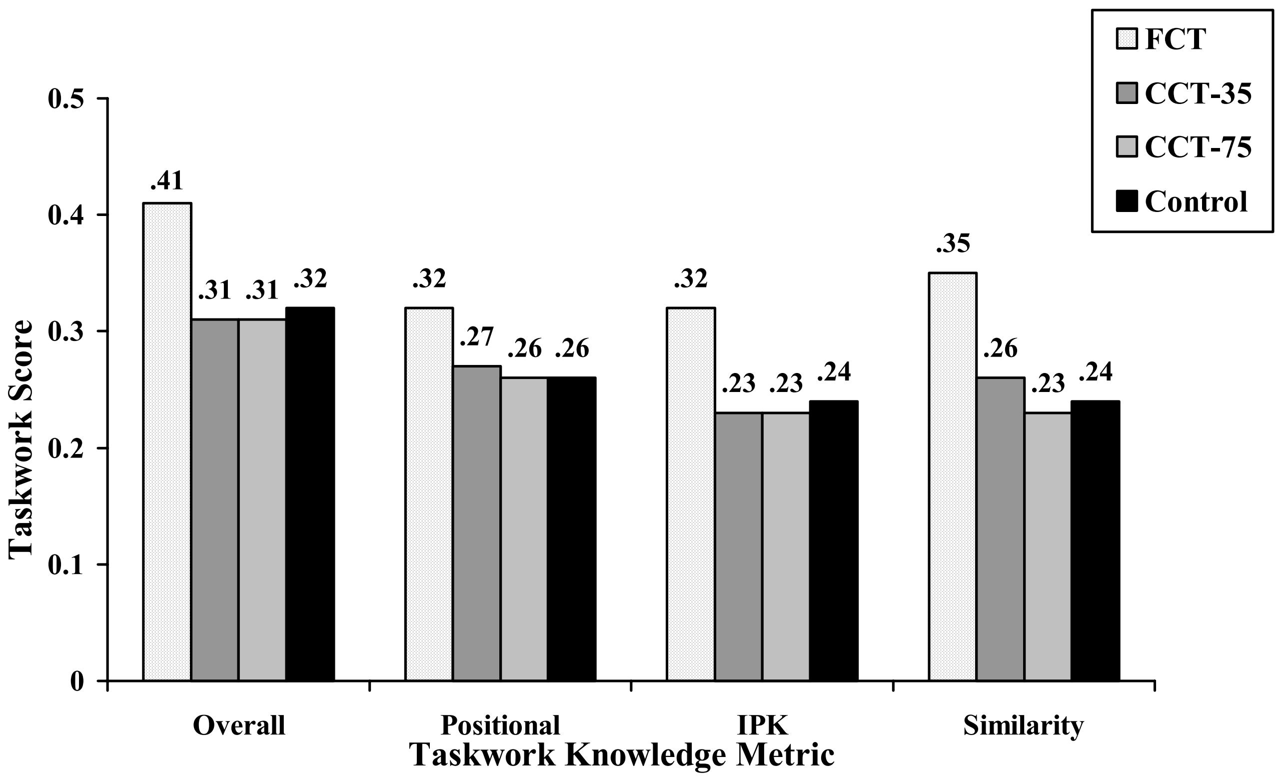
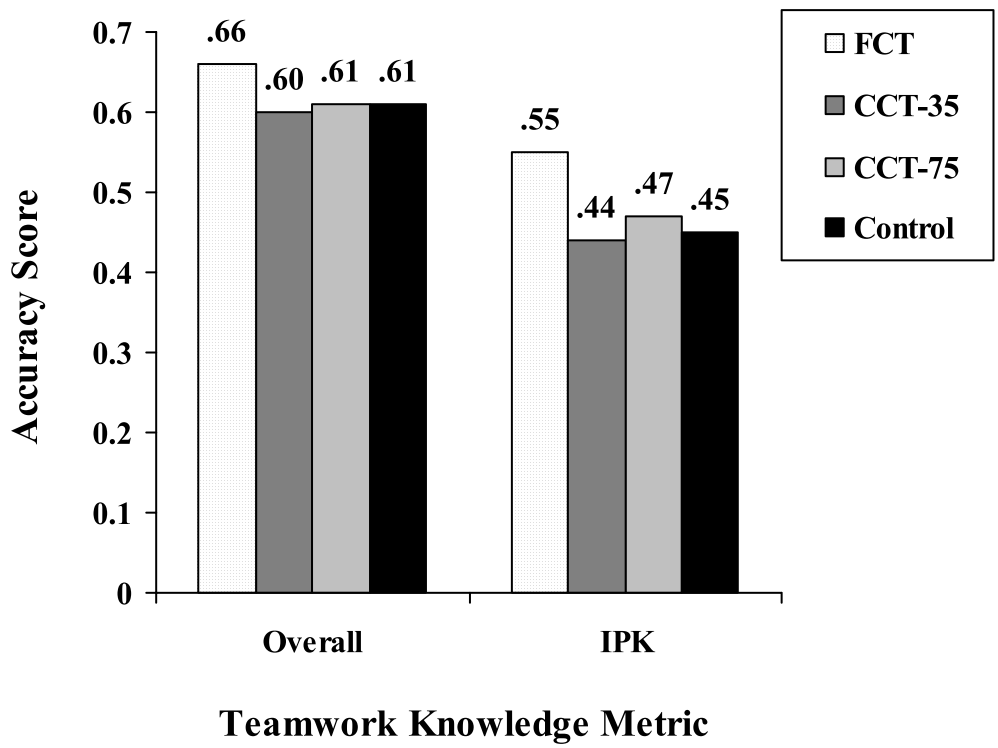

FCT
CCT-35
CCT-75
Control
1.2
1
0.8
0.6
0.4
0.2
0
Completion Rate
.65
.53
.50
.81
1.07
.48
.82
.68
.55
.50
.34
.29
.64
.58
.60
.68
Plan - M1
Plan - M2
Fly - M1
Fly - M2
Segment & Mission


FCT
CCT-35
CCT-75
Control
0.5
0.4
0.3
0.2
0.1
0
Taskwork Score
.41
.31
.31
.32
.32
.27
.26
.26
.32
.23
.23
.24
.35
.26
.23
.24
Overall
Positional
IPK
Similarity
Taskwork Knowledge Metric



.66
.60
.61
.61
.55
.44
.47
.45
Accuracy Score
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Overall
IPK
Teamwork Knowledge Metric
FCT
CCT-35
CCT-75
Control