Title: Macrocognition in teams: Understanding knowledge building for team problem solving

Abstract: Macrocognition in teams involves individual and team cognitive processes to generate new knowledge to solve unique problems. Four empirical studies present different approaches to examine the learning and knowledge creation processes in team problem solving. The research incorporates multilevel theory with a focus on dynamic processes in team cognition.

Press Paragraph: It’s not always easy when teams have to solve problems. Individual team members might not share all the relevant information, members may ignore what others communicate, and factors like time pressures work against a team trying to find the best solution. Research in team macrocognition focuses on the learning and knowledge creation processes that underlie the emergence of new ideas and solutions. Some results from research presented in this symposium showed training in communication behaviors was related to transferred knowledge. In addition, macrocognition processes help explain why computer-mediated teams can have similar performance outcomes as face-to-face teams.

Special Requests: None

Number of Authors/Participants: 14

Amount of Time Requested: 80 minutes
Macrocognition in teams involves individual and team cognitive processes to generate new knowledge to solve unique problems (Fiore et al., 2010). We know from meta-analytic research that team cognition is an important predictor of team behavior, motivational processes, and team performance (DeChurch & Mesmer-Magnus, 2010). However, research has generally not carefully distinguished the processes of collaborative knowledge construction and the knowledge outcomes that result from that process. Thus, we know relatively little about the learning and knowledge creation processes that underlie shared cognition (Kozlowski & Ilgen, 2006). The focus of this symposium is on understanding the process of collaborative knowledge building in teams – team macrocognition. Four empirical investigations of team macrocognition are presented to advance our understanding of how individuals work together, learning and sharing relevant information needed for effective decision making.

Integrating Multilevel Theory (Kozlowski & Klein, 2002) and Macrocognition Theory (Fiore et al., 2010), Kozlowski et al. (2011) presented a theoretical approach to understand and measure the processes by which macrocognition emerges from the dynamic interaction of individual-level, internal knowledge building and its transformation to team-level, externalized knowledge building in the service of collaborative problem solving. The presentation by Kozlowski et al. describes how results from agent-based simulations and human-based simulation converged to support the macrocognitive process model, provide validation evidence for the team knowledge typology, and demonstrate the diagnostic value of the team knowledge metrics. This research paradigm can guide future theory and research by testing initial conditions and relationships in computer-based simulations and then evaluating specific hypotheses in human-based tasks (Davis, Eisenhardt, & Bingham, 2007).
The second presentation focuses on relationships among team cognition and knowledge building variables. Rentsch, Delise, Salas, and Letsky (2010) found that teams trained to build knowledge with an interactive information board using specified communication behaviors had higher knowledge transfer, knowledge interoperability, and performance than control teams. Building on this research, Rentsch et al. examined the relationships among the cognitive variables and present results from a study designed to examine team cognitive processes in a hidden profile task. Positive relationships were found between information sharing, knowledge transfer, task schema congruence, and specific schema enriched communication behaviors. In addition to directly assessing relationships among knowledge building processes, the results contribute to the study of cognition in teams by identifying specific unique schema enriched communication behaviors associated with transferred knowledge.

Researchers have shown that converged mental model content is related to team performance. Yet, much of that research has been based on data collected after teams have completed a task. In the third presentation, McComb examines the convergence process when it occurs during team activities, as it may better inform our understanding of the similarities and differences in performance outcomes across teams. To that end, she examines (1) how the mental model convergence process occurs over time using event history analysis, (2) temporal interdependencies among mental model convergence points and taskwork initiation, and (3) the impact of media types (i.e., computer-mediation or face-to-face), time availability (i.e., unlimited time or time pressure), and interruptions (i.e., unanticipated changes in working conditions) on the mental model convergence and re-convergence processes that occur while teams are completing their tasks.
Finally, the Fiore presentation views collaborative problem solving as rising in prominence as public and private sector organizations are increasingly addressing problems requiring the combination of diverse sets of individual expertise to address novel situations. But much of the research in teams has focused on behavioral coordination in routine tasks. As such, there is a need for developing an understanding of, and interventions for, the support of collaborative problem solving focusing more on knowledge-based performance in teams. His presentation provides data from studies in the area of macrocognition -- an extension to team cognition research which seeks to build upon traditions examining team process and unite them with ideas from cognitive science. The findings are organized around a multi-level theoretical approach. This incorporates the role of internalized and externalized team knowledge along with individual and team knowledge building process as teams move through phases of problem solving.

In summary, the four presentations describe different ways to investigate macrocognition in teams. They include computer-based simulations, synthetic team learning tasks, hidden profile tasks, and problem solving tasks under a variety of team environments. Results illustrate the need to understand how teams collaborate to build a shared knowledge base for effective problem solving and decision making. Following the presentations, the chairs will moderate a discussion of team macrocognition with the panel and audience. The primary goal of this discussion is to initiate innovative thinking and research on macrocognition and teams.

References


The literature on team cognition has broadly delineated between approaches which examine products, constructs, and outcomes related to team knowledge-building activities (i.e., shared mental models, transactive memory, Mohammed, Ferzandi, & Hamilton, 2010; DeChurch & Mesmer-Magnus, 2010) and those which examine the inter- and intra-personal dynamics that underlie team-level knowledge acquisition (i.e., macrocognition, Cooke, Salas, Kiekel, & Bell, 2004; Fiore et al., 2010). Of these two research foci, the former has largely dominated empirical research (e.g., Rentsch, Small, & Hanges, 2008; Wildman et al., in press). However, attempts to theoretically and empirically depict the cognitive processes/mechanisms by which team knowledge outcomes emerge are imperative to understanding the nature of team cognition. Identifying key developmental stages of team learning, diagnosing problems that emerge/are present during team collaboration, and designing interventions that assist group members in acquiring important information are needed to make effective decisions in team contexts (e.g., Kozlowski & Chao, in press; Kozlowski & Ilgen, 2006). In this symposium, we intend to present exemplary data and implications from our research paradigm on macrocognition. Specifically, we will summarize our efforts to apply a dynamic process model of macrocognition based on relevant theory and measurement to develop, analyze, and validate data from a computer-based simulation and a human-based task of team learning.

**Research Paradigm**

**Theory integration and model development.** Based on our previous conceptualizations of macrocognition and its measurement (Kozlowski & Chao, in press; Kozlowski et al., 2011),
we integrated tenets of Multilevel Theory (Kozlowski & Klein, 2002) and Macrocognition Theory (Fiore et al., 2010) to form a dynamic process model representing how individual team members incrementally acquire problem-relevant knowledge and share that knowledge with other members as they collectively integrate information necessary for team decision-making and problem-solving (see Figure 1). Akin to Reynolds’ (1987) studies of systemic behavior in artificial agents (“Boids”), this macrocognitive process model employs a relatively small number of simple rules/functions that, given unique variation in constituent members, is capable of capturing/describing complex patterns of emergence in the knowledge-building activities and outcomes of teams.

**Computer-based simulation.** Based on the above foundations, a computational model that instantiates the knowledge acquisition and sharing processes characteristic of macrocognition was developed (cf., Hulin & Ilgen, 2000). Using this model, computer-simulated data was calculated for 3000 agent-based teams (“Droids”) whose composition varied across 36 unique conditions. Data reflecting conceptually identified metrics of team knowledge acquisition (e.g., proportion of total information acquired, proportion of information overlapping, etc.; Kozlowski & Chao, in press) were collected and used to validate the metrics and demonstrate their diagnostic utility for tracking different patterns of team knowledge emergence over time.

**Human-based Task Environment.** Lastly, a synthetic team learning task which emulated the structure of macrocognitive problem solving (i.e., iterative knowledge acquisition, individual to team knowledge emergence, effects on decision effectiveness examined, etc.) was constructed to empirically evaluate the diagnostic value of the metrics and their utility to drive interventions that enhance macrocognition in human-based teams (Human - “Noids”). A key feature of the task is that measures of knowledge acquisition and knowledge sharing activities
are collected via task behavior, thus avoiding issues with self-reported data. Furthermore, this permits continuous observations of team learning activities across multiple problem-solving scenarios. As a result, both individual and team knowledge emergence trajectories could be tracked over time, therefore offering a highly flexible platform for observing (and, in future interventions, influencing) team cognition and decision effectiveness. Pilot data from six, 3-member teams was gathered; further data collection (~200 teams) is scheduled to begin this fall.

**Preliminary Results**

Utilizing data from both the computer- and human-based environments, comparisons of team knowledge emergence between simulated “Droids” and real “Noids” were used to evaluate the accuracy of the macrocognitive process model and examine the usefulness of the team knowledge metrics for capturing variation in team knowledge building. Figure 2 demonstrates that the underlying processes modeled with our computational agents accurately parallels knowledge acquisition rates found within human teams. Similarly, measures of knowledge emergence and information distribution across team members specified by the process model demonstrated remarkably similar patterns in both Droids and Noids (Figure 3). In sum, these preliminary results suggest that the dynamic process model and measurement typology proposed in previous research (e.g., Kozlowski & Chao, in press) are theoretically and empirically valid representations of macrocognition. Implications of the paradigm described for future research and practice will be discussed, including the capability to test (with “Droids”) and evaluate (with “Noids”) interventions targeted at various stages of team knowledge-building (e.g., Fiore et al., 2010; SUMMIT, 2010).
References


Kozlowski, S.W.J., Chao, G.T., Grand, J.A., Keeney, J., Braun, M.T., & Kuljanin, G. (2011). Macrocognition and teams: The emergence and measurement of team knowledge. Symposium presented at the 26th annual meeting of the Society for Industrial and Organizational Psychology, Chicago, IL.


Figure 1. Dynamic process model of macrocognition
Figure 2. Patterns of knowledge acquisitions for high performing “Droid” and “Noid” teams

*Note.* Each line represents the total amount of information learned by each different team member. Y-axis units are reported as proportion of total knowledge pool, X-axis as total time elapsed.
Figure 3. Patterns of knowledge configuration for high performing “Droid” and “Noid” teams

Note. The red line represents amount of information uniquely known by only one team member, the green line represents amount of information known by any two team members, and the black line represents amount of information known by all three team members. Y-axis units are reported as proportion of total knowledge pool, X-axis as total time elapsed.
The Relationships among Team Cognition and Knowledge Building Variables

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Research on information sharing suggests that maximum benefit from decision making teams consisting of experts will occur only if team members are able to communicate, share, and integrate their uniquely held information (e.g., Stasser & Titus, 1985). Members of this panel (Chao, Fiore, Kozlowski, McComb, & Rentsch) and others have articulated team cognition variables associated with high quality team decision making. For example, Rentsch, Delise, Salas, and Letsky (2010) defined information sharing, knowledge transfer, knowledge interoperability, and team member task schema congruence as variables associated with high quality team decision making.

Research evidence supports the relationship between information sharing and high quality team outcomes (e.g., Campbell & Stasser, 2006; Postmes, Spears, & Cihangir, 2004; Stasser, Vaughn, & Stewart, 2000), although the process by which shared information becomes team cognition has not been explicitly examined. To address this issue, in the reported study we explored a process by which teams use shared information to build knowledge (e.g., Rentsch, Delise, & Hutchison, 2008).

Shared information is expected to become transferred knowledge when the receiver assimilates the shared information in a manner such that he/she can use it. Knowledge transfer occurs as team members integrate the shared information into their own existing schemas (e.g., Mulder, Swaak, & Kessels, 2004) in a cyclical knowledge building process that involves interaction and collaboration. The knowledge building process also provides team members with the opportunity to build common ground (e.g., Carlile, 2004). Members encounter shared information, interact with teammates, assimilate the shared information, and experience a
cognitive change enabling them to integrate the information and to organize it similarly as they achieve consensus on the shared task information.

Rentsch et al. (2010) have demonstrated the effects of an intervention involving technology and training to increase teams’ ability to transfer knowledge, develop knowledge interoperability, increase task schema congruence, and ultimately improve team decision making. The training and technology emphasized communication methods for sharing information and offered team members a simple information board on which they could develop a knowledge object (e.g., Carlile & Rebentisch, 2003; Nosek, 2004) to aid them in sharing information and building knowledge. The intervention was associated with increases in team members’ ability to transfer their expert knowledge to their teammates, so that the other teammates would understand the information (i.e., knowledge transfer). It was also associated with team members’ ability to think similarly about the task information such that they understood and organized task information similarly. That is, they developed schema congruence with respect to the task. The present study was conducted to understand team cognitive processes, particularly in teams where members possess unique knowledge. Specifically, the purpose of the present study was to examine relationships among the team cognition variables.

Participants were undergraduate students from a large southeastern university who participated in three member teams. Teams were assigned to make a complex decision. A hidden profile task developed by military personnel was used that involved each team member receiving unique information associated with a specific role. All team members received general information. In order to achieve a high quality solution, teams had to integrate information from the three roles and from the general information. All teams received
significant instruction regarding the task. They also received training on schema enriched communication behaviors.

Team members were allotted 45 minutes to study the materials and to prepare independently for the team discussion. Teams were then given one hour to make the decision. Members’ communication was computer mediated. After completing the task, they responded to cognitive assessments. Trained raters coded the transcripts produced from the team member interactions.

The results supported the primary hypotheses. Teams sharing the most information also transferred the most knowledge. Teams that transferred the most knowledge also had higher team member task schema congruence. Additional analyses on a subset of teams revealed that specific schema enriched communication behaviors were related to knowledge transfer.

The results of the present study contribute to the literature on team cognition by demonstrating that a well-designed technology can have positive effects on team cognition, knowledge building, and team processes. Furthermore, the nature of specific relationships among team cognition variables was explored. Additional implications of the results will be discussed.

In conclusion, the findings revealed that shared information and specific schema enriched communication behaviors were associated with transferred knowledge, which was associated task schema similarity among team members. Additionally, specific schema enriched communication behaviors were associated with interoperable knowledge.

References


Examining Similarities and Differences in the Mental Model Convergence Process across Varying Conditions

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Mental models are basic cognitive structures used by team members to explain what is going on in the world, draw inferences, and make decisions (Cannon-Bowers et al., 1993). Over time the content of team members’ mental models evolves as they encode, process, and store new information gathered through team interaction (McComb, 2007). This evolution continues until the team members’ mental model content has become similar, or converged. These resulting cognitive structures are often called shared mental models (Cannon-Bowers et al., 1993) and have a positive relationship with team performance (DeChurch & Mesmer-Magnus, 2010). The increased performance may occur because team members with shared mental models have similar expectations about the way the team will function and the responsibilities assumed by teammates (Marks et al., 2002).

In this study, our purpose is to uncover how mental model convergence occurs during collaborative activities. To facilitate this study, we exploit the theoretical connection that has been established between communication and cognition (Cooke et al. 2001; Kennedy & McComb, 2010). Specifically, we examine team-level communication strings to identify patterns that inform our understanding of how (and what) mental model content is exchanged among team members, how the mental model convergence process unfolds over time, and what impact the exchange of mental model content, and the corresponding convergence process, have on team performance.

Additionally, we examine how the convergence process is impacted by the conditions under which the team is working. First, time pressure may impact the convergence process. On the one hand, teams with less time may adapt by communicating more concisely and, therefore, generate shared mental models more quickly (Kelly & Loving, 2004). On the other hand, information may not be processed efficiently, and without time for repetition some information
exchange may be compromised (Chong et al., 2005). In such cases, mental model convergence may be limited or not occur at all. Second, the introduction of new information may require that teams revisit and revise their mental models to accommodate the new reality. Fowlkes and colleagues (2000) and McComb (2007) provide preliminary evidence for this type of re-convergence process when they identify shifts in mental model content occurring as team member experience increased. Such shifts indicate that as new information is communicated, mental models are revisited and revised.

Data were collected at a research university in the Northeastern United States in a controlled laboratory setting using a 3x2 factorial design where the factors indicate the working conditions to which the teams were subjected (baseline, time pressure, or interruptions) and medium through which they collaborated (face-to-face or computer-mediated). Undergraduate students earned class extra credit for participation. They were assigned to teams of three and completed a scheduling task, where ten employees earning different wages were assigned to two-hour shifts during seven, twelve-hour days. The team’s goal was to minimize the schedule’s cost; teams with the lowest cost schedules were awarded $150 (odds of winning were 1:5). To encourage collaboration, each team member was given unique rules about how assignments could be made (e.g., no more than 10 hours per day; at least 30 hours per week). Performance was measured as the cost of a team’s schedule.

The verbal exchanges among the face-to-face team members were transcribed and the chat logs of the computer-mediated teams were captured. Each exchange among team members was coded by two researchers unfamiliar with the study hypotheses (agreement ranged from 87% to 99%). The codes were developed by subject matter experts, who reviewed the initial transcripts with a focus on activities that have been shown to enhance team collaboration such as understanding the rules governing the task and the approach the team will use (Hackman et al., 1976; Weingart, 1992; Woolley, 1998). Approach, Rules, Task, Work Allocation, and Other were the codes.
We used event history analysis to identify convergence points of the multiple mental models being investigated, any time-varying co-variation among the convergence points, and any performance co-variation. The results from the baseline teams demonstrate a temporal pattern among mental model convergence points. For instance, team members converge on the rules governing in the task, then the approach they will use to complete the task, and finally how they will allocate work among themselves. Moreover, mental model convergence processes help explain why the performance by computer-mediated teams was similar to that of face-to-face teams yet performance of teams with unlimited time differed from teams facing time pressure. When examining teams that faced interruptions, we found a temporal order to reconvergence, performance implications, and media differences.

References


Collaborative problem solving is rising in prominence with teams being formed to solve tasks requiring a diverse set of individual expertise and often to address novel situations. But much of the research in teams has focused on behavioral coordination in routine tasks. As such, there is a need for developing an understanding of, and interventions for, the support of collaborative problem solving focusing more on knowledge-based performance in teams. This paper provides data from studies in the area of macrocognition in teams (Letsky et al., 2008), an extension to team cognition research which seeks to build upon a variety of traditions examining team process and unite them with ideas from cognitive science (Fiore, Rosen, et al., 2010a; Fiore, Smith-Jentsch, et al., 2010b; (Patterson & Miller, 2010).

Our model of macrocognition in teams integrates three theoretical elements meant to help us better understand complex collaborative problem solving (see Fiore et al. 2010a). First, it is multi-level, encompassing individual and team level factors. Second, it addresses internalized and externalized cognitive functions. Third, it incorporates temporal characteristics to examine problem solving phases through which a group moves. Across these is the examination of “knowledge building” and how teams work to transform data to information to knowledge (Fiore, Elias et al., 2010). We define knowledge building as the synthesizing of relationships among problem relevant content to create a broader integrated understanding of the task. This produces actionable knowledge which did not exist before. We argue that knowledge building is facilitated by the development of cognitive artifacts, that is, external problem representations that scaffold teamwork. To examine these factors we developed a testbed where participants engage
in a resource-based problem solving task requiring interaction among team members with heterogeneous knowledge and resources. The testbed has support for examining audio and text communication and externalized cognitive processes such as sketches and diagrams created during the problem solving. Additionally, psychophysiological measures allow for eye-tracking and measurement of vocal parameters.

In our analysis of communications, we find that the exchange of “information” has a negative relationship with performance, while the exchange of “knowledge” has a positive relationship. The implications of this is that, in complex problem solving, sharing knowledge (e.g., “My airplane can move your pallets if they arrive by 1500 hours”) is more important than sharing information (e.g., “I have an airplane at D4a”). Further, when examining externalized problem representations, we find interactions between the impact of information, knowledge, and externalizations (e.g., annotations of task relevant factors). Teams with lower quality external problem representations (e.g., notations on a map), produce acceptable solutions only if they share more knowledge relative to information. But, teams which create higher quality external problem representations, do well whether sharing information or knowledge during their verbal communications.

We also examine behavioral and cognitive data and find that the relationship between team-level macro-cognitive processes and team-level problem solving outcomes is moderated by internalized knowledge states. Team interaction processes improve outcomes for teams with similar internalized knowledge but have negative effects for teams with highly dissimilar internalized knowledge. More specifically, engaging in the process of solution alternative evaluation is only beneficial when teams similar task mental models. Teams engaging in a high degree of solution alternative evaluation produce less efficient solutions if they have dissimilar
task mental models. Finally, we have found relationships between physiological and cognitive data. First, by measuring eye fixations within a team, we find that high numbers of team fixations is related to the completion of more objectives. Second, measuring vocal parameters has highlighted that variability of pitch within a team is related to poor exchange of information and a team’s maximum pitch intensity is indicative of longer planning times.

In conclusion, the work we describe highlights how macrocognition in teams contributes to theory in shared cognition. Our findings suggest that shared cognition is not just a mental phenomena in that externalizations produced by, for example, computer drawing tools, allow for cognition outside the mind and can support team performance. We illustrate how physiological indicators like vocal parameters and eye-movements can aid in measuring team performance outcomes. Finally, we illustrate the importance of studying the relation between shared mental models and team process. Evaluating solutions to complex problems only helps when teams have a shared mental model. And, when information sharing was poor, externalizations scaffold team outcomes. In short, macrocognition in teams theory adds to the growing body of work in team cognition and can increase our understanding of complex collaborative problem solving (Fiore et al., 2010a; Fiore et al., 2010b).

References


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