SHARED MENTAL MODELS: ACCURACY AND VISUAL REPRESENTATION

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Abstract

Teams are important for organizational work but coordinating teamwork is not always easy. Oftentimes members are separated by time or geographic distance, thus making coordination even more difficult. Recent research suggests that teams develop shared mental models about the task and each other, which helps them develop mutual explanations and expectations about the task environment, thus helping its members coordinate implicitly. The theoretical grounding of this research literature is strong, and recent evidence is beginning to provide some support for it. But in order to make good progress in this area we need to develop and validate shared mental model measures that can be used across studies. In this study we build upon methodological contributions on shared mental model measurement and propose, describe, and empirically validate a measure for shared mental model accuracy using network analysis methods. We also use the resulting network data to illustrate the visual representation of shared mental models and their accuracy.

Introduction

Teams are important units of organizational work, in part because members bring diverse expertise and skills to the task, which may be too complex for a single individual to undertake. However, teams need to be coordinated, particularly when members are separated by time or geographic distance because members have fewer opportunities to meet face-to-face. While recent advances in telecommunication and groupware technologies have made team work more effective, we need to learn more about how these tools can help teams coordinate their work. Coordination is necessary to manage interdependencies among members, resources and sub-tasks (Malone and Crowston 1994). The research literature suggests that coordination is accomplished via programming (e.g., schedules, plans, workflows, etc.) and communication (March and Simon 1958; Thompson 1967; VanDeVen et al. 1976). Consequently, most groupware developers have focused their efforts on the implementation of features aimed at helping team members organize and communicate. More recent literature suggests that as team members interact in a task context, they also develop shared mental models about the task and each other, which helps them coordinate implicitly (Cannon-Bowers et al. 1993). Understanding how shared mental models can help team coordination and performance can help identify important features for team collaboration tools. This research focuses on two specific aspects of shared mental models: accuracy and visual representation. More specifically, we employ network analysis techniques to develop and propose methods to measure and visually represent shared mental model accuracy.

Shared Mental Models

Mental models or schemas are organized knowledge individuals posses about the environment they interact with (Johnson-Laird 1983; Rouse and Morris 1986). Mental models help us make sense of the environment around us and help us anticipate its future states. It has been suggested that as teams interact over time they also develop shared mental models (Cannon-Bowers et al. 1993; Rentsch and Hall 1994; Kraiger and Wenzel 1997). While different types of team mental models have been described in the literature, most of the knowledge shared by team members can be reduced to things related to either the team or the task (Klimoski and Mohamed 1994; Cooke et al. 2000; Mathieu et al. 2000). It has been suggested in this literature that shared mental models help teams coordinate implicitly, thus improving performance. While most of these arguments center around real-time tasks (e.g., emergency crew operations, squadron flights, etc.), some studies are beginning to produce preliminary evidence that shared mental models also have a positive affect on coordination and performance in asynchronous and distributed teams (Fussell et al. 1999;
A recent study with decision teams has also suggested that different types of shared mental models have different effects on various aspects of team coordination and performance (Espinosa et al. 2001). More specifically, this study found that the shared mental model of the task had a positive effect on task and strategy coordination, and that strategy coordination positively influenced team performance. But it did not find any significant effects for the shared mental model of the team, suggesting that this model may not be as important for asynchronous teams than for fast-paced real-time teams in which anticipating team members’ actions are key to performance. In this study we pursue an alternative explanation that, as others have suggested (Cooke et al. 2000), the shared mental model of the team may only have positive effects as long as it is accurate. Conversely, strong but inaccurate shared mental models may actually have detrimental effects.

Measures: Shared Mental Model of the Task and Team

There are a number of methods suggested in the literature to measure shared mental models (Carley 1997; Fussell et al. 1999; Cooke et al. 2000; Levesque et al. 2000; Mathieu et al. 2000). While these methods vary in their implementation details, they are all based on measures of knowledge similarity. Thus, the shared mental model of the task can be measured as the knowledge similarity among members with respect to the task. Similarly, the shared mental model of the team can be measured as the knowledge similarity members have about each other. The use of knowledge similarity to measure shared mental models was further explored in another study that used network analysis methods (Espinosa and Carley 2001) based on the knowledge each dyad in the team has in common. Measuring knowledge similarity for dyads in a team has the advantage that the shared mental model of the team can be represented using “adjacency matrices” and “sociograms” (Scott 1991; Wasserman and Faust 1994). An adjacency matrix is one in which members are listed as rows and columns, with null diagonal elements, and off-diagonal elements $x_{ij}$ representing a particular relationship between members i and j. A knowledge similarity matrix is then an adjacency matrix with off-diagonal elements $ks_{ij}$, representing the knowledge similarity between members i and j.

A “sociogram” is the graphical representation of an adjacency matrix. Each member is depicted as a node in a graph, and the relationship between any two members (e.g., their knowledge similarity) is represented as a line between the two nodes. “Valued” graphs depict line densities proportional to the value of the relationship, but they can be somewhat confusing, especially with dense graphs, so they are often represented using “dichotomized” graphs, in which a line is drawn only if the relationship value exceeds a certain threshold amount deemed important. A sociogram is “directed” if the relation from i to j is asymmetrical (e.g., i’s judgement of j may be different than j’s judgement of i) or “undirected” if the relationship between i and j is symmetrical (e.g., knowledge similarity between i and j). Figures 1 and 2 show representative incidence matrices and sociograms for shared mental models of the task and for accuracy of shared mental models of the team. Both matrices are dichotomized with a value of 1 (i.e., a connecting line) if the task knowledge similarity value exceeds the average knowledge rating for all team members in all task areas and 0 (i.e., no connecting line) otherwise. In these examples we use thicker connecting lines when the task knowledge similarity of a dyad is greater than average by two standard deviations or more (noted with a cell value of 2 in the incidence matrix). Shared mental model graphs are undirected because the shared knowledge between two members is symmetric. For example, as illustrated in Figure 1, member 1 in Team 1 has above average knowledge similarity with 2 but not with 3.

Measures: Shared Mental Model Accuracy

While shared mental models have potential benefits for teams, these models could be detrimental to coordination and performance if they are inaccurate because of misperceptions or biases. Shared mental model accuracy can be measured by comparing member’s shared knowledge with that of a referent domain expert (Cooke et al. 2000). When a domain expert is not available, accuracy can be measured by other means, either by comparing members’ knowledge to actual facts or by having members rate each other on different aspects of their task knowledge. These ratings can be used to compute, not only shared mental models of the team, but also their accuracy by comparing members’ ratings of others against their corresponding self-ratings. While self-ratings may be influenced by perceptions and attitudes, comparing members’ ratings of others against self-ratings is an important aspect of the shared mental model of the team. That is, the shared mental model of the team can be thought of as having two components. The first one is a pure measure of the model about similarities in knowledge ratings about other members’ knowledge, excluding self-ratings. The second one is a measure of accuracy, which looks at the similarity of knowledge ratings made about other members and their respective self-ratings. It is important to note that we do not claim that self-ratings of knowledge are accurate, but simply that similarity between self-ratings and ratings by others is a good measure of accuracy in shared beliefs about members’ knowledge. Dyadic similarities can then be used to construct accuracy incidence matrices and sociograms. An accuracy matrix is asymmetric (i.e., it’s graph is directed) because member i’s accuracy about j’s is not necessarily the same as j’s accuracy about i. The arrow originates in the row member, for which we are judging accuracy. For example, in Figure 1, member 3 in Team 2 is highly accurate about member 5’s knowledge (compared to the average accuracy for all members and task areas), but member 5 is not accurate about member 3.
Empirical Validation of the Accuracy Measure

To the best of our knowledge, only one empirical study has developed and used measures of shared mental model accuracy (Fussell et al. 1999), and no study has validated such measures. In this section we test the concurrent validity of the proposed accuracy measure (Ghiselli et al. 1981). The data used for this study comes from 57 teams of 4 to 6 graduate students from a management simulation course, who worked together for approximately 14 weeks. Each team managed a simulated firm, competing against other teams by making decisions and formulating business. The data was obtained from voluntary surveys completed by members at 3 time periods, with an approximate response rate of 70%. Shared mental model variables were computed from survey items in which members rate each teammate, including themselves, on their knowledge in three task areas of their simulated company’s performance: production, finance, and marketing. The shared mental model of the task network (i.e., adjacency matrix) is constructed using knowledge similarity values for each dyad (i.e., the amount of knowledge of the least knowledgeable member in the dyad), averaged across all member ratings and all task areas. The shared mental model of the task measure is obtained from the average value across all dyads in the team (Espinosa and Carley 2001). The shared mental model of the team network is obtained in a similar manner, but using the similarity in ratings by each dyad about all other members of the team (Espinosa and Carley 2001), excluding self-ratings. The accuracy network measure is also computed in a similar manner but only using similarities between a member’s rating of another member, and that member’s knowledge self-ratings for each task area. Rows correspond to members rating others and columns correspond to members rating themselves, such that cell (i,j) in the matrix contains member i’s accuracy about j. All measures were normalized to the scale used to obtain values in a 0-1 scale. The task coordination variable was computed as the average of responses to 9 survey items (Chronbach’s \( \alpha = 0.79 \)) that asked about the teams’ state of task coordination. The strategy coordination variable is the average of responses to 6 survey items (Chronbach’s \( \alpha = 0.84 \)) that asked about the teams’ state of strategy coordination.

Concurrent validity can be evaluated by exploring the correlation between the accuracy measure and another related variable (Ghiselli et al. 1981). As suggested in the literature (Cooke et al. 2000; Mathieu et al. 2000), we anticipate that an accurate shared mental model of the team, more than the model itself, will be concurrently related to team coordination. A prior study (Espinosa et al. 2001) found that the shared mental model of the task had a significant effect on task coordination and strategy coordination, but that the shared mental model of the team did not have a significant effect on either. Using the same data we decomposed the model’s measure into two components: (1) a pure shared mental model of the team, which does not include comparisons with self-ratings; and (2) the accuracy measure we are trying to validate, which only includes comparisons with self-ratings. Since the accuracy measure is correlated with shared mental model of the task (\( r=0.324, p<0.001 \)), and with this new shared mental model of the team variable (\( r=0.417, p<0.001 \)), we include both variables in regression models to avoid problems with omitted variable bias (Kennedy 1992; Greene 1997). Also, since the data set contains repeated measures, we run the regressions using random effects models. We include the time variable a fixed effect to further avoid omitted variable bias if time effects are present, but we model team effects as a random effects because differences among teams are best represented as random shifts than parametric shifts (Kennedy 1992; Greene 1997). As before, results show positive and significant association between shared mental model of the task with both, task coordination (\( p=0.007 \)) and strategy coordination (\( p<0.001 \)), and no association between shared mental model of the team and either coordination variable. However, results do show a positive and significant relation between the accuracy variable and both, task coordination (\( p=0.002 \)) and strategy coordination (\( p=0.045 \)), thus providing empirical validation for the measure.

Conclusions

This study has developed and validated a measure for shared mental model accuracy and suggested a method for its visual representation. It has also found preliminary evidence that while the shared mental model of the team is not related to asynchronous team coordination in our study, its accuracy is, suggesting that it complements the effects of shared mental model of the task on coordination. As figures 1 and 2 illustrate, Team 1 has a somewhat dense shared mental model of the task network diagram, but Team 2 does not. However, they both have very dense accuracy network diagrams and they both performed well. While these teams have near average shared mental models of the task, their respective shared mental models of the team are highly accurate. In contrast, Team 3 has a weak shared mental model of the task, while Team 4 has a well-developed model. However, they are both inaccurate and they both performed poorly. These results illustrate both, the importance of measuring shared mental model accuracy, and the usefulness of its visual representation in sociograms. This study has several limitations, including use of self-report questionnaire data and lack of referent expert evaluations to measure accuracy. But the main purpose of the article was to illustrate computational and visual representation methods for shared mental model accuracy.
References


Shared Mental Model of the Task

Accuracy of Shared Mental Model of the Team

(Note: P denotes the team’s president)

Figure 1. Illustration with High Performance Teams: Visual Representation of Shared Mental Model of the Task and Accuracy
Shared Mental Model of the Task

**Figure 2. Illustration with Low Performance Teams: Visual Representation of Shared Mental Model of the Task and Accuracy**