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# MEASURING TEAM COGNITION: CONCEPT MAPPING ELICITATION AS A MEANS OF CONSTRUCTING TEAM SHARED MENTAL MODELS IN AN APPLIED SETTING

*Debra L. O'Connor, Purdue University*
*Tristan E. Johnson, Learning Systems Institute, Florida State University*
*Mohammed K. Khalil, Learning Systems Institute, Florida State University*
*Email: doconnor@purdue.edu*

**Abstract**.—This paper highlights recent research on team cognition and discusses the benefits of concept mapping techniques used in representing shared levels of understanding among team members. Team cognition is comprised of several factors including shared understanding as measured by shared mental models (SMM). To represent team shared mental models more accurately we present a data analysis methodology that utilized individually constructed concept maps as the primary data source. This data is translated into an aggregate map (analysis constructed shared mental model—AC-SMM) that represents team understanding. AC-SMM maps can be compared over a period of time in order to understand the development of team cognition.

## 1 Introduction

Teams and teamwork are an indispensable part of our society, especially when dealing with difficult, complex, or ill-structured situations, problems, and decision-making tasks not easily addressed by a single individual (Stout, Cannon-Bowers, Salas, & Milanovich, 1999). The benefit of using teams is that each team member contributes to team performance through their individual knowledge/background, specific skills, and particular roles/responsibilities for the team task.

Team cognition has been linked to effective team performance (Orasanu & Salas, 1993; Stout, Cannon-Bowers, & Salas, 1996). However, in order to learn how to improve team cognition and team performance, we need to have an understanding about the teams' development of shared mental models (SMM). One method of measuring mental models is with concept mapping. This method traditionally utilizes the individual as the unit of analysis.

In obtaining a measure of team cognition, we have the option of taking a holistic approach in which team members work together to construct one concept map that represents the team's understanding as a whole. However, the processes of team interaction naturally changes how individuals think. Our intent is to capture the team's shared mental model (SMMi) (see Figure 1). Hence, our alternative in trying to capture the team's SMM is to use individual measures (ICMM) and perform some type of aggregate analysis methods to show team sharedness while retaining individual understanding.

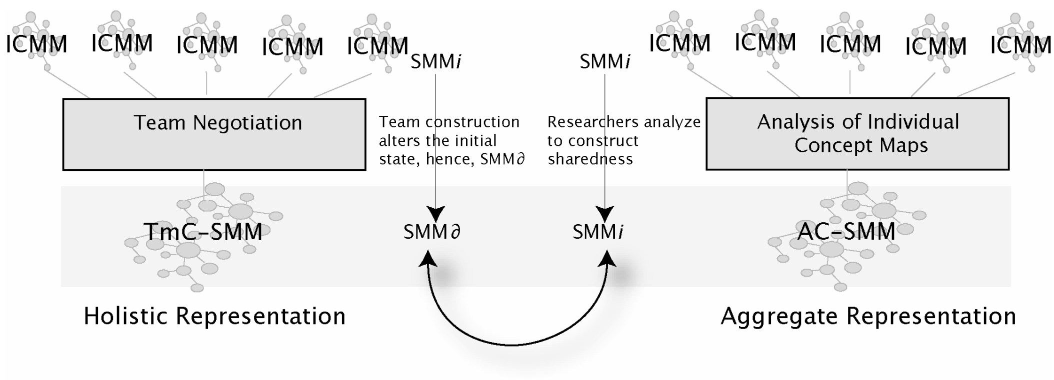


**Figure 1**. Alternative methods of measuring team shared mental models. ICMM—Individually Constructed Mental Models; SMM*i*—desired shared mental model state; TmC-SMM—Team Constructed Shared Mental Models involving team negotiation and interaction; SMM∂—Altered team shared mental model state; AC-SMM—Analysis Constructed Shared Mental Model that retains the current status of the individually constructed mental models

Langan-Fox, Code, and Langfield-Smith's (2000) review of the literature found that SMM in teams have been investigated by several qualitative and quantitative methods. These methods included different elicitation techniques (e.g., cognitive interviewing, observation, card sorting, causal mapping, pairwise ratings) and representation techniques (e.g., MDS, distance ratio formulas, Pathfinder) that utilize aggregate methods. Each method has various strengths and limitations.

Through concept mapping, similarity of mental models has been measured in terms of the proportion of nodes and links shared between one concept map (mental model) and another (Rowe & Cooke, 1995). Utilizing qualitative techniques with an aggregate method of creating AC-SMM, we hope to capture a more descriptive understanding than that offered by quantitative techniques. Qualitative data analysis tends to offer more detail and depth of information than that which may be found through statistical analyses (Miles & Huberman, 1994; Patton, 2000). Using qualitative analysis, we obtain greater understanding about the relationships between concepts within the context of the individual mental model. We also gain better insight about the sharedness of understanding between team members. In addition, qualitative analysis generates information about the team shared mental model that is not found in an aggregated team shared mental model using only quantitative methods. For example, although we may find that there is a statistically significant relationship between two concepts, the qualitative analysis may reveal information that suggests otherwise. In cases similar to our study, which looked at mental models of team process, qualitative data may reveal inappropriate or inaccurate relationships between concepts.

While there have been many studies conducted using qualitative methods, there are cases where the research setting has constraints such that utilizing various methods are not feasible due to limitations such as time, logistical issues, multiple teams using the same process but focusing on different topics, and the unavailability of necessary data collection instruments. Consequently, utilizing cognitive interviewing, card sorting, computerized elicitation techniques and many other forms of data collection may not be viable options in applied settings.

Because a SMM is potentially different from the sum (aggregate) of individual mental models, and because a holistically created SMM potentially changes individual mental models through the process of creating the holistic SMM representation, we designed a new qualitative analysis technique. This new technique translates individual mental models into a team sharedness map without losing the original perspective of the individual, thereby representing a more accurate representation of team sharedness.

If we use these methodologies, we believe that we can better qualitatively represent a team shared mental model thereby facilitating greater understanding of the notion of team cognition and the development of team performance. In comparing the analysis-constructed shared mental model (AC-SMM) at various points during the team process, we should be able to determine how team SMMs change over time. Not only will this information benefit further study in team cognition, but also if we can identify how team SMMs change over time and find indicators of why they changed, we should be able to develop methods for improving overall team performance.

## 2 Methodologies

Four Performance Improvement teams participated in this study. Each team was newly formed and working in their natural environment on the complex task of revising personnel qualification standards. Team compositions ranged from four to twenty team members. Except for team facilitator(s), team members had background experience and training directly related to the topic of their team task, and most team members had little or no experience with the process involved in performing the team task. Using the common factors between all teams, this study focused on the elicitation of mental models about the process of performing the team task.

In this section, we describe the Analysis Constructed Shared Mental Model methodology for taking team members' individually constructed mental model (ICMM) and using a qualitative analysis technique to construct a representation of the team's shared mental model, or AC-SMM. First, consider the data elicitation methods for construction of the ICMMs.

### *2.1 Instruments*

Prior to data collection, the researchers conducted a task analysis of the process involved in performing the team task. Concepts identified from the task analysis were given to several process experts. These experts were asked to use the concepts in constructing a map to represent their individual understanding of the team task process. Each map was analyzed for key concepts, sequence of concepts, clusters, and concepts identified as being most important to the team task. All experts' concept maps were compared to identify commonalities, or sharedness.

Based on process expert input, three concepts were changed to reflect terminology that was more accurate. This task analysis resulted in an original listing of 22 concepts for study participants to use in creating their ICMMs.

In addition to the listing of key concepts, the lead researcher designed a concept mapping exercise to use during an instructional demonstration with participants. The demonstration focused on how to construct a concept map. Results of pilot testing this exercise showed that the first exercise would take approximately 45 minutes and subsequent repetitions of concept mapping would take 15-20 minutes. Because the results were satisfactory and the exercise took a relatively short period, concept mapping was used as the main form of data collection with all participating teams. Secondary sources of data collection included non-participant researcher observation and audio recordings of teams' work sessions.

## *2.2 Data Collection Protocol*

### 2.2.1 Concept Maps

To obtain measures for determining change in levels of sharedness between individual team members, concept-mapping exercises were done before the team began working on their task, mid-task, and immediately following task completion. For each concept map, participants were asked to label the concepts they felt were most important and to number any concepts that held a particular sequence.

Prior to the start of the team task, an interactive and instructional demonstration involving all participants was done so that each participant had a brief overview of what was expected during the concept mapping exercises. Although the topic of the demonstration was different from that of the team task, the instruction covered the use of concepts, links, directional links, prepositional phrases, indicators for the most important concepts, and numbers for any concepts that had a particular sequence. Participants were also informed that although they would be given a list of concepts, they were not limited to those concepts and they did not have to use all of the concepts on the list.

Following the concept mapping demonstration, participants were given the list of concepts identified through the task analysis, paper and pens with which to create their concept maps. In addition to these items, participants were reminded that they were not limited to the 22 concepts on the list, but could add concepts they felt were necessary to represent the process of performing their task. Participants were also reminded that they did not have to use all of the concepts presented in the initial list. Each team member was then instructed to create a concept map that represented their understanding about what their team was going to do. All pre-task concept maps were collected by the researcher prior to starting the task.

Midway through the task, team members were asked to construct another concept map that represented their understanding of what they had been doing and what remained to be done. Again, participants were reminded about adding new concepts and not needing to use all concepts provided. Mid-task concept maps were collected from all participants before they continued working on their team task.

A final post-task concept mapping exercise was conducted immediately following completion of the team task. In the final exercise, team members were asked to construct a concept map that represented what their team had done. Instructions for this final exercise also included previous reminders. Final concept maps were collected from the participants before they left.

### 2.2.2 Supportive Data

Additional data include the task analysis; the analysis of the ICMMs; a comparison of sharedness between the ICMMs, the task analysis, and the actual team task performance; and subsequent analyses of ICMM data. Supportive data also included the non-participant observation notes made by the researcher and audio recordings of the teams' work sessions.

## *2.3 Data Analysis*

Team members individually created concept maps representing their pre-, mid-, and post-task understanding of the team task process. Data obtained from individual team members' ICMMs were used to create an AC-SMM. This section describes the steps taken in analyzing ICMMs.

### 2.3.1 ICMM Analysis Factors

In order to analyze, compare, and measure a degree of sharedness in ICMMs, we use common factors used in analyzing concept maps such as the number of concepts, links, and node-link-node combinations (Doyle, Radzicki, & Trees, 1998; Jonassen, Reeves, Hong, Harvey, & Peters, 1997; Novak & Gowin, 1984). Additionally, it is necessary to use criteria that are appropriate for the domain (Jonassen, et al.). Because we asked our participants to focus on the process of revising personnel qualification standards as it pertains to their work sessions and not the content within standards, we determined it was better to use causal measures (directional links, sequence of concepts, and clusters) than hierarchical measures and cross-links as suggested by Novak and Gowin.

Analysis of individual maps involved several steps. Before we began data analysis, all data was coded for all participant-added concepts. The same coding scheme was used for all concept maps from each data collection period (pre-, mid-, and post-task). The data from each ICMM were then analyzed in using the following factors.

Factor 1: Concept List—All concepts used in the ICMMs were compiled into a table. Each concept used by a participant is coded. The table includes concepts provided to the participants as well as concepts that are added by participants from the elicitation activity during the data collection phase. In compiling the concept list, each concept is listed only once even if a participant used a concept multiple times.

Factor 2: Sequence—Concepts that are ordered with numbers or letters are coded. Concepts not explicitly ordered are not coded for the sequence factor.

Factor 3: Links—Two or more concepts can be explicitly (clearly stated on the concept map) linked in several ways. Concepts that were linked with arrows are coded as directional links. Single-headed arrows indicate a unidirectional relationship between the connected concepts. Double-headed arrows indicate a bidirectional relationship between concepts. Concepts that are linked with a simple line (without arrows) are coded as non-directional links. These links do not imply a direction.

There are two general types of explicit links: simple and complex (including branch, bracket, and open-end). In each case, the link connector may be a line, a single-headed arrow, or a double-headed arrow. Simple explicit links are just a connector (with or with out arrows) between two concepts. Complex explicit links are minimally two intersecting/shared connectors bridging three or more concepts. These links can include cases where multiple connectors intersect/share in a branch, bracket, or open-end like fashion.

Branch links are minimally a connector that intersects another connector before reaching the next concept. Branched links can also include cases where multiple lines intersect in a hub or cluster-like fashion. A bracket link is a connector that minimally links one concept to a bracket that contains two or more concepts (bracket cluster). In this case (as contrasted with a branch link), a connector only links to a bracket cluster and not the separate concepts within the bracket. Explicit open-end links are connectors that end short of another concept or cluster of concepts.

Factor 4: Important Concepts—Participants were asked to indicate which concepts they felt were most important to their task. Important concepts are noted either by placing a star next to the concept or by listing concepts in order of importance.

Factor 5: Clusters—Next, concept maps are analyzed with the specific objective of combining concepts that are related explicitly and/or implicitly. Implicit relationships primarily focus on concepts that are related spatially. These clusters can include single or hybrid link types (refer to Figure 2, explicit branch cluster).

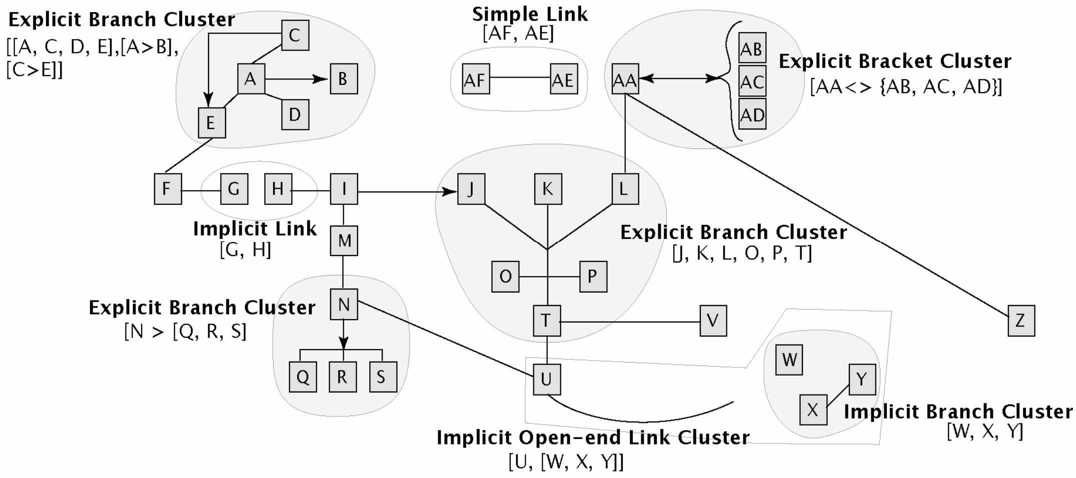


**Figure 2**. Sample ICMM with coded links and clusters.

When identifying clusters, three key components are considered: spatial information, structural information, and logic information. Spatial information refers to the location of concepts within the map. Interpreting spatial component information requires considering the visual groupings of the concepts as they are presented. Structural information component refers to any type of explicit/implicit links. Valid cluster structures are determined based on cluster concepts all being adjacent to each other or all cluster concepts are all adjacent to a single central concept (in a hub like fashion). The logic information component refers to the conceptual relationship among the concepts in the identified cluster. The conceptual relationship does not have to be complete, but it does have to have logical merit. In identifying clusters, at least two of the three information components need to be present in order to include the cluster in subsequent analysis.

After identifying clusters, examine all clusters from all participants' concept maps for possible sub-clusters. For example, one explicit cluster in Figure 2 contains concepts [N > [Q, R, S]]. It also contains a sub-cluster of [Q, R, S]. Likewise, clusters may be part of larger, more complex super-clusters as found when combining clusters [[A, C, D], [A>B]] and [[C, A, E], [C>E]] resulting in a super-cluster of concepts [[A, C, D, E], [A>B], [C>E]]. Sub- and super-clusters may not have been readily recognized because of their relationship to other components within the individual maps. As with the initially identified clusters, sub- and super-clusters must meet at least two of the three information components to be included in further analysis.

### 2.3.2 Shared Analysis

Once the ICMM concept maps are analyzed, all of the complex concepts are represented as simple links and simple clusters. Simple links and clusters are then analyzed to show simple sharedness. Complex links and clusters are then analyzed to determine sharedness. The identified simple and complex links and clusters are used as the basic elements for the AC-SMM. Similarities would later be used in the construction of an AC-SMM for each mapping session.

In looking for similarities, all concepts are compared across participants for the mapping session. For all analysis factors, any items that are represented by more than one of the participants are considered shared. Percentage of participants sharing the item is recorded, and the shared factor items are carried forward for use in constructing the AC-SMM.

### 2.3.3 AC-SMM

The AC-SMM is constructed from the shared ICMM data set. The construction process includes the following five steps. First, all of the shared concepts are listed in the construction area. Second, the clusters are represented and the concepts are adjusted to represent the sequence data. Third, the shared links are added, and fourth, the non-linked concepts are resolved using the original ICMM data as well as secondary data. Lastly, shared important concepts are added.

Step 1: Shared Concepts List—Shared concepts are listed in the construction area. For example, A, B, C, D, E, F, H, and I were identified as shared concepts and each of these elements are included in the initial AC-SMM (Figure 3).

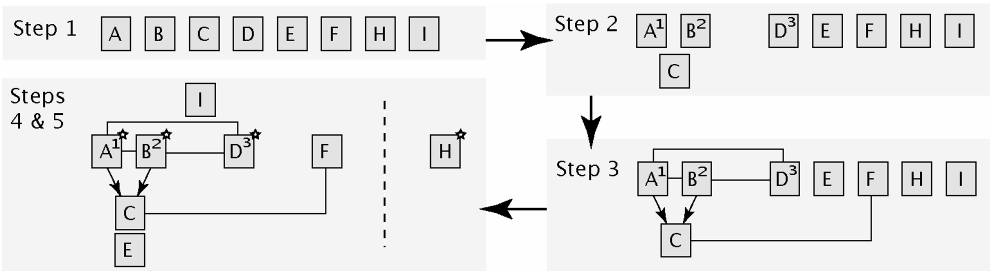


**Figure 3**. AC-SMM Steps Example

Step 2: Shared Cluster and Sequence Representation—Shared concepts are adjusted to represent the clusters and sequence data. Figure 3 shows only one cluster [[A, B], [A>C], [B>C]] that was shared the participants. Simultaneously, shared sequence data was added to the map. Because concepts A, B, and D were given sequential order by more than one of the participants, these concepts are kept in order from left to right.

Step 3: Shared Links—Shared links are added to the developing shared concept map. Non-directional links [A, D], [A, B], [B, D], and [F, C] are added along with directional links [A>C] and [B>C].

Step 4: Non-linked Concepts—Concepts that are not grouped or related are analyzed using additional data. Specifically, the supporting data includes the original ICMM data as well as secondary data comprised of the initial task analysis (the original listing of concepts used to support interpretation and analysis of pre-task ICMMs) and the ICMM elicitation observation notes. The first consideration in determining placement of unlinked concepts is to see if there are any similarities between participants regarding where the concepts were placed in the ICMMs. If no similarity is found in the ICMMs, then the next step is to check observation notes for data that indicates the concept's relationship to other concepts. If no supporting data are found, then the next step is to check for similarities between concept placements in ICMMs with the location of the concepts in the task analysis. If there is no supporting data indicating where unlinked concepts should be placed in the AC-SMM, then unlinked concepts are separated from the AC-SMM with a vertical dashed line.

In this hypothetical example, we will assume that we found that participant ICMMs showed a similar relationship between concepts C and E even though there were no direct links or clusters. Consequently, unlinked concept E was placed near concept C in the AC-SMM (see Figure 3). Although the ICMMs did not indicate a similarity in placement for either concept H or concept I, observation data from the team task performance indicated a relationship between concepts A, D and I. Therefore, concept I was placed near the non-directional link between concepts A and D. Observation data did not indicate a connection for concept H. After comparing the placement of concept H with the ICMMs, observation data, and the task analysis, there were no similarities found other than the inclusion of concept H. Without specific data to support the placement of concept H, the unlinked concept H is placed outside the concepts represented in the AC-SMM.

Step 5: Shared Important Concepts—Shared important concepts are added to the AC-SMM. In the example, each of the concepts A, B, D, and H were indicated to be the shared important concepts.

The resultant AC-SMM represents the various shared concepts for a team. After the five steps are completed, the shared data is represented in the new map.

## 3 Discussion

As teams engage in cognitive activities, we would expect to see improvements in individual mental models. In order to show this change, pre and post AC-SMMs would be analyzed to show a comparison between the mental models. This analysis has an emphasis on how things are different rather than the shared focus emphasis that we have described so far. By comparing these differences with other measures such as performance, efficacy, or communication, we can start to understand if indeed the change is related to specific types of cognitive activity.

Based on initial findings?, as teams work together, the similarity among ICMMs tends to increase as does the number of clustered concepts, even though the tendancy is for the number of concepts used to decrease. These factors provide evidence that ICMMs were becoming more structured and more representative of the team task in addition to becoming more similar to the ICMMs of other team members. These ideas are not yet proven. We have designed a set of studies to try and validate our hypothesis. Currently, we are looking at concept maps collected from three content domains: performance improvement (performance standards development), instructional systems (formative evaluation), and science education (mentoring). This work is intended to not only learn about teams that work in the various settings, but to validate the AC-SMM analysis model as delineated in this article.

The use of qualitative analysis we hope provides a richer description of the detail included in the AC-SMM than would have been found with other qualitative and quantitative methods. However, this methodology lacked the weighted measures and precise distances between concepts in the resulting AC-SMM maps as is found in shared maps generated using quantitative methods such as Pathfinder or MDS. Also, as is often the case in concept mapping, there was a lack of prepositional descriptors to define the exact relationship between concepts in ICMMs, requiring the rater to engage in a more exhaustive analysis procedures that are based on other supportive data. In our current studies, we have supportive data from the non-participant researcher observations to support many of these assumptions and decisions. Most importantly, we are in the process of validating the idea that the AC-SMM is a more accurate representation of the SMMi. In addition, we are able to create this shared mental model with minimal disturbance to the team's cognitive activities.

Future steps we are considering include the combination of the AC-SMM methodology with quantitative analysis. This could provide the weighted measures needed for greater precision in the resulting team concept maps in addition to the qualitative descriptions representing fluctuations in team cognition. Once we have a more precise and descriptive analysis of shared mental models, we can utilize the new knowledge to better describe, explain, and understand team cognition. We can also use this deeper understanding about the development of team mental models for determining how to train team members in developing shared mental models. This in turn will facilitate team training with this intent to improve team performance outcomes.

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