DEVELOPMENTS OF TRANSACTIVE MEMORY SYSTEMS AND COLLECTIVE MIND IN VIRTUAL TEAMS

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In this study, we examine the developments of transactive memory systems and collective mind and their influence on performance in virtual teams. Although one of the oft-cited benefits of the virtual team is the ability of its members to contribute diverse knowledge and expertise, the question of how virtual team members can bring their respective knowledge and expertise to solve the problems they face has been largely ignored in the past research on virtual teams. Building on an emerging body of socio-cognitive literature, we argue that transactive memory systems and the collective mind are two important variables that explain team performance. We tested our hypotheses with a longitudinal data set that was collected from 38 virtual teams of graduate management students from six universities in four countries over eight weeks. The results suggest that the influence of team members' early communication volume on team performance decreases as teams develop transactive memory systems and a collective mind. The results further suggest that the development of a collective mind represents a high-order learning in team settings.

An increasing number of firms are adopting or experimenting with various new methods of organizing in order to respond to changing environments (DeSanctis & Monge, 1999; Fulk & DeSanctis, 1995; Jarvenpaa & Ives, 1994). Among those new methods, virtual teams whose members are (1) geographically distributed, (2) electronically linked, (3) functionally and/or culturally diverse, and (4) laterally (versus hierarchically) connected (DeSanctis & Monge, 1999) have emerged as a viable, alternative organizing method. Scholars in information systems and organizational behavior have begun to examine various factors that influence the effectiveness of virtual teams (Coutu, 1998; Iacono & Weisband, 1997; Jarvenpaa & Leidner, 1999; Maznevski & Chudoba, 2000; Yoo & Alavi, 1996). Building on the tradition of the social psychology literature, these studies focused on various social dimensions of virtual teams such as trust, group development,
communication patterns, and leadership. While these studies made important contributions to our understanding of virtual teams, recent developments in the “socio-cognition” literature (Hutchins, 1995; Liang, Moreland, & Argote, 1995; Resnick, Levine, & Teasley, 1991; Wegner, 1987; Weick & Roberts, 1993) suggest that a better understanding of virtual teams might be gained by studying cognitive dimensions of virtual teams. As an initial step toward understanding the socio-cognitive process in virtual teams, we report the results of a longitudinal study in which the development of the socio-cognitive process among 38 global, virtual teams of MBA students was examined over an eight week period and its impact on teams’ performance was assessed.

Our work contributes to the growing body of virtual teams literature by explicitly examining cognitive dimensions that have been largely ignored in virtual team research. Given that one of the oft-cited benefits of the virtual team is the ability of its members to contribute diverse knowledge and expertise (Jarvenpaa, Knoll, & Leidner, 1998; Sole & Applegate, 2000; Townsend, DeMarie, & Hendrickson, 1998), it is important to examine how virtual teams coordinate their knowledge and expertise to solve the problems they face. We incorporate the concept of the “collective mind” (Weick & Roberts, 1993) and “transactive memory systems” (Moreland, Argote, & Krishnan, 1996; Wegner, 1987) in order to theorize how individuals in virtual teams coordinate and interrelate their expertise and knowledge. Our main argument in this paper is that, in virtual team environments where a high degree of cognitive interdependence among team members is required for successful decision-making, an effective coordination of knowledge as well as carefully interrelated actions among members are important determinants of team performance.

In addition to integrating the socio-cognitive perspective into virtual team research, this paper also contributes to the existing body of the socio-cognition literature by examining the relationship between the collective mind and transactive memory systems over time and their influence on team performance. While both of these constructs deal with the socio-cognitive processes in supraindividual collectives such as teams, they focus on different, yet interrelated, aspects of the socio-cognitive process in teams. The collective mind refers to a social cognitive system in which individuals heedfully interrelate their actions (Weick & Roberts, 1993). Transactive memory system is a “shared system for encoding, storing, and retrieving information” (Wegner, Erber, & Raymond, 1991, p. 923). Our argument is that a transactive memory system without a collective mind is not enough to explain teams’ performance. While a transactive memory system provides a shared place to store and retrieve information for a team, the team’s collective mind is the one through which the transactive memory system is appropriated (Moreland et al., 1996). Thus, although a transactive memory system plays an important role in team performance early in the team’s life cycle, as the team’s collective mind develops over time, the influence of the transactive memory system will be mediated through its collective mind.

The paper is organized as follows. After reviewing the literature of virtual teams, we will briefly discuss the recent developments in the socio-cognition literature, focusing primarily on the concepts of the collective mind and transactive
memory system. We will then introduce the study we conducted to test our theory followed by the results of the study. We conclude our paper with a discussion of the results and implications for future research and practice.

**Theory**

**Virtual Teams**

Virtual teams stretch the scope of their activities in both time and space, and thus amplify the traditional challenges in managing teams. At the same time, however, they present unexpected emerging issues to managers and team members alike. While the literature of virtual teams has yet to grow in theoretical and empirical works, scholars have started examining some of the salient issues in virtual teams.

Among those issues, trust and its development in virtual teams over time has been examined. Iacono and Weisband (1997) noted that virtual teams with a high level of trust tended to engage in continuous and frequent communications, focus on work content, and adequately socialize during the early stage of the project. Jarvenpaa and Leidner (1999) and Jarvenpaa et al. (1998) observed that virtual teams followed a pattern of “swift trust” (Meyerson, Weick, & Kramer, 1996). Some virtual teams in their study started with a high level of trust that was not based on past experiences and history; these ended up with a much lower level of trust. Crisp and Jarvenpaa (2000) extend these earlier works by examining the relationship between trust and control behaviors in virtual teams and their subsequent influences on team performance. They found that trust among virtual teams was fragile, but teams’ communication and control behaviors strengthened the trust among members.

In addition to trust, communication patterns of virtual teams have been also examined in the past. For example, Maznevski and Chudoba (2000) argue that a virtual team’s effectiveness is influenced by the temporal dynamics of the team’s decision-making process, task complexity, and communication forms. They argue that, in order for virtual teams to improve their effectiveness, there must be a fit between the communication media and the task complexity paced in temporal dynamics of virtual teams’ decision-making processes over time. Past research also suggests that the communication patterns and the use of communication technology in virtual teams are influenced by a team’s norms (Orlikowski, 1993; Sole & Applegate, 2000; Yoo, 1998).

An important aspect of virtual teams that has not been examined is how virtual team members bring their knowledge and expertise together to perform their tasks. An emerging body of socio-cognitive literature has shed light on this question.

**Socially Shared Distributed Cognition**

A growing body of evidence suggests that knowledge and cognition in supraindividual collectivities, such as teams or organizations, is socially shared among the individuals who constitute the collectivity (Brown & Duguid, 1991;
Hutchins, 1995; Resnick et al., 1991; Weick & Roberts, 1993). According to this perspective, individuals know only part of what the team as a whole knows, and the knowledge in teams is distributed unequally among the members (Boland & Tenkasi, 1995; Moreland et al., 1996; Tsoukas, 1996). As such, teams can be characterized as socially shared distributed cognitive systems. Virtual teams present an extreme case of such systems in that individual members are dispersed in time and space and connected via electronic communication technology. In this study, we draw upon the concepts of transactive memory systems and the collective mind to examine how virtual teams coordinate and interrelate their knowledge and actions in order to perform their tasks.

Wegner (1987; Wegner et al., 1991) first developed the notion of a transactive memory system based on the observation that few people rely exclusively on their own memories. He noted that couples in close relationships seemed to treat their partners as external memory aids, relying on each other to remember details about specific domains of expertise. Simply put, the transactive memory system is the team members’ meta-knowledge about who knows what in the team. Later empirical works expand the application of the concept into work group settings and provide further evidence that a transactive memory system can enhance a team’s performance particularly when the task is complex and requires considerable contribution of knowledge from the team members (Faraj & Sproull, 2000; Lewis, 2000; Liang et al., 1995; Moreland, 1999; Moreland et al., 1996; Stasser, Stewart, & Wittenbaum, 1995).

How is a transactive memory system then developed in a virtual team environment? In earlier studies in face-to-face settings, transactive memory systems were examined in the context of existing close relationships between couples (Wegner et al., 1991) or group training (Liang et al., 1995; Moreland et al., 1996). In virtual team environments, where team members do not have any prior experience in working together, nor do they have any joint training or team building exercise, interactions via communication media will be the primary means of developing transactive memory systems. As noted earlier, previous studies of virtual teams found that communication volume of virtual team members had a significant influence on team performance (Crisp & Jarvenpaa, 2000; Iacono & Weisband, 1997). However, we argue that when the role of the transactive memory system of a virtual team is considered, the direct influence of communication volume on team performance will be substantially decreased. Further, we suggest that as a team develops its transactive memory system through their repeated interactions over time, the direct influence of the communication volume of team members on the team’s performance will decrease while the influence of the team’s transactive memory system will increase. Thus, we hypothesize:

Hypothesis I: The direct positive influence of the communication volume of virtual team members on team performance will decrease as its transactive memory system is developed over time.

While transactive memory systems would influence virtual teams’ performance, simply knowing who knows what in virtual teams may not be enough if team members are not able to carefully coordinate their knowledge and heedfully inter-
relate their actions in performing the task. Weick and Roberts (1993, p. 363) have
developed the notion of the “collective mind” based on their observations of
crewmembers on a Navy aircraft carrier. They argue that the collective mind is
manifested through the way in which individuals heedfully interrelate their actions.
That is, individuals construct their actions while envisaging a social system of joint
actions and interrelate that constructed action with the system that is envisaged.
According to Tsoukas (1996) and Faraj and Sproull (2000), such patterns of inter-
relating knowledge are socially embedded and emerge over time through repeated
demonstrated that these emerging patterns in socially shared distributed cognitive
systems are influenced by the initial condition of the system and the manner in
which individual members interact with each other.

We argue that the collective mind represents a more advanced form of socio-
cognitive systems in teams. A team cannot develop its collective mind without a
transactive memory system, although a transactive memory system can be devel-
oped without a collective mind. We find Argyris and Schön’s (1978) double-loop
learning concept to be a useful metaphor here. They argue that an individual can
change underlying norms, policies, and objectives through double-loop learning
that aims to alter the tacit structure of perceptions, thinking, and actions in the
learner’s mental model. They contrast double-loop learning with single-loop
learning where the goal is simply to change learner behaviors in order to achieve
desired outcomes. This can be achieved primarily though the acquisition of factual
knowledge. Likewise, in a team setting, an improvement in transactive memory
systems alone without changes in the collective mind can be likened to the acquisi-
tion of new facts and information without a change in the mental model for an
individual. Thus, we argue that an improvement in the collective mind represents a
high-order learning in team setting. Therefore, one can expect that the direct influ-
ence of transactive memory systems on team performance will decrease as a team
develops its collective mind. This leads us to hypothesize the following:

Hypothesis 2: The transactive memory system of a virtual team will have a
positive influence on the team’s collective mind.

Hypothesis 3: The influence of a virtual team’s transactive memory system
on the team’s performance will be increasingly mediated by
the team’s collective mind as the collective mind’s influence
on the team’s performance increases over time.

Method

We tested our hypotheses in a longitudinal quasi-experimental study. Data
were collected from the following three sources: (1) survey questionnaires; (2)
archives of the electronic communication; and (3) objective team performance
scores.

Participants

Participants were recruited through an email announcement broadcasted by an
Internet list-serve popular among faculty members in the information systems area.
Six different MBA courses that were taught by five professors in four different countries (listed in Table 1) were recruited for the study.

<table>
<thead>
<tr>
<th>University</th>
<th>Country</th>
<th>No. of participants</th>
<th>Time Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Australia</td>
<td>6</td>
<td>GMT +9:30</td>
</tr>
<tr>
<td>2.</td>
<td>Hungary</td>
<td>12</td>
<td>GMT +1:00</td>
</tr>
<tr>
<td>3.</td>
<td>Thailand</td>
<td>18</td>
<td>GMT +7:00</td>
</tr>
<tr>
<td>4.</td>
<td>USA</td>
<td>27</td>
<td>GMT -5:00</td>
</tr>
<tr>
<td>5.</td>
<td>USA</td>
<td>49</td>
<td>GMT -6:00</td>
</tr>
<tr>
<td>6.</td>
<td>USA</td>
<td>34</td>
<td>GMT -5:00</td>
</tr>
</tbody>
</table>

A total of 146 MBA students (100 males; 46 females) of ten nationalities participated in the study. The average age and work experience of the participants were 28 and 5 years, respectively. Students took part in the project as part of their course. Students were randomly assigned to forty 4-member teams. Team members were students from four different universities; two teams had two members from the same university. During the course of the project, two teams were removed due to member inactivity. This left 38 teams for the data analysis.

**Task**

A web-based complex and realistic business simulation game, Inc 2000®, was used for the study. The engine of the game was developed by the second author and his colleagues and has been used regularly in both academic institutions and corporations in more than 100 sessions over the last three years. Inc 2000® is a strategic business simulation game built on generic business concepts. It equally emphasizes all four major functional areas of business—marketing, finance, production & operations, and human resources. The game is framed on the assumption that every team has been in business for 2 years.

All teams started with the same position (market shares, financial resources, human resources, inventory, etc.). Each team managed a $356 million company, producing and selling high-end server computers and competing against the other teams. The goal was to maximize the stock price of the company, which in turn is influenced by several firm performance indicators that include market share, profit, ROA, and ROE. For each week, teams needed to make a decision on 25 variables in the four functional areas. At the end of each week (after all weekly decision

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¹The first author taught two of them.

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were submitted), the game administrator processed the decisions. Each team’s weekly performance results were then distributed. The outcomes from prior weeks were taken into account in the subsequent week. The game was conducted over an eight-week period (see Table 2 for the schedule).

### Table 2

**Project Timeline**

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9/11/00 – 9/17/00</td>
<td>Introduction (provide brief biography and other demographic information), set up name, vision and objectives for their teams</td>
</tr>
<tr>
<td>2</td>
<td>9/18/00 – 9/23/00</td>
<td>Make quarter 9 decision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>First questionnaire and one-page summary</td>
</tr>
<tr>
<td>3</td>
<td>9/24/00 – 9/30/00</td>
<td>Make quarter 10 decision</td>
</tr>
<tr>
<td>4</td>
<td>10/1/00 – 10/7/00</td>
<td>Make quarter 11 decision</td>
</tr>
<tr>
<td>5</td>
<td>10/8/00 – 10/14/00</td>
<td>Make quarter 12 decision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second questionnaire and one-page summary</td>
</tr>
<tr>
<td>6</td>
<td>10/15/00 – 10/21/00</td>
<td>Make quarter 13 decision</td>
</tr>
<tr>
<td>7</td>
<td>10/22/00 – 10/28/00</td>
<td>Make quarter 14 decision</td>
</tr>
<tr>
<td>8</td>
<td>10/29/00 – 11/4/00</td>
<td>Make quarter 15 decision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Third questionnaire and one-page summary</td>
</tr>
</tbody>
</table>

Each member was randomly assigned to one of four business roles—VP of marketing, VP of productions and operations, VP of finance, and VP of human resources. Apart from the first week of the project, during which participants spent time getting to know other team members, reading the game manual, and collectively setting the vision and objectives for their fictitious companies, team members discussed how they should run their company for each week (from weeks 2–8) primarily through text-based, computer-mediated communication.

A web-based interface was designed to support and facilitate communication and knowledge coordination among team members in different places. The interface design allowed the participants (1) to enter/edit/view their decisions and to see their team’s performance, and (2) to communicate and exchange ideas/information.
from anywhere at anytime through a web-based discussion database that is tightly integrated into the game (Figure 1). During the summer of 2000, the usability and reliability of the web-based business simulation game was tested using 55 students on 13 teams who played the game over an eight-week period. Minor errors were corrected and small changes were made as a result of the pilot test. In addition to the web-based discussion database, members were provided an electronic mailing list for e-mail communications. All e-mail messages sent via the mailing lists were archived.

![Figure 1](image)

**Team Discussion Database Screen**

As shown in Figure 2, the web interface is purposely designed to allow only the member who is assigned to a particular functional area to input decision variables in that area, while other members can only view these variables once they are entered. The purpose of this split interface design, along with the interdependence among four functional areas in the game’s logic, was not only to make the business game more realistic, but also to make each individual’s decision part of a larger system. Individual members’ effective interrelating actions through communication, therefore, became critical to the team’s performance.

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Figure 2
Decision Form of a Member in Charge of Marketing Function Screen

Measures

The survey was administered three times at the end of weeks 2 (Phase 1), 5 (Phase 2), and 8 (Phase 3). These three points were chosen to collect data at the beginning, in the middle, and at the end of the project. A questionnaire was administered via a web page once all the decisions were submitted for the week but before the teams received weekly team performance feedback.

Team Performance (PERF). Weekly team performance was assessed using 6 criteria—profit, return on asset (ROA), return on equity (ROE), stock price, unit sold (market share), and unit cost—all generated from Inc. 2000. Each performance criterion value was separately ranked relative to other teams. The six rankings were then compiled as a composite performance score ranging from 6 to 240 (6 criteria × 40 teams). For example, the team having 1st, 4th, 10th, 8th, 23rd, and 5th ranks in profit, ROA, ROE, stock price, market share, and unit cost,
respectively will have a composite score of 51 (1 + 4 + 10 + 8 + 23 + 5). These composite scores were then reversed and normalized to arrive at a performance score that ranged from 1 (low) to 100 (high).

**Transactive Memory System (TM).** Since both the transactive memory system and the collective mind are group-level cognitive concepts, it is difficult to measure them directly. Researchers, however, have determined that when such socio-cognitive systems are developed, teams appear to have behavioral attributes, of which perceptions can be measured by asking individual members through questionnaires (Lewis, 2000).

The development of transactive memory systems was assessed by asking three 5-point Likert scale questions about team members’ knowledge of who knows what. This scale was adopted from Faraj (1998). Since the measure was developed relatively recently, we examined the reliability and validity of these items through a pilot study. The results showed the acceptable psychometric properties of these measures. All items are in Table 3.

**Collective Mind (CM).** Based on the Weick and Roberts (1993), eleven candidate items were initially developed to capture three main behavioral aspects—contributions (acting), representation (understanding), and interrelating (interrelating)—that contributed to the team’s collective mind. Through the procedure recommended by Churchill (1979), these items were trimmed to the final four items used in the current study. All four of them were measured with a 5-point Likert scale and listed in Table 3.

**Team Communication Volume (CV).** Team communication volume was estimated using the number of messages that were posted on the web pages and the email messages participants exchanged during the week. All email messages sent through the provided mailing lists were automatically archived and included for the analysis. Participants were also asked to forward a special account other email messages that were sent directly to their teammates.

**Analyses**

We conducted our analyses in three steps. First, we examined the validity and reliability of measures through a confirmatory factor analysis using the individual participants’ responses (Nunnally & Bernstein, 1994). The James’ index ($r_{wg}$), was then used to examine the intra-group reliability of responses (James, Demaree, & Wolf, 1984). The James’ index ($r_{wg}$), commonly known as an inter-rater agreement, provides a basis for justifying whether the aggregation of individuals’ responses into a group score is appropriate. Janz, Colquitt, and Noe (1997) suggested a median of .70 or above as a guideline. The results showed acceptable $r_{wg}$ values of both transactive memory systems ($r_{wg} = .66$, median = .81) and the collective mind ($r_{wg} = .70$, median = .80), suggesting high levels of agreement among team members on these measures.

Finally, we aggregated the data for each team in order to test the hypotheses using a structural equation modeling tool called Partial Least Square (PLS). PLS generates estimates of standardized regression coefficients (i.e., beta coefficients) for the model paths, which can then be used to measure the relationship between latent variables (Wold, 1985). PLS also generates the factor loading of measure-
ment items, which are interpretable within the context of principal-components analysis. Among several available structural equation modeling tools, PLS is most suitable during the early stage of a theory development because it does not require a large sample size. Additionally, the assumptions of normality and interval scale data are not necessary.

We constructed a path model in order to run PLS (see Figure 3). In the model, we tested direct influences of Communication Volume (CV), Transactive Memory (TM), and Collective Mind (CM) on Team Performance (PERF) for each phase\(^2\). This allowed us to examine how the direct influences of CV, TM and CM on PERF change over time as we hypothesized. To examine Hypothesis 2 and Hypothesis 3, we also put a path from TM to CM. Finally, in an attempt to control the continuity effect of TM and CM and to simplify the model at the same time, our model only has a direct link between the adjacent phases for these two variables, for example, \( \text{TM}_1 \) to \( \text{TM}_2 \) and \( \text{TM}_2 \) to \( \text{TM}_3 \). Thus, there is no indirect link of measures from Phase 1 to Phase 3.

Results

Preliminary Analyses

We examined the discriminant and convergent validity of our two perceptual measures of socio-cognitive constructs, CM and TM, using a confirmatory factor analysis. We tested a two-factor measurement model using the EQS 5.7b package. The results of this test allowed us to see if we indeed estimated two distinctive measures (see Table 3). All goodness-of-fit indexes clearly indicated that the model fit well with the data \( \chi^2 (13) = 48.39, n = 373, p < .001, \text{CFI} = .99, \text{GFI} = .96, \text{RMSEA} = .086 \), therefore suggesting that the data indicated that there were indeed two separate underlying constructs. Finally, both factors achieve a high reliability (.91, and .90 for TM and CM, respectively) as measured by Cronbach’s alpha. In Table 3, we also report conventional exploratory factor analysis results with an oblique rotation.

Table 4 shows the descriptive statistics and correlation matrix of all measures for all three phases of measurement.

Test of Research Model

Figure 4 shows the results of PLS analysis. In our first hypothesis, we predicted that the early influence of communication volume on team performance would decrease over time. The results of PLS analysis clearly support our hypothesis. In phase 1, CV had a significant positive influence on PERF. However, its influence on PERF, as well as on TM and CM, has significantly deteriorated in phases 2 and 3, as expected.

\(^2\)A subscript denotes the phase. For example, \( \text{CV}_1 \) denotes communication volume measured in phase 1.
Figure 3
Tested Path Model

Time 1

Time 2

Time 3

Table 3
Result of Confirmatory\(^a\) and Exploratory\(^b\) Factor Analysis (\(N = 373\))

<table>
<thead>
<tr>
<th></th>
<th>CFA(^c)</th>
<th>EFA(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transactive Memory (TM)</strong> Cronbach’s (\alpha = .91)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. The team has a good “map&quot; of each others’ talents and skills.</td>
<td>.91</td>
<td>.85</td>
</tr>
<tr>
<td>2. Team members know what task-related skills and knowledge they each possess.</td>
<td>.88</td>
<td>.86</td>
</tr>
<tr>
<td>3. Team members know who on the team has specialized skills and knowledge that is relevant to their work.</td>
<td>.85</td>
<td>.85</td>
</tr>
<tr>
<td><strong>Team collective mind (CM)</strong> Cronbach’s (\alpha = .90)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Our team members had a global perspective that includes each other’s decisions and the relationship among them.</td>
<td>.80</td>
<td>.63</td>
</tr>
<tr>
<td>2. Our team members carefully interrelated actions to each other in this project.</td>
<td>.89</td>
<td>.77</td>
</tr>
<tr>
<td>3. Our team members carefully made their decisions to maximize an overall team performance.</td>
<td>.83</td>
<td>.95</td>
</tr>
<tr>
<td>4. Our team members had developed a clear understanding of how each business function should be coordinated.</td>
<td>.81</td>
<td>.74</td>
</tr>
</tbody>
</table>

\(^a\) The results were based on ERLS method in EQS 5.7b.

\(^b\) Using Maximum Likelihood extraction and oblique (Promax) rotation with SPSS 10.0.

\(^c\) All loadings were significant; \(t\)-values are between 7.83 and 22.64.

\(^d\) For EFA, no cross-loadings are greater than .3.

The results also show that CV\(_1\) had a significant influence on TM\(_1\). This implies that early communication among team members is important in finding out who knows what in the team. However, once the team develops its transactive memory system and collective mind, the importance of communication volume was significantly reduced.

In our second hypothesis, we predicted that a team’s transactive memory system would have a positive impact on both team performance and the collective mind. In our third hypothesis, we further predicted that the influence of a team’s transactive memory system on its performance would be mediated through its collective mind as the influence of the team’s collective mind on its performance increases over time. Again, the results from PLS analysis support both hypotheses.
Table 4
Descriptive Statistics and Correlation Matrix (Pearson coefficients) of Group-Level Measures Scales in the Model

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Time 1 (week 2)</th>
<th>Time 2 (week 5)</th>
<th>Time 3 (week 8)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Time 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 PERF1</td>
<td>55.55</td>
<td>22.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 TM1</td>
<td>2.64</td>
<td>0.63</td>
<td>.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 CM1</td>
<td>3.03</td>
<td>0.67</td>
<td>.12</td>
<td>.75</td>
<td></td>
</tr>
<tr>
<td>4 CV1</td>
<td>31.34</td>
<td>22.20</td>
<td>.19</td>
<td>.43</td>
<td>.46</td>
</tr>
<tr>
<td>Time 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 PERF2</td>
<td>51.50</td>
<td>23.57</td>
<td>.15</td>
<td>.08</td>
<td>.25</td>
</tr>
<tr>
<td>6 TM2</td>
<td>3.14</td>
<td>0.65</td>
<td>.11</td>
<td>.35</td>
<td>.48</td>
</tr>
<tr>
<td>7 CM2</td>
<td>3.37</td>
<td>0.69</td>
<td>.19</td>
<td>.27</td>
<td>.41</td>
</tr>
<tr>
<td>8 CV2</td>
<td>12.50</td>
<td>9.66</td>
<td>.28</td>
<td>.02</td>
<td>.15</td>
</tr>
<tr>
<td>Time 3</td>
<td></td>
<td></td>
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<tr>
<td>9 PERF3</td>
<td>52.32</td>
<td>19.23</td>
<td>.26</td>
<td>.09</td>
<td>.33</td>
</tr>
<tr>
<td>10 TM3</td>
<td>3.08</td>
<td>0.65</td>
<td>.13</td>
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</tr>
<tr>
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<td>.09</td>
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<td>.33</td>
</tr>
<tr>
<td>12 CV3</td>
<td>7.00</td>
<td>6.67</td>
<td>.28</td>
<td>.06</td>
<td>.16</td>
</tr>
</tbody>
</table>

Note: N = 38. PERF = Performance, TM = Transactive memory, CM = Collective mind, CV = Communication volume.
*p < .05. **p < .01. (two-tailed)
Figure 4
Results of PLS Analysis

Note: Beta for path coefficient *p < .05, **p < .01, (two-tailed)
First, we found that in all three phases, the beta path coefficients from TM to CM are statistically significant. However, the path from TM to PERF was significant and positive only in phase 2. Additionally, in phase 3 only, the path from CM to PERF was positive and significant. Furthermore, the results of phase 3 clearly show that the influence of TM on PERF was mediated through CM since the path between TM$_3$ to CM$_3$ was positive and significant. This implies that transactive memory systems had a direct influence on team performance in phase 2, but it has only indirect influence through collective mind in phase 3. Thus, both Hypothesis 2 and Hypothesis 3 were supported. Additionally, the $R^2$ of PERF at time 3 is the highest with the value of .29 compared to .15 and .22 at time 1 and 2, respectively.

Discussion

In this study, we examine the socio-cognitive aspects of virtual team dynamics over time. Building on recent literature in the socio-cognition area, we incorporated the concepts of transactive memory systems and the collective mind in the study of virtual teams. We found that transactive memory systems and the collective mind have significant influences on virtual team performance in particular later in the process. In our study, we found that while the communication volume among team members had an early positive influence on team performance, that influence quickly deteriorated as teams developed their transactive memory systems and a collective mind. This result suggests that past emphasis in the literature (Crisp & Jarvenpaa, 2000; Iacono & Weisband, 1997) on virtual team communication interactions could be misleading. The importance of communication interactions in team performance that was observed in the past research might have been the result of overlooking the socio-cognitive aspects of virtual team interactions.

However, our results also point out the importance of early communications among virtual team members, since they allow team members to build a transactive memory system and a collective mind. Particularly, communication volume had a significant and direct influence on the development of transactive memory systems early in the process.

Past research on transactive memory system shows that when the role was arbitrarily assigned to members (Wegner et al., 1991), the impact of the transactive memory system on team performance was significantly reduced. Since we assigned roles to participants of the study, the significant relationship among communication volume, transactive memory system, and performance that we found are intriguing. We collected short essays from the participating students in the two classes where the first author was teaching in order to better understand their behaviors and perceptions. An unstructured examination of these essays provided additional insights into how teams in our study developed transactive memory systems. We found that early in the process, several students “confessed” their lack of experience in their assigned role and asked other team members to help them out. Several of them noted that such communications led to a successful exchange of background information about members’ expertise. Other teams began the first week by explicitly exchanging background information on their work experiences, major,
and their expertise in functional areas. In some cases, team members even explicitly exchanged their roles to better align their roles in the project to their expertise. Taken together, we speculate that even when the roles were arbitrarily assigned to participants, some team members actively seek other members’ “real” expertise.

In light of this discussion, we argue that in virtual team environments, communications without an established transactive memory system and collective mind would not lead to higher performance by the team. We would further argue that team members must exchange their expertise and background information to quickly develop a transactive memory system. This, however, should not be confused with more traditional team-building, ice-breaking activities that are intended to improve group cohesiveness and trust among team members. While we do not downplay the importance of such “social” activities in virtual teams, we emphasize that virtual teams should explicitly attempt to develop their transactive memory system early in the process.

The results of our study also suggest that a virtual team’s collective mind, theorized as a more advanced form of team cognition, does not fully develop in the early stage of the project’s life; instead, it is more likely to develop in the later stages after a transactive memory system representing the map of team knowledge is put into place. Collective mind, once fully developed, however, is mediating the influence of the team’s transactive memory system on its performance. This is consistent with the prediction made by Moreland et al. (1996). They argued that a transactive memory system would allow team members to coordinate their actions and knowledge to best perform the given task.

Students’ essays also provide additional insights into the role of the collective mind. Several students noted that they deliberately changed their decision making strategy over the weeks to better understand how the game’s model behaves and how the members should interrelate their actions. Other students observed that it was their team’s poor performance in the early stage that prompted them to start thinking systematically. They recognized that it was their careless individual actions that caused their team’s poor performance. Also, other students, particularly among high performing teams, noted that once they “figured out” how the system works, they seldom discussed their decisions unless they experienced a sudden drop in their performance. This observation is consistent with the deteriorated impact of communication volume on the team performance that we found in our PLS analysis.

Our study has several limitations. First, as noted before, we arbitrarily assigned roles to participating students. We felt that this might have suppressed the influence of the transactive memory system on team performance. Although we identified the significant role the transactive memory system plays, future research should attempt to align participants’ expertise to their assigned role. Alternatively, future research can examine the role of transactive memory systems and the collective mind in real organizational settings. Second, we did not include more traditional group variables such as trust and group cohesion in our study. Future studies should include those variables and directly compare the relative influence of social and socio-cognitive dimensions of virtual team dynamics on team performance. Finally, we measured transactive memory systems and the collective mind through
perceptual measures. While past studies have developed and used similar approaches to study the transactive memory system (Faraj & Sproull, 2000; Lewis, 2000; Liang et al., 1995), we felt that a better understanding can be gained by analyzing team members' actions. In the context of virtual teams where members are geographically separated, this means one needs to examine the contents of their communication interactions. A micro-level content analysis of team communication interactions would undoubtedly improve our understanding in this area.

Despite these limitations, our study suggests directions for future research in virtual teams. First, as noted earlier, one can examine the role of transactive memory system and the collective mind in the field setting with real virtual teams. Such field studies would deepen our understanding of virtual teams. Second, one can introduce changes in decision-making environments to see how established collective mind and transactive memory systems react to such changes. Weick and Roberts (1993) noted that routinized work practice can harmfully influence team performance since team members may not take the heed in their actions when they perform familiar tasks repeatedly. Our qualitative analysis of student essays shows that students tend to routinize their decision-making process once they reach a certain level of collective mind. However, in our study, there were no major, disruptive changes in the environments³; therefore, such careless actions did not lead to poor performance. Future research can examine how teams with an established collective mind react to sudden changes in the task and environments. Third, we used only a web-based threaded discussion board and email as communication tools in our study. Future research can examine the role of different media on the development of transactive memory system and the collective mind. One can also examine the potential role of causal map tools (Boland, Tenkasi, & Dov, 1994; Weick & Bougon, 1986) on the development of the collective mind in virtual teams.

Practical Implications

Our results also provide several important implications for virtual team practice in organizations. First, they suggest that socio-cognitive aspects such as the transactive memory system and the collective mind play important roles in determining virtual team performance. Although the transactive memory system allows members to recognize the available expertise and knowledge in the team, it is the collective mind that enables team members to connect and relate the distributed expertise and knowledge to perform the task as a coherent unit.

Current literature on virtual teams and computer-mediated communication in general tend to emphasize the social aspect of communications (Chidambaram, 1996; Jarvenpaa et al., 1998; Jarvenpaa & Leidner, 1999; Kiesler, Siegel, & McGuire, 1984; Sproull & Kiesler, 1986). We suggest that organizations that implement virtual teams need to pay equal attention to the cognitive aspect of team dynamics.

³The game includes several minor environmental changes, however, such as fluctuations in demand, delays in production schedule, and the availability of labor.

Second, given the important role of transactive memory systems we found in this study, organizations can develop tools that facilitate the development of transactive memory systems. The concept of transactive memory systems is closely related to the idea of using external storages or external memory aids in order to access needed information. The automatic electronic repository of email and threaded discussion messages can serve as an external memory aid for a team. Such archived messages can be used to identify who is good at what and to track the development of issues and problems the team might have. This in turn will improve the utilization of resources, task allocation, and coordination in the team. Furthermore, simple tools such as electronic directories that show members’ domains of expertise could be a good starting point (Moreland, 1999). More sophisticated and dynamic tools that reflect members’ changing profiles of knowledge and expertise could be even more effective.

Third, organizations need to find ways to facilitate the development and maintenance of the collective mind in virtual teams. As noted before, tools like the one developed by Boland et al. (1994) allow each member to express how he/she understands the overall problem and thinks systematically (Argyris & Schön, 1978; Senge & Sterman, 1992; Weick & Bougon, 1986). Given the important influence of the collective mind on team performance we found in this study, organizations which implement virtual teams need to consider such tools to support their virtual teams.

Finally, although our study did not look at the impact of cultural differences among team members on the development of team cognition and team performance, we fully acknowledge the importance of cross cultural differences that might have had impact on how virtual teams work together. It is well understood that national culture influences individuals’ cognitions, attitudes, and behaviors (Griffith, 1998; Hampden-Turner & Trompenaars, 1993; Hampden-Turner & Trompenaars, 1997; Hofstede, 1993; Hutchins, 1995; Segall, 1986; Yoo & Torrey, in press). While, as Kayworth and Leidner (2000) found from their study of 12 global virtual teams, language and time differences can make it difficult for teams members to communicate and interpret the meanings accurately in cross-cultural settings, the different perspectives that members from different cultures bring into the discussion will undoubtedly enrich the quality of the team outcomes. The cultural differences, thus, add another layer of complexity in the development of shared cognition in global virtual teams. At the same time, national culture can be seen as a form of collective cognition at a high level (Halbwachs, 1952; Hutchins, 1995; Middleton & Edwards, 1990; Orr, 1990; Resnick et al., 1991). As such, a strong culture can be seen as a way to facilitate the development of the collective mind. Given these potential influences of culture on team cognition, managers need to educate their employees to be more “sensitive” to cultural differences among global virtual team members so that the cost of developing a transactive memory system of the team can be minimized. At the same time, managers should try to exploit the cultural artifacts and traditions to improve the coordination of individuals’ cognition and behaviors.
References


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